
Edible Medicinal and Non-Medicinal Plants

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Volume 6, Fruits

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Introduction

This book continues as volume 6 of a multi-compendium on *Edible Medicinal and Non-Medicinal Plants*. It covers edible fruits/seeds used fresh, cooked or processed into other by-products, or as vegetables, cereals, spices, stimulant, edible oils and beverages. It covers selected species from the following families: Sapindaceae, Sapotaceae, Schisandraceae, Solanaceae, Thymelaeaceae, Urticaceae, Vitaceae and Winteraceae. However, not all the edible species in these families are included. The edible species dealt with in this work include to a larger extent lesser-known, wild and underutilized crops and also common and widely grown crops.

As in the preceding five volumes, topics covered include: taxonomy (botanical name and synonyms); common English and vernacular names; origin and distribution; agro-ecological requirements; edible plant part and uses; plant botany; nutritive and medicinal/pharmacological properties with up-to-date research findings, traditional medicinal uses; other non-edible uses; and selected/cited references for further reading.

Sapindaceae, the soapberry family, under the order sapindales, contains about 124 genera with 1,478 acceptable species name (The Plant List 2010). The largest genera are *Serjania*, *Paullinia*, *Acer* and *Allophylus*. The family occurs mainly in tropical and subtropical regions especially in Malesia and South America but may also be found in temperate areas. The species consist of trees, shrubs and climbers, rarely herbaceous and

contain milky sap. Many species may contain mildly toxic saponin in the bark, twigs, leaves, seeds or roots that is used as a foaming agent and as a fish poison. Several yield valuable timber; many species yield edible fruit, such as the better known lychee (*Litchi chinensis*) longan (*Dimocarpus longan* subsp. *longan* var. *longan*) and the rambutan (*Nephelium lappaceum*). Other lesser-known species with edible fruit include *Nephelium ramboutan-ake* (pulasan), *Nephelium maingayi* (serait), *Nephelium cuspidatum* var. *robustum* (giant rambutan), *Dimocarpus longan* subsp. *malesianus* var. *malesianus* (mata kucing, isau, kakus, sau), *Dimocarpus longan* subsp. *malesianus* var. *echinatus* (spiny longan), *Dimocarpus fumatus* (Blume) Leenh. subsp. *fumatus* (green mata kucing), *Blighia sapida* (akee), *Lepisanthes alata* and *L. fruticosa*. All these edible fruit species together with *Paullinia cupana* (guarana), a caffeine rich fruit, used in energy drinks, are covered in this volume.

Sapotaceae is a family of evergreen flowering plants, belonging to order Ericales with 58 genera and 1,271 accepted species name (The Plant List 2010). The family is pantropical and comprises shrubs or trees with milky sap and are often further characterized by the presence of reddish-brown hairs on the leaf undersides and other plant surfaces. Economic species include species' of *Palaquium* in particular *P. gutta* that produces an important latex with industrial uses, *Vitellaria paradoxa* (African shea tree) that produces shea butter from its soil-rich nuts and *Argania*

spinosa, the seeds of which yield an edible oil and is traditionally harvested in Morocco. Species that produce edible fruits include *Chrysophyllum cainito* (starapple), *Chrysophyllum oliviforme*, *Manilkara jaimiqui*, *Manilkara kauki*, *Manilkara zapota* (sapodilla, chiku), *Mimusops elengi* (Spanish cherry), *Pouteria caimito* (abiu), *Pouteria campechiana* (canistel, egg fruit), *Pouteria sapota* (mamey sapote), *Pouteria viridis* (green sapote) and *Synsepalum dulcificum*, also known as miracle fruit that produces a glycoprotein compound called miraculin that can alter the perceived sweetness of sour food. All the above mentioned species with edible fruit are treated in this volume.

Schindraceae is a recognised family under the modern molecular-based APG II system, (Angiosperm Phylogeny Group II system) of plant classification of 2003. The family is placed under the order Austrobaileyales, APG II assumes Schisandraceae sensu lato to be a family of three genera, *Illicium*, *Kadsura* and *Schisandra*. The Plant List (2010) also accepted these 3 genera and listed 181 species name out of which 81 were accepted, 81 were synonyms and 29 unassessed. The family consists of woody shrubs or small trees containing essential oils and found in tropical to temperate regions of East and Southeast Asia and the Caribbean. The species, *Illicium verum* with edible fruit and seeds used as a spice is treated in this volume. Its fruit contain catechins, protoanthocyanidin, shikimic acid, volatile oil, fixed oil and other phytochemicals like and its pharmacology includes anticancer, antiviral, antimicrobial, antiinflammatory, anticholinesterase and analgesic attributes.

Solanaceae is a large family of angiosperms with 105 genera and 2,030 accepted plant species out of a list of 8,216 scientific plant names of species rank (The Plant List 2010). The family comprise herb, shrubs or small trees, or rarely woody vines; spines present or absent. The family is ubiquitous in tropical and temperate zones, chiefly native of Central and south America. The family contains many ornamental plant species *Browallia*, *Brunfelsia*, *Cestrum*, *Datura*, *Lycium*, *Nicotiana*, *Nierembergia*, *Petunia*, *Physalis*, *Salpiglossis*, *Schizanthus*, *Solanum*, *Solandra*

and *Streptosolen*. Several genera like *Nicotiana* species, Deadly Nightshade (*Atropa belladonna*), thornapples (*Datura* species) are poisonous or have medicinal or narcotic properties. The family also contain many food plants whose fruit are eaten as fruits or eaten as vegetables (usually cooked); all these are covered in this volume. The fruit group includes Cape gooseberry (*Physalis peruviana*), *Physalis angulata* (wild gooseberry), *Solanum betaceum* (tamarrilo), *Solanum muricatum* (pepino), *Solanum quitoense* (naranjilla), and *Solanum sessiliflorum* (cocona). The vegetable group include eggplant (*Solanum melongena*), capsicum, chili and peppers (*Capsicum annuum*, *Capsicum baccatum*, *Capsicum chinense*, *Capsicum frutescens*), potato (*Solanum tuberosum*) and tomato (*Solanum lycopersicon*), *Lycium barbarum* and *L. chinense* (Goji berry), *Solanum americanum*, *Solanum lasiocarpum*, *Solanum linearifolium*, *Solanum macrocarpon*, *Solanum mammosum*, *Solanum nigrum* and *Solanum torvum*.

Thymelaeaceae is a family of dicotyledonous flowering plants with 898 species in 50 genera under the order Malvales. The family is cosmopolitan with greater diversity in the southern hemisphere, in Australia and Africa, than in the north. The species are shrubs, trees, or lianas. One species with edible fruit *Phaleria capitata* is covered in this volume.

Urticaceae, the nettle family of flowering plant comprises 52 genera with 1,303 accepted species name, under the order Rosales. The family is cosmopolitan apart from the polar regions and occurs mainly in the tropical and subtropical regions. Species are shrubs (e.g. *Pilea*), lianas, herbs (e.g. *Urtica*, *Parietaria*), or, rarely, trees (*Dendrocnide*, *Cecropia*, *Pourouma*). Economically the Urticaceae are most important for their fibres (e.g. ramie, *Boehmeria nivea*). They can be troublesome weeds (*Urtica* and *Parietaria* spp.), pot herbs (*Pilea* spp. in the tropics; *Urtica* spp. in temperate zones), and frequently cultivated ornamentals (*Pilea* spp). One species with edible fruit, *Pourouma cecropiaefolia* is treated in this volume.

Vitaceae is a family of woody or herbaceous climbing, deciduous or evergreen dicotyledonous

flowering plants. It encompasses about 700 species in 12 genera, mainly in tropical and subtropical regions. It has one economically important edible species grapes, *Vitis vinifera*, cultivated for wine and table grapes, is treated in this volume. Besides vitamins, proteins, carbohydrates and minerals, grapes have phenolic compounds including phenolic acids, bisphenols including stilbenes (*cis*- and *trans*-piceid, *cis*- and *trans*-resveratrol), tricyclic phenols (flavonoids) and their subclasses, and oligomeric and polymeric species, the proanthocyanidins and anthocyanidins (Sovak 2001) imparting many beneficial pharmacological activities.

Winteraceae, a mostly southern-hemisphere family associated with the Antarctic flora, is found tropical to temperate climate regions of Malesia, Oceania, Eastern Australia, New Zealand, Madagascar and the Neotropics. The family is traditionally regarded as the least-specialized descendents of the first flowering plants, based largely on their lack of xylem vessels (Feild et al. 2002, 2012). Since vessels have been viewed as a key innovation for angiosperm diversification, Winteraceae have been portrayed as declining relicts, limited to wet forest habitats where their tracheid-based wood does not impose a significant hydraulic constraints .e.g. *Tasmannia cordata*. Many species are fragrant and yield essential oil. Two species with edible seeds used as condiment and spice, *T. lanceolata* (Tasmanina pepper) and *T. insipida* (pepper tree) are covered in this volume.

Selected References

- Angiosperm Phylogeny Group (1998) An ordinal classification for the families of flowering plants. *Ann Mo Bot Gard* 85(4):531–553
- Angiosperm Phylogeny Group II (2003) An update of the angiosperm phylogeny group classification for the orders and families of flowering plants: APG II. *Bot J Linn Soc* 141:399–436
- Angiosperm Phylogeny Group III (2009) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. *Bot J Linn Soc* 161:105–121
- D'Arcy WG (1979) The classification of the Solanaceae. In: Hawkes JG, Lester RN, Skelding AD (eds) *The biology and taxonomy of the Solanaceae*. Academic, London, pp 3–47
- D'Arcy WG (1991) The Solanaceae since 1976, with a review of its biogeography. In: Hawkes JG, Lester RN, Nee M, Estrada N (eds) *Solanaceae III: taxonomy, chemistry, evolution*. Royal Botanic Gardens, Kew, pp 75–137
- Feild TS, Brodribb T, Holbrook NM (2002) Hardly a relict: freezing and the evolution of vesselless wood in Winteraceae. *Evolution* 56(3):464–78
- Feild TS, Chatelet DS, Balun L, Schilling EE, Evans R (2012) The evolution of angiosperm lianescent without vessels—climbing mode and wood structure-function in *Tasmannia cordata* (Winteraceae). *New Phytol* 193(1):229–40
- Friis I (1993) Urticaceae. In: K. Kubitzki K (general editor) (1990 onward) *The families and genera of vascular plants*, vol 2. Springer, Berlin/Heidelberg, pp 612–630
- Heywood VH, Brummitt RK, Seberg O, Culham A (2007) *Flowering plant families of the world*. Firefly Books, Ontario
- Hou D (1960) Thymelaeaceae. *Flora Males Ser I Spermatophyta* 6(1–48):982
- Huxley AJ, Griffiths M, Levy M (eds) (1992) *The new RHS dictionary of gardening*, 4 vols. MacMillan, New York
- Jansen RK, Kaitanis C, Lee SB, Saski C, Tomkins J, Alverson AJ, Daniell H (2006) Phylogenetic analyses of *Vitis* (Vitaceae) based on complete chloroplast genome sequences: effects of taxon sampling and phylogenetic methods on resolving relationships among rosids. *BMC Evol Biol* 6:32
- Liu Y, Xia N, Saunders RMK (2008) Illiciaceae. In: Wu ZY, Raven PH, Hong DY (eds) *Flora of China*, vol 7 (Menispermaceae through Capparaceae). Science Press/Missouri Botanical Garden Press, Beijing/St. Louis
- Sovak M (2001) Grape extract, resveratrol, and its analogs: a review. *J Med Food* 4(2):93–105
- Stevens PF (2001 onwards) Angiosperm phylogeny website. Version 9, June 2008. <http://www.mobot.org/MOBOT/research/APweb/>
- The Plant List (2010) Version 1. Published on the internet; <http://www.theplantlist.org/>
- Watson L, Dallwitz MJ (1992 onwards) *The families of flowering plants: descriptions, illustrations, identification, and information retrieval*. Version: 4th Mar 2011. <http://delta-intkey.com>
- Zhang ZY, Lu AM, D'Arcy WG (1994) Solanaceae A. L. Jussieu. In: Wu ZY, Raven PH, Hong DY (eds) *Flora of China*, vol 17 (Verbenaceae through Solanaceae). Science Press/Missouri Botanical Garden Press, Beijing/St. Louis

Blighia sapida

Scientific Name

Blighia sapida Koenig.

Synonyms

Cupania akeesia Spach, *Cupania edulis* Schumacher, *Cupania sapida* Voight.

Family

Sapindaceae

Common/English Names

Ackee, Akee, Akee Apple, Aki, Savory Akee Tree, Vegetable Brain.

Vernacular Names

Benin: Diremou (Baatonu (language), Batombou (ethnic group)), Moufodom (Ditamari, Otamari), Lissetin, sissitin (Fongbe/Mahi, Fon), Ichin, Iguchin (Nagot/Idatcha, Yoruba), Foulama (Nateni, Natmeba);
Colombia: Bien Me Sabe, Pan Y Quesito;
Costa Rica: Akí;

Cuba: Arbol De Seso, Palo De Seso;
Czech: Mýdelník Obvejčitý;
Danish: Aki;
Eastonian: Maitsev Akipuu;
French: Akée, Arbre Fricassee, Blighia Savoureuse, Fausse Anacarde, Fisanier, Pommier D'aki, Ris De Veau Végétal;
Guatemala: Huevo Vegetal, Fruto De Huevo
German: Akibaum, Aki-Pflaume;
Guinea: Finsan (Manding-Bambara);
Guinea-Bissau: Otau (Bidyogo), Feso (Fula-Pulaar);
Haiti: Arbre Fricassé, Arbre A Fricasser (French);
Ivory Coast: Kaka, Finzan;
Martinique: Yeux De Crabe, Ris De Veau;
Mexico: Arbor Del Huevo, Pera Roja;
Nigeria: Akee, Ishin;
Panama: Huevo Vegetal, Fruto De Huevo;
Portuguese: Castanha, Castanheiro De Africa, Castanheiro-Da-África;
Senegal: Finza (Manding-Bambara);
Sierra Leone: Maiyosundo, Sundo (Kissii), Μυγγοπο (Kono),
Spanish: Akí, Arbol De Seso, Huevo Vegetal, Seso Vegetal;
Sudan: Finza;
Surinam: Akie;
Venezuela: Merey Del Diablo;
West Africa: Akye, Akyen, Finzan, Ishin, Kaka.

Origin/Distribution

The akee is indigenous to the forests of the Ivory Coast and Gold Coast of West tropical Africa. It is now widespread in tropical and subtropical environments and is the national fruit of Jamaica. It has also been introduced into Australia.

Agroecology

The akee tree is tropical to subtropical; flourishes from sea-level to an elevation of 900 m and is frost sensitive. The tree thrives in full sun or partial shade on deep, fertile loamy soils with abundant moisture, but makes satisfactory growth on shallow sandy soils or calcareous soils.

Edible Plant Parts and Uses

The akee fruit must be allowed to open fully (ripe) before it is detached from the tree. The fleshy arils from fully ripe fruits are eaten fresh or used for many dishes after parboiling, cooking or frying. Arils of the ripe fruit are nutty-flavoured, and cooked arils have texture of scrambled eggs. The seeds are discarded and the arils, while still fresh and firm are best parboiled in salted water or milk and then lightly fried in butter. In Jamaica, they are often cooked with codfish, onions and tomatoes. After parboiling, they are added to a stew of beef, salt-pork and scallions, thyme and other seasonings. Sometimes they are curried and eaten with rice. They are served, not only in the home, but also in hotel dining rooms and other restaurants. The fleshy arils are also processed in brine, canned and exported.

In Africa, they may be eaten raw or in soup, or after frying in oil. In Benin, ripe arils are consumed directly fresh, added to sauce to replace sesame seeds or peanuts, or grounded into powder and added to the sauce. Arils are also fried in peanut oil or palm oil. (Ekué et al. 2010). In Benin, the ethnic group, Natemba, use the young leaves as vegetables.

Botany

A perennial evergreen tree, growing to 10–12 m with a short trunk of 1.8 m circumference and grey, smooth bark and a dense crown of spreading branches. The leaves are alternate, pinnately compound with 3–5 pairs of oblong, obovate-oblong, or elliptic leaflets, 15–30 cm long, with obtuse base and acuminate apex, glossy bright-green on the upper surface (Plate 1), dull and paler and finely hairy on the prominently raised lateral veins on the under side (Plate 2). Flowers are bisexual and male borne together in simple racemes 7.5–17.5 cm long, fragrant, 5-merous, greenish-white and pubescent. The fruit is a leathery, pear shaped, more or less distinctly 3–4 lobed capsule (Plates 1–3), 7–10 cm long, yellow with splashes of bright-scarlet. When fully mature, it splits open revealing 3 cream-colored, fleshy, glossy, crisp arils attached to the large, black, nearly round, smooth, hard, shining seeds (Plate 4) – normally 3; often 1 or 2 may be aborted. The base of each aril is attached



Plate 1 Dark green glossy leaves and fruit of Ackee



Plate 2 Pale green and raised veins of the lower leaf surface and 3–4 lobed ackee fruit



Plate 3 Cluster of ackee fruits



Plate 4 White edible arils and black glossy seeds

to the inside of the stem-end of the “jacket” by pink or orange-red membranes.

Nutritive/Medicinal Properties

The fruit was reported to contain significant amount of protein, fibre and potassium. The fruit pulp contained higher percentages of crude fat,

crude protein, total ash and moisture than the seed (Akintayo et al. 2002). The most abundant mineral was potassium, in both. The reddish-coloured oil obtained from *B. sapida* had an acid value of 14.2 mg KOH/g, specific gravity of 0.9510, refractive index of 1.462, and saponification value of 177. Protein solubility studies showed that both seed and pulp protein were soluble at acidic and basic pH regions, indicating that they may be useful in formulating acid foods, such as meat and milk analogue products and protein-rich beverages. The protein solubility curves showed that two different fractions might be recovered from pulp at pH 4.0 and 10.0 and from the seed at pH 3.0 and 7.0. Their relatively high emulsion and oil absorption capacities facilitate their use in the production of sausages, soups and cakes with improved flavour-retaining capacities and mouth-feel. *B. sapida* fruit oil yield was found to be 20.02% (Oladiji et al. 2009). The oil consisted of 22.22% saturated, 56.43% monounsaturated, and 21.35% polyunsaturated fatty acids. It was richer than soybean oil in behenic, palmitoleic, oleic, gadoleic, erucic, and 9,12-eicosanoic acids by 15.70, 0.89, 7.22, 12.05, 8.27, and 21.35%, respectively. The smoke, flash, and fire points as well as peroxide, iodine, and acid values of the fruit oil were significantly lower, whereas the specific gravity, relative density, saponification, and ester values compared well with soybean oil.

Proximate composition of dried ackee aril was reported as: moisture 6.84%, crude fat 45.32%, protein 11.99%, carbohydrate 4.13%, crude fibre 3.21%, total soluble sugar 3.31%, reducing sugar 1.52%, ash 4.90%, K 1503.30 mg/100 g, Mg 53.17 mg/100 g, Ca 139.67 mg/100 g, Na 53.17 mg/100 g, Fe 17.33 mg/100 g, Zn 4 mg/100 g (Howél et al. 2010). The oil from the dried aril was yellowish in colour with a specific gravity of 0.933, refractive index of 1.48, acid value of 7.38, peroxide value of 174.44, iodine value of 56.26 and saponification value of 188.40. The results indicated dried ackee aril to be nutritionally rich with high oil and carbohydrate content, but its protein content was found to be lower than that recommended by the Food and Agriculture Organisation. The extracted aril oil contained low unsaturated fatty acid, with a low deteriorating

rate and can therefore be stored for a relatively long time. It is a non drying oil, edible and may be suitable for soap making. It can also serve to make margarine. In another study, ackee seed oil was found to have a saponification value of 145 and an iodine value of 66, consistent with the high mono-unsaturated fatty acids content (63.8 wt%) (Djenontin et al. 2009). The oil had a prominent concentration of eicosenoic acid (48.4 wt%). Arachidic acid being the main component within the saturated group, the C20 fatty acids fraction accounted for 68.4wt%. Among the unsaponifiable fraction (2.4wt%), the major sterol was stigmasterol (54.6wt%), surpassing β -sitosterol. Tocols (338ppm) comprised mainly α - and γ -tocopherol. The defatted cake contained high starch content and a noticeable amount of proteins and fibres (44.2, 22.4, 15.6 wt%, respectively). Seventeen amino acids were identified together with valuable minerals (total ashes 3.5 wt%).

The phytochemical screening of extracts of *Blighia sapida* showed the presence of some groups of phytochemicals such as saponins, reducing sugar, phytosterols, and polyamide (Antwi et al. 2009). Pure (2S, 1' S, 2' S)-2-(2'-carboxycyclo-propyl)glycine was isolated from *Blighia sapida* (Natalini et al. 2000).

Two toxic, non-proteinogenic amino acids, hypoglycin A and B were isolated from the seeds of unripe ackee fruit and hypoglycin A from the unripe fruit arils (Hassall et al. 1954; Hassall and Reyle 1955). Another non-proteinogenic amino acid (2S, 1' S, 2' S)-2-(2'-carboxycyclopropyl)glycine (CCG 1), was isolated from ackee fruit with a structure similar to hypoglycin A with respect to the presence of a cyclopropane ring structure (Natalini et al. 2000). Blighinone, a sparingly soluble quinone was isolated from the aril of ackee fruit (Garg and Mitra 1976). Vomifoliol was isolated from the leaves and stems of *B. sapida* and had been implicated in the endogenous regulation of stomatal aperture (Stuart et al. 1976).

Antioxidant Activity

The IC₅₀ value of the H₂O:MeOH Diaion HP-20SS fractions of *B. sapida* fruit in the DPPH

radical scavenging assay was 6.6 μ g/mL (Einbond et al. 2004). *B. sapida* not known for a high sugar content, eluted 43% w/w of the semi-purified aqueous fraction in the Diaion HP-20SS H₂O fraction.

Antidiarrhoeal Activity

Administration of ethanolic and aqueous stem bark extracts of *Blighia sapida* before castor oil challenge caused significant dose-dependent inhibitions of the castor oil-induced diarrhoea (39.7–93.2%) and intestinal motility (31.9–77.5%) with the highest dose (1,060 mg/kg) showing inhibitions (70.4–93.2%) comparable to loperamide (89–100%) and atropine (72.8–100%), respectively (Antwi et al. 2009). Castor oil-induced enteropooling was significantly inhibited by the ethanolic and aqueous extracts in rats (23.8–25.9%) and mice (58.4–59.0%) at the highest dose compared to 41.6–46.8% for loperamide. The results indicated that there were no significant differences between the ethanolic and aqueous extracts of *B. sapida* in the reduction or prevention of castor oil-induced diarrhoea and that *B. sapida* may act through the inhibitions of intestinal motility and enteropooling.

Hypocholesterolemic Activity

Daily administration of the aqueous and ethanolic ackee leaf extracts (50 and 100 mg/kg body weight) for 21 days significantly reduced the levels of total cholesterol, triglycerides and LDL-cholesterol in all extract treated rats compared with the control (Owolabi et al. 2010). For the atherogenic indices, there was a significant increase in HDL-cholesterol/Total cholesterol ratio, while LDL-cholesterol/HDL-cholesterol and log (TG/HDLCH) ratio showed a significant decrease in extract treated groups compared to the control group.

The liver- and kidney-body weight ratios as well as the serum concentrations of cholesterol and high-density lipoprotein cholesterol of the rats maintained on diet formulated with the oil from the fruit of *B. sapida* increased significantly,

but the triglyceride and atherogenic index decreased (Oladiji et al. 2009). The low-density lipoprotein cholesterol concentration and the heart-body weight ratio of the rats fed with the fruit oil diet compared well with those on soybean oil-based diet. Animals fed with the fruit oil-based diet had their activities of liver glutamate oxaloacetate transaminase and glutamate pyruvate transaminase as well as alkaline phosphatase activities of the liver and kidney decreased with corresponding increase in the serum enzymes. The oil is also unlikely to predispose the animals to cardiovascular risk, but may labilize the plasma membrane of the hepatocytes and nephrons. It may also have a negative effect on the metabolism and regulation of amino acid in the animals. Therefore, the oil from *B. sapida* fruit may not be completely safe for consumption (Oladiji et al. 2009).

Miscellaneous Pharmacological Activity

Aqueous and lipid extracts of the unripe fruit of *Blighia sapida* were reported to significantly lower neutrophil and platelet counts in treated mice (Gardner et al. 1996). The percentage reduction in neutrophil and platelet counts relative to the controls for the aqueous and lipid (data in parentheses) extracts were 63.4% (59.3%) and 37.46% (32.44%) respectively after 6 weeks of treatment. The significant reduction in neutrophil and platelet numbers suggested that these extracts may be useful in disease conditions where these two blood parameters were elevated, for example chronic myeloid leukaemia, essential thrombocythaemia and polycythaemia.

Adverse Toxic Effects

Scott (1917) first associated Jamaican vomiting sickness with ingestion of unripe ackee fruit. The fatal disorder was characterised by vomiting, severe hypoglycaemia and depletion of liver glycogen (Hill and Bras 1953; Jelliffe and Stuart 1954). Two hypoglycemic non proteinogenic amino acids were isolated from the seeds of

unripe ackees and named hypoglycin A and B as they induced severe hypoglycaemia (Hassall et al. 1954). Hypoglycin A was also isolated from the aril of unripe fruit but not hypoglycin B (Hassall and Reyle 1955). Hypoglycin A is found predominantly in the immature ackee fruit. Concentrations within the arilli were found to range from over 1,000 ppm in the immature fruit to less than 0.1 ppm in the fully mature fruit (i.e., pod coloured up, split and opened fully) (Brown et al. 1991). At all stages the seed contained considerable hypoglycin A, about 1,000 ppm, and the membrane mirrored aril levels. These analyses supported earlier observations that unopened or partially opened ackee should not be consumed, whereas fruit which open naturally to >15 mm lobe separation pose little health hazard, provided that all seed and membrane portions are removed. Chase et al. (1990) also determined that hypoglycin-A concentrations in the unripe ackee fruit components to be 939 mg, 711 mg and 41.6 mg/100 g of seed, aril and husk components respectively. Analysis of the ripe fruit components showed that hypoglycin-A in the seed decreased to 269 mg/100 g and remained unchanged in the husk while the concentrations in the edible ripe aril decreased below the detection limit of 1.2 mg/100 g. Hypoglycin A was also detected in canned ackee fruit. Unripe ackee fruit samples were found to contain significantly higher quantities of hypoglycin A when compared with ripe fruit samples (Golden et al. 2002). Uncooked unripe fruit was found to contain 124.4 mg/100 g fresh weight and uncooked ripe fruit 6.4 mg/100 g fresh weight. The seed of the uncooked unripe fruit was found to contain 142.8 mg/100 g fresh weight, and the seed of uncooked ripe fruit has 106.0 mg/100 g fresh weight. Boiling fruit in water for approximately 30 min was efficient in removing hypoglycin A from the edible arils; however, low levels of 0.54 mg/200 ml were detected in the water that was used to cook the ripe fruit. Kean and Hare (1980) found that γ -glutamyl transpeptidase catalyzed the formation of hypoglycin A from hypoglycin B and glutathione at pH 9.5 following a 5 h incubation. Within ackee plants, the highest level of enzymatic activity (per mg of protein in

a crude extract) was found to occur in young and unripe seeds, followed by leaf, and pericarp tissues. The lowest levels of activity were found in the arillus regardless of developmental stage. The average percent recovery of hypoglycin A was 80.34%. As the fruit matures, the concentration of hypoglycin B increased from 0.4 mg/g to 3.3 mg/g (Kean and Hare 1980). Hypoglycin B was only found in the seeds of the fruit. It also possessed hypoglycemic activity but was less potent than hypoglycin A. Recent studies by Bowen-Forbes and Minott (2011) found that hypoglycin A decreased from about 8,000 mg/kg in the green arilli and seeds to 271 and 1,451 mg/kg, respectively, in the ripe fruit whereas hypoglycin B levels in the seeds increased from 1,629 to 11,774 mg/kg. The strong inverse relationship demonstrated that hypoglycin B in the seeds served as a sink for hypoglycin A from the ripening arilli and was thereby involved in the detoxification mechanism of the fruit.

The chemical structure of hypoglycin A was subsequently elucidated as L- α -amino- β -methylene cyclopropane propionic acid by Carbon et al. (1958) who determined that causative agent of Jamaican vomiting sickness was a metabolite of hypoglycin A called methylenecyclopropane acetyl CoA (MCPA-CoA). Hypoglycin A was found to transaminate to methylenecyclopropyl-alanine (MCPA) and subsequently underwent oxidative decarboxylation to form MCPA-CoA (Von Holt 1966). MCPA-CoA exerted its effect by inhibiting several coenzyme A dehydrogenases which were essential for gluconeogenesis (Von Holt et al. 1966). Depletion of glucose reserves and the inability of cells to regenerate glucose led to hypoglycaemia. Two hypoglycin metabolites methylenecyclopropanepyruvate and methylenecyclopropaneacetate were formed in the rat's liver (Von Holt et al. 1966). Methylenecyclopropanepyruvate slightly inhibited the decarboxylation of 1-14C pyruvate in mitochondria whereas methylenecyclopropaneacetate did not affect the oxidation of 2-14C pyruvate. Methylenecyclopropaneacetate inhibited in the mitochondria the oxidation of C12- to C18-fatty acids but not that of C4- to C10-fatty acids. Also oxidative phosphorylation in mito-

chondria was uncoupled and respiration inhibited by methylenecyclopropaneacetate. The data suggested that hypoglycin toxicity was due to the formation of its metabolite methylenecyclopropaneacetate which inhibited the oxidation of long-chain fatty acids, uncoupling oxidative phosphorylation, and interfering with gluconeogenesis.

Minor direct effect of hypoglycin was observed on glucose metabolism, either on glucose oxidation to respiratory CO² or on conversion of glucose to liver lipid or muscle glycogen. Synthesis of glycogen from glucose in diaphragm muscle was inhibited by hypoglycin without altering glucose uptake (McKerns et al. 1960). The major effects of hypoglycin were those concerned with fatty acid metabolism. The administration of hypoglycin to rats caused an increase in the level of non-esterified fatty acids in the serum, an increase in the total lipids of the liver and a significant inhibition in the conversion of butyrate or stearate to respiratory CO². Liver mitochondria isolated from hypoglycin-treated rats showed an impaired ability to form high energy phosphate bonds associated with the oxidation of pyruvate and malate. Since hypoglycin lowered blood glucose level only after 3 or 4 h, the active compound may be a metabolite or the effects on blood sugar may be secondary to some primary metabolic block. Methylenecyclopropanepyruvic acid and methylenecyclopropaneacetic acid, both likely metabolites, did produce hypoglycemia. Hypoglycin and hypoglycin-like compounds were found to cause profound hypoglycemia which may be largely attributed to their effects on gluconeogenesis (Bressler et al. 1969). Their toxicity was attributed to their capacity to become activated to acyl CoA derivatives whose further oxidation was impaired.

Hypoglycin toxicity in rats was found to cause changes in hepatic ultrastructure such as progressive mitochondrial swelling in the hepatocytes with loss of granules and pallor of the matrix, followed by incorporation into autophagic vacuoles (Brooks and Audretsch 1970). Kean (1972) found that liver of rats administered hypoglycin exhibited drastically reduced levels of acyl-CoA dehydrogenase activity with butyryl-CoA as

substrate and less so with palmitoyl-CoA as substrate. The observed effect was consistent with quite general inhibition of fatty acid β -oxidation by hypoglycin. Studies by Lai et al. (1991, 1993) found that (methylenecyclopropyl)acetyl-CoA (MCPA-CoA), a metabolite of hypoglycin A, inactivated medium-chain acyl-CoA dehydrogenase, a FAD (flavin adenine dinucleotide)-dependent enzyme that catalyzed the first step of the fatty acid oxidation cycle. When General acyl-CoA dehydrogenase was exposed to (methylenecyclopropyl)acetyl-CoA (MCPA-CoA), time-dependent inhibition occurred with concomitant bleaching of the active-site FAD.

Hypoglycin A was more potent than B and had been reported in the literature as the causative agent in incidences of acute toxicity termed Jamaican vomiting sickness or toxic hypoglycemic syndrome (Blake et al. 2006). The toxic peptide compounds of *Blighia sapida* fruit, hypoglycin A and B had been shown to induce hypoglycemia in rabbits, monkeys, rats and mice upon intravenous injection (Chen et al. 1957). Administration of hypoglycin A to animals caused drowsiness progressing to coma, and when large doses were given the animals died (Feng and Patrick 1958). For the rat, the oral and intraperitoneal LD₅₀ values were 98 and 97 mg/kg respectively. The most outstanding biochemical change produced by hypoglycin-A was a delayed hypoglycaemia, the depth of which was related to the dose. The hypoglycaemia was preceded by exhaustion of liver glycogen. There were also smaller decreases in the glycogen stores of the heart, skeletal muscle and kidney, without any increase in blood pyruvate or lactate. Hypoglycin-A lessened the effect of adrenaline on blood glucose and decreased both glucose tolerance and insulin sensitivity. Hypoglycin-A also decreased oxygen consumption and carbon dioxide production of the intact rat. All these effects were consistent with the hypothesis that the primary action of hypoglycin-A was the interference with glycogen production by the liver.

Hypoglycin A, the causative agent of the Jamaican vomiting sickness, produced a marked increase in concentration of isovaleric acid in

the plasma of rats, when administered in a single dose (Tanaka et al. 1972). α -methylbutyric acid, a position isomer, also accumulated. The use of hypoglycin A reproduced some features of human isovaleric acidemia. Accumulation of these branched pentanoic acids may be another factor contributing to the pathogenesis of the Jamaican vomiting sickness.

Subacute intraperitoneal administration of the lipid portion of the unripe ackee aril (ackee oil) in rats resulted in marked neutropenia and increase in platelets without anaemia (Singh et al. 1992). Blood urea, sodium and aspartate aminotransferase levels were significantly decreased but glucose and bilirubin levels were similar to those of controls. The lungs showed areas of petechial haemorrhages and a dose-related perivascular and peribronchial mononuclear cell infiltration. The pulmonary toxicity may be interpreted as a hypersensitive reaction to ackee oil.

In Jamaica, ackee consumption was highest in the lower socio-economic group, particularly in children (Blake et al. 2004). Hypoglycin occurrence levels in typical ackee diets ranged from 1.21 to 89.28 μ g hypoglycin/g ackee. Animal feeding studies showed that the acute toxic dose for male and female rats was 231.19 mg hypoglycin A/kgBW and 215.99 mg hypoglycin A/kgBW, respectively (Blake et al. 2006). This was considerably greater than the dose of 100 mg hypoglycin/kg BW reported in a previous study when aqueous hypoglycin was administered orally. The maximum tolerated dose of hypoglycin A in both male and female rats was 1.50 mg hypoglycinA/kg BW/day. These findings suggested that the form in which hypoglycin in ackee was administered could affect the toxicological properties it exhibited.

Hypoglycin Toxicity Treatment

The administration of riboflavin and glycine had been reported to reverse the effects of hypoglycin A intoxication (Duff et al. 1980; Brooks and Audretsch 1971). It was believed that riboflavin stimulated the de novo synthesis of

acyl-CoA dehydrogenases while glycine conjugated with excess dicarboxylic acids produced due to impaired lipid metabolism (Al-Bassam and Sherratt 1981). Study by Brooks and Audretsch (1971) found that mitochondrial swelling was reduced in rats given riboflavin prior to hypoglycin, compared with rats given hypoglycin alone. Riboflavin appeared less effective if given 10 min after hypoglycin.

Studies in mice showed that as a treatment for ackee poisoning, glucose was more effective than methylene blue and elicited the same survival as methylene blue in conditions of early treatment (Barennes et al. 2004). Methylene blue must be given in multiple doses and the first administration should be performed early, at least within 3 h of poisoning, which may decrease the practical value of methylene blue in the field.

Traditional Medicinal Uses

Various parts of the plant have been used in folkloric medicine in many tropical countries (Irvin 1965; Morton 1987; Asamoah et al. 2010; Ekué et al. 2010). In Brazil, repeated small doses of an aqueous extract of the seed has been administered to expel parasites. The treatment is followed by a saline or oily purgative. In Colombia, the leaves and bark are regarded stomachic. Various preparations are made for treatment of epilepsy and yellow fever. Cubans blend the ripe arils with sugar and cinnamon and give the mixture as a febrifuge and as a treatment for dysentery.

In Ghana, the bark is mixed with pungent spices (*Capsicum* pepper) in an ointment applied to relieve pain. The crushed new foliage is applied on the forehead to relieve severe headache. The seeds are ingested to treat nausea and vomiting. In Côte d'Ivoire and Nigeria, the leaves, crushed with salt, are poulticed on ulcers and yaws. In Côte d'Ivoire, *finsan* is widely used for the treatment of yellow fever, epilepsy and oedema, and as a laxative and diuretic. The leaf juice is employed as eye drop in ophthalmia and conjunctivitis. The bark pulp is used as liniment for oedema intercostals pains. In Benin, leaves are employed for the therapy of fever and vertigo, and twigs for

hepatitis, cirrhosis and amygdalitis. In Togo, decoctions of bark or fruit walls are applied to wounds, and the fruit pulp to treat whitlow. Pounded bark is administered as an antidote to snake, stings and scorpion bites, and pounded seeds to treat stomach complaints.

In Benin, 22 ailments have been reported to be healed with ackee (Ekué et al. 2010). To treat whitlow, ackee bark is crushed with common bean or cowpea and salt and applied to the finger; or crushed roasted seeds added to palm oil and similarly applied; or a mixture of ackee seeds and cashew nuts is incinerated and the ash applied to the finger. To treat head lice the fruit capsule is incinerated and the ashes are used to wash the head. To treat dental decay, the crushed seeds and salt is applied on the decaying teeth or crushed dried bark is placed on the hole of the decaying teeth. For apparition of the first children's teeth, a decoction of leaves and bark is drunk. To treat child fever, the child is washed with a root infusion or with a water decoction of pounded leaves. To treat fever, pounded leaves of ackee and teak or pounded leaves of ackee and mango are used. To treat yellow fever powdered dried bark and salt is added to porridge and ingested, or crush bark and African locust bean (*Parkia biglobosa*) are eaten. For eye problems, a bark solution is used to wash the eyes. To treat malaria, a bark infusion; decoction of dried bark; an infusion of the bark plus green pepper seeds (*Capsicum anuum*) and soyabean leaves; an infusion of ackee and papaya leaves or a leaf decoction is taken. Powdered dried bark and salt is applied on wounds caused by scorpion and snake bites. Powdered seed or bark; or crushed, roasted seed and palmoil is used to heal wounds. Crushed bark plus cowpea or common bean is applied on abscesses. Juice from crushed bark and honey is applied on burns. To treat cutaneous infections, buttons on the body, a shower is taken with an infusion of leaves and bark. Macerated leaves are used as a massage for fractured limbs. To treat internal haemorrhage crush dried bark is taken with porridge. To treat pregnant women blood flow, macerated leaves previously exposed to the dew plus limestone is drunk. A bark decoction is taken for constipation; root decoction for anemia,

leaf decoction for vomiting and decoction of leaves of akee and shea butter (*Vitellaria paradoxa*) is taken for dysentery. To treat Guinea worn infection, crushed dried bark plus shea butter (*Vitellaria paradoxa*) and potash are applied on the skin.

Other Uses

The fruit of *Blighia sapida* has molluscicidal activity. An extract prepared from freeze-dried, semi-ripe fruits of *B. sapida*, resulted in a mortality of 95% mortality of the snails after an exposure for 24 h (LC95) were at concentrations of 232.7 and 161.2 ppm for the juveniles and adults of *Bulinus globosus* and 187.6 and 140.2 ppm for the juveniles and adults of *Bulinus truncatus* (Anto et al. 2005). Oil from *B. sapida* fruit could be edible and may be explored as raw materials in the paint, margarine, and soap industries (Oladiji et al. 2009).

Feed intake and digestibility studies in Nigeria showed that *Blighia sapida* leaves could be a very good feed resource for West African dwarf goats especially in the dry season (Aderinola et al. 2007). Ackee leaves had the highest value for feed intake and nutrient digestibility.

The ethnic groups, Otamari and Natemba, located in the North-West of Benin use powdered bark, seeds and capsule to poison fish rendering them easier to catch. ackee soap is mainly produced and commercialized by women from the ethnic groups Otamari (63.3%), Batombu (57.5%) and Natemba (50%) (Ekué et al. 2010). The soap is valued mainly for its medicinal and esthetical properties. In the Pobè region (South-East Benin), the whole immature fruits are cut into small pieces and plunged into water for washing clothes. in the region of N'Dali (North-East Benin) the ash from calcined capsules is used as a repellent for some insect pest in cowpea (*Vigna unguiculata*) or common bean (*Phaseolus vulgaris*). In Boukoumbe, the dried, crushed bark is mixed with seeds of pearl millet (*Pennisetum glaucum*) and African finger millet (*Eleusine coracana* ssp. *africana*) before sowing to thwart insects' attacks.

In Cuba, an extract of the flowers is appreciated as cologne.

The sapwood is white or light greenish-brown. The heartwood is reddish-brown, hard, coarse-grained, durable and immune to termites. It is used locally for light construction and pilings, building materials, carpentry and related applications, farming, forestry, hunting and fishing apparatus and has been recommended for railway sleepers. It is also fashioned into boxes, oars, tool handles, mortars, handicraft, carvings, paddles and casks. In the timber trade, the wood is marketed as *achin* or *tsana*. The wood is also used for fuel and lighting.

Comments

Ackee can be readily and successfully propagated from seeds, stem cuttings, grafting or air layering.

Selected References

- Aderinola OA, Farinu GO, Akinlade JA, Olayen, TB, Ojebiyi OO, Oggunniyi PO (2007) Nutritional potential of *Blighia sapida* K Konig (Ackee ackee) leaves as a dry season feed resource for West African dwarf goats in the derived savanna zone of Nigeria. Livest Res Rural Dev 19(6): Article No.78
- Akintayo ET, Adebayo EA, Arogundade LA (2002) Chemical composition, physicochemical and functional properties of akee (*Blighia sapida*) pulp and seed flours. Food Chem 77:333–336
- Al-Bassam SS, Sherratt HSA (1981) The antagonism of the toxicity of hypoglycin by glycine. Biochem Pharmacol 30:2817–2824
- Anto F, Aryeetey ME, Anyorigiya T, Asoala V, Kpikpi J (2005) The relative susceptibilities of juvenile and adult *Bulinus globosus* and *Bulinus truncatus* to the molluscicidal activities in the fruit of Ghanaian *Blighia sapida*, *Blighia unijugata* and *Balanites aegyptiaca*. J Ann Trop Med Parasitol 99(2):211–217
- Antwi S, Martey ONK, Donkor K, Nii-Ayitey OLK (2009) Anti-diarrhoeal activity of *Blighia sapida* (Sapindaceae) in rats and mice. J Pharmacol Toxicol 4(3):117–125
- Asamoah A, Antwi-Bosiako C, Frimpong-Mensah K, Atta-Boateng A, Montes CS, Louppe D (2010) *Blighia sapida* K.D. Koenig. In: Lemmens RHMJ, Louppe D, Oteng-Amoako AA (eds) Protas 7(2): Timbers/Bois d'œuvre 2. [CD-Rom]. PROTA, Wageningen, the Netherlands
- Bailey LH (1949) Manual of cultivated plants most commonly grown in the continental United States and

- Canada (Revised edition). The Macmillan Co., New York, 1116 pp
- Barennes H, Valea I, Boudat AM, Idle JR, Nagot N (2004) Early glucose and methylene blue are effective against unripe ackee apple (*Blighia sapida*) poisoning in mice. *Food Chem Toxicol* 42(5):809–815
- Blake OA, Jackson JC, Jackson MA, Gordon CLA (2004) Assessment of dietary exposure to the natural toxin hypoglycin in ackee (*Blighia sapida*) by Jamaican consumers. *Food Res Int* 37(8):833–838
- Blake OA, Bennink MR, Jackson JC (2006) Ackee (*Blighia sapida*) hypoglycin A toxicity: dose response assessment in laboratory rats. *Food Chem Toxicol* 44(2):207–213
- Bowen-Forbes CS, Minott DA (2011) Tracking hypoglycins A and B over different maturity stages: implications for detoxification of ackee (*Blighia sapida* K.D. Koenig) fruits. *J Agric Food Chem* 59(8):3869–3875
- Bressler R, Corredor C, Brendel K (1969) Hypoglycin and hypoglycin-like compounds. *Pharmacol Rev* 21(2):105–130
- Brooks SE, Audretsch JJ (1970) Studies on hypoglycin toxicity in rats. I. Changes in hepatic ultrastructure. *Am J Pathol* 59(1):161–180
- Brooks SE, Audretsch JJ (1971) Hypoglycin toxicity in rats. II. Modification by riboflavin of mitochondrial changes in liver. *Am J Pathol* 62(3):309–320
- Brown M, Bates R, McGowan C, Cornell J (1991) Influence of fruit maturity on the hypoglycin A level in ackee (*Blighia sapida*). *J Food Safety* 12:167–177
- Burkill HM (2000) Useful plants of West Tropical Africa, vol 5. Families S–Z. Royal Bot. Gardens, Kew, 686 pp
- Carbon JA, Martin WB, Swett LR (1958) Synthesis of a-aminomethylenecyclopropane-panepropionic acid (hypoglycin A). *J Am Chem Soc* 80:1002
- Chase GW, Landen WO Jr, Soliman AGM (1990) Hypoglycin A content in the aril, seeds and husks of ackee fruit at various stages. *J Assoc Off Anal Chem* 73(2):318–319
- Chen KK, Anderson RC, McCowen MC, Harris PN (1957) Pharmacologic action of hypoglycin A and B. *J Pharmacol Exp Therap* 121(3):272–285
- Djenontin ST, Wotto VD, Lozano P, Pioch D, Sohounhloué DKC (2009) Characterisation of *Blighia sapida* (Sapindaceae) seed oil and defatted cake from Benin. *Nat Prod Res* 23:549–560
- Duff DA, Price SC, Snell K (1980) Effect of hypoglycin on alanine release by skeletal muscles in vitro. *Biochem Soc Trans* 8:574–575
- Einbond LS, Reynertson KA, Luo XD, Basile MJ, Kennelly EJ (2004) Anthocyanin antioxidants from edible fruits. *Food Chem* 84:23–28
- Ekué MR, Sinsin B, Eyog-Matig O, Finkeldey R (2010) Uses, traditional management, perception of variation and preferences in ackee (*Blighia sapida* K.D. Koenig) fruit traits in Benin: implications for domestication and conservation. *J Ethnobiol Ethnomed* 6:12
- Feng PC, Patrick SJ (1958) Studies of the action of hypoglycin-A, a hypoglycaemic substance. *Br J Pharmacol Chemother* 13(2):125–130
- Gaillard Y, Carlier J, Berscht M, Mazoyer C, Bevalot F, Guitton J, Fanton L (2011) Fatal intoxication due to ackee (*Blighia sapida*) in Suriname and French Guyana. GC-MS detection and quantification of hypoglycin-A. *Forensic Sci Int* 206(1–3):e103–e107
- Gardner MT, Williams LAD, The TL, Fletcher CK, Singh PDA, Wharfe G, Choo-Kang E, Sawh RN, Rickards E (1996) Extracts from *Blighia sapida* (Koenig) produce neutropenia and thrombocytopenia in mice. *Phytother Res* 10(8):689–691
- Garg HS, Mitra CR (1976) Structure of blighinine. *Tetrahedron Lett* 9(13):1549–1552
- Golden KD, Williams OJ, Bailey-Shaw Y (2002) High-performance liquid chromatographic analysis of amino acids in ackee fruit with emphasis on the toxic amino acid hypoglycin A. *J Chromatogr Sci* 40(8):441–446
- Hassall CH, Reyle K (1955) Hypoglycin A and B, two biologically active polypeptides from *Blighia sapida*. *Biochem J* 60(2):334–339
- Hassall CH, Reyle K, Feng P (1954) Hypoglycin A, B: biologically active polypeptides from *Blighia sapida*. *Nature* 173:356–357
- Hedrick UP (1972) Sturtevant's edible plants of the world. Dover Publications, New York, 686 pp
- Hill KR, Bras G (1953) Symposium on the vomiting sickness of Jamaica. *W Indian Med J* 2:93–124
- Howélé O, Bobelé N, Théodor D, Séraphi KC (2010) Nutritional composition studies of sun dried *Blighia sapida* (K. Koenig) aril from Côte d'Ivoire. *J Appl Biosci* 32:1989–1994
- Irvin FR (1965) Botany and medicine in West Africa. Ibadan University Press, Ibadan, pp 102–130
- Jelliffe DB, Stuart KL (1954) Acute toxic hypoglycaemia in the vomiting sickness of Jamaica. *Br Med J* 1:75–77
- Kean EA (1972) Selective inhibition of acyl-CoA dehydrogenases by a metabolite of hypoglycin. *Biochim Biophys Acta* 422(1):8–14
- Kean EA, Hare ER (1980) γ -glutamyl transpeptidase of the ackee plant *Blighia sapida*. *Phytochemistry* 19(2):199–203
- Kennard WC, Winters HF (1960) Some fruits and nuts for the tropics. USDA Agric Res Serv Misc Publ 801:1–135
- Lai MT, Liu LD, Liu HW (1991) Mechanistic study on the inactivation of general acyl-CoA dehydrogenase by a metabolite of hypoglycin A. *J Am Chem Soc* 113(19):7388–7397
- Lai MT, Li D, Oh E, Liu HW (1993) Inactivation of medium-chain acyl-CoA dehydrogenase by a metabolite of hypoglycin: characterization of the major turnover product and evidence suggesting an alternative flavin modification pathway. *J Am Chem Soc* 115:1619–1628
- McKerns KW, Bird HH, Kaleita E, Coulomb BS, de Renzo EC (1960) Effects of hypoglycin on certain aspects of glucose and fatty acid metabolism in the rat. *Biochem Pharmacol* 3(4):305–315
- Morton JF (1987) Akee. In: Fruits of warm climates. Julia F. Morton, Miami, pp 269–271

- Natalini B, Capodiferro V, De Luca C, Espinal R (2000) Isolation of pure (2S, 1' S, 2' S)-2-(2'-carboxycyclopropyl)glycine from *Blighia sapida* (Akee). *J Chromatogr A* 873:283–286
- Oladiji AT, Shoremekun KL, Yakubu MT (2009) Physicochemical properties of the oil from the fruit of *Blighia sapida* and toxicological evaluation of the oil-based diet in Wistar rats. *J Med Food* 12(5): 1127–1135
- Owolabi OA, James DB, Ibrahim AB, Folorunsho OF, Bwalla I, Akanta F (2010) Changes in lipid profile of aqueous and ethanolic extract of *Blighia sapida* in rats. *Asian J Med Sci* 2(4):177–180
- Purseglove JW (1968) Tropical crops: dicotyledons. 1 & 2. Longman, London, 719 pp
- Scott HH (1917) On the “vomiting sickness” of Jamaica. *Ann Trop Med Parasit* 10:1–78
- Singh P, Gardner M, Poddar S, Choo-Kang E, Coard K, Rickards E (1992) Toxic effects of ackee oil (*Blighia sapida* L) following subacute administration to rats. *West Indian Med J* 41(1):23–26
- Stuart KL, Roberts EV, Whittle YG (1976) A general method for vomifolol detection. *Phytochemistry* 15(2):332–333
- Tanaka K, Isselbacher KJ, Shih V (1972) Isovaleric and α -methylbutyric acidemias induced by hypoglycin a: mechanism of Jamaican vomiting sickness. *Science* 175(4017):60–71
- Von Holt C (1966) Methylenecyclopropaneacetic acid, a metabolite of hypoglycin. *Biochim Biophys Acta* 125(1):1–10
- Von Holt C, Von Holt M, Bohm H (1966) Metabolic effects of hypoglycin and methylenecyclopropaneacetic acid. *Biochim Biophys Acta* 125(1):11–21

Dimocarpus fumatus subsp. *fumatus*

Scientific Name

Dimocarpus fumatus (Blume) Leenh. subsp. *fumatus*.

Southern China, Indo-China, Thailand, Peninsular Malaysia, Sumatra, Java, Borneo (throughout the island) and the Philippines.

Synonyms

Nephelium fumatum Blume, *Pseudonephelium fumatum* (Blume) Radlk. p.p. nom. illeg.

Agroecology

This subspecies is found in primary forests, mainly on the flat lowland as well as hill slopes or hill tops or along river banks, at altitudes mostly below 100 m, up to 1,200(–1,350) m altitude. It is usually found on sandy soils.

Family

Sapindaceae

Edible Plant Parts and Uses

The arillode of ripe fruit is sweet and edible fresh.

Common/English Names

Green Cat's Eye, Green Mata Kucing.

Botany

Mid-canopy tree up to 27 m high, dbh up to 1 m, sometimes with buttresses. Twigs terete, rarely less than 3 mm in diameter, dark to greyish brown, early glabrescent lenticels inconspicuous. Leaves (2-) 3- or 4-jugate; petiole up to 11.5 cm long. Leaflets usually subopposite to alternate, 6.5-28 by 2.8-10.5 cm, apex tapering to narrowly acuminate, base cuneate to rounded margin, entire, penniveined, glands along both mid-rib and margin, abaxial surface sparsely patent short hairy in the basal part on midrib and nerves,

Vernacular Names

Borneo: Katumbar, Mambuakat, Merakiang;
Sabah: Kekucing;

Origin/Distribution

This subspecies is found throughout Borneo Island and perhaps also in Peninsular Malaysia. The species *Dimocarpus fumatus* is found in



Plate 1 Tree habit



Plate 2 Leaf with three pairs of sub-opposite leaflets

adaxial surface glabrous, minutely punctate (Plates 1 and 2). Inflorescences usually terminal lax up to 45 cm long, branched with many-flowered cymules, bracts subulate, pedicels 2-4 mm long. Sepals up to 1/3 connate, tomentose inside. Petals absent or rarely 1, much reduced. Stamens with glabrous filaments. Fruits globose to subglobose, 2.0-2.5 cm diameter, smooth, granular, glabrous, hardly warty, yellowish-green. Pericarp thin, arillode, fairly thick, translucent, juicy and sweet enclosing a large short-oblong seed (Plates 3 and 4).

Nutritive/Medicinal Properties

No information on its fruit nutritive value has been published.

The ethanolic extract from *Dimocarpus fumatus* stem bark showed in-vitro cytotoxic activity



Plate 3 Globose yellowish-green fruit with translucent, juicy arillode



Plate 4 Fruit with arillode and seed removed

against KB (human nasopharynx carcinoma) cells (Voutquenne et al. 1999). Fractionation of the extract afforded compounds belonging to different classes. The two major components were identified as a benzoquinone, sargaquinone, and a chromene, sargaol. One sphingolipid, soyacerebroside I, two glycosides of sitosterol, and fatty acids were also identified. Besides these known compounds, two new glycosides of long-chain fatty alcohols were identified as 1-*O*-[α -L-rhamnopyranosyl-(1 $\rightarrow$ 2)- β -D-glucopyranosyl-(1 $\rightarrow$ 3)- α -L-rhamnopyranosyl-(1 $\rightarrow$ 6)- β -D-glucopyranosyl]hexadecanol and 1-*O*-[[α -L-arabinopyranosyl-(1 $\rightarrow$ 3)]- α -L-rhamnopyranosyl-(1 $\rightarrow$ 2)- β -D-glucopyranosyl-(1 $\rightarrow$ 3)- α -L-rhamnopyranosyl-(1 $\rightarrow$ 6)- β -D-glucopyranosyl]

hexadecanol, and a mixture of three new diacylglycerylglucosides were also isolated.

Mono-desmosidic and bidesmosidic saponins with haemolytic activity were isolated from five Sapindaceae species including *Dimocarpus fumatus* (Voutquenne 2001). Additionally, other metabolites were also isolated from *Dimocarpus fumatus*, including isoprenyphchromenes and three new glycosides of long chain fatty alcohols. Comparison of activities of monodesmosidic and bidesmosidic saponins showed that monodesmosidic saponins were generally more active in haemolytic activity and suggested a polar balance between the two sugar chains at positions 3 and 28 (Voutquenne et al. 2002).

Other Uses

Parts of the plant that contain saponins can be used as fish poison and as detergent for washing clothes.

Comments

Dimocarpus fumatus subsp. *fumatus* can be differentiated from other Malesian subspecies (Adema et al. 1994) as follows:

Dimocarpus fumatus subsp. *philippinensis* (syn. *Nephelium fumatum* Radlk. pp., *Nephelium intermedium* auct. Non Radlk.) - Twigs rarely more than 3 mm in diameter glabrous; leaves 1- or 2-jugate (exceptionally 1-foliolate), leaflets opposite, glabrous, base acute; petals absent, fruits short spiny. Found in the Philippines (Luzon, Samar, Panay).

Dimocarpus fumatus subsp. *javensis* (Radlk.) Leenhout (Syn. *Pseudonephelium javanicum* Radlk.) - Twigs about 5 mm in diameter, early glabrescent; leaves 3–4 jugate, leaflets alternate

base acute; inflorescence incompletely known, petals 4, reduced; fruits not observed. Found in Sumatra and Java

An article in *Nature Malaysiana* erroneously showed a picture of *Dimocarpus dentatus* with subglobose greenish fruit and leaflets with smooth, entire margin. *D. dentatus* has serrate-dentate leaflets and granular, aculeate (spiny) fruits.

Selected References

- Adema F, Leenhouts PW, van Welzen PC (1994) Sapindaceae. In: Flora Malesiana. Ser 1, vol 11, (Cip-Gegevens Koninklijke Bibliotheek: Den Haag.), pp 419–768
- Backer CA, Bakhuizen van den Brink Jr RC (1965) Flora of Java, (Spermatophytes Only). Vol 2. Wolters-Noordhoff, Groningen, The Netherlands, 641 pp
- Leenhouts PW (1971) A revision of *Dimocarpus* (Sapindaceae). *Blumea* 19:113–131
- Slik JWF (2006) Trees of Sungai Wain. Nationaal Herbarium Nederland. <http://www.nationaalherbarium.nl/sungaiwain/>
- Van Welzen PC, Lamb A, Wong WWW (1988) Edible Sapindaceae in Sabah. *Nat Malaysiana* 13:10–25
- Voutquenne L (2001) Saponins and hemolytic activity. Saponins and glycosides from five species of Sapindaceae. *Ann Pharm Fr* 59(6):407–414 (In French)
- Voutquenne L, Lavaud C, Massiot G, Sevenet T, Hadi HA (1999) Cytotoxic polyisoprenes and glycosides of long-chain fatty alcohols from *Dimocarpus fumatus*. *Phytochemistry* 50(1):63–69
- Voutquenne L, Lavaud C, Massiot G, Men-Olivier LL (2002) Structure-activity relationships of haemolytic saponins. *Pharm Biol* 40(4):253–262
- Wong KC (2000) Longan production in Asia. RAP 200/20. Food and Agriculture Organization of the United Nations Regional Office For Asia and the Pacific, Bangkok, Thailand
- Wong KC, Gan YY (1992) The diversity of *Dimocarpus longan* ssp. *malesianus* var. *malesianus* in Sarawak. *Acta Hort* 292:29–39
- Wong KC, Saichol K (1991) *Dimocarpus longan* Lour. In: Verheij EWM, Coronel RE (eds) Edible fruits and nuts. Plant Resources of Southeast Asia, Pudoc, Wageningen, pp 146–151

Dimocarpus longan subsp. *longan* var. *longan*

Scientific Name

Dimocarpus longan Lour. subsp. *longan*
Leenhout var. *longan* Leenhout.

Synonyms

Dimocarpus longan Lour., *Euphoria echinulata* Radlk., *Euphoria longan* (Lour.) Steudel, *Euphoria longana* L., *Euphoria longana* Lamk. nom. illeg., *Euphoria sinensis* Gmel., *Nephelium bengalense* G. Don., *Nephelium didymum* Craib, *Nephelium longana* (Lam.) Cambess., *Nephelium longan* (Lour.) Hook., *Nephelium longana* Cambess., *Nephelium longana* var. *pallida* Trim., *Nephelium longana* var. *acuminata* Pierre, *Nephelium pupillum* Wight.

Family

Sapindaceae

Common/English Names

Dragon's eye, Dragon's eye fruit, Longan, Lonagn Tree, Lungan.

Vernacular Names

Brazil: Olho-De-Dragão (Portuguese);

Burmese: Kyet Mouk;

Chinese: Lóng Yǎn, Longan, Lung Ngaan, Gui Yuan, Yang Yan Guo Shu, Yuan Yan;

Cuba: Mamoncillo Chino (Spanish);

Dutch: Lengkung;

French: Longan, Longanier, Oeil De Dragon;

German: Longane, Longanbaum, Longanbeere;

India: Ash-Fol (Bengali), Kanakindeli (Kannada), Chempoovana, Chempunna, Malampoovathi, Malampuvanna, Mulei, Pasakotta, Poripuna (Malayalam), Kattupuvam Shempuvam (Tamil);

Indonesia: Kalengleng (Madurese), Lengkung;

Japanese: Rongan, Ryugan;

Khmer: Mien,

Laos: Lam Nhai, Nam Nhai;

Malaysia: Lengkung, Longan Lungan;

Philippines: Longan (Tagalog);

Russian: Longan, Longana;

Portuguese: Longana, Pitomba Longana;

Spanish: Longán, Mamoncillo Chino;

Sri Lanka: Mora (Sinhalese);

Thailand: Lamyai Pa, Ma Lamyai;

Vietnam: Nhãn, Long Nhãn.

Origin/Distribution

The longan is native to southern China, in the provinces of Kwangtung, Kwangsi, Szechwan and Fukien, Hainan, Yunnan, between elevations of 150–700 m. The species has also reported to be found in India, Sri Lanka, Upper Myanmar, North Thailand, Kampuchea, North Vietnam and New Guinea. The crop is mainly grown in

southern China, Taiwan and north Thailand, Kampuchea, Laos and Vietnam with small acreages elsewhere in India, Sri Lanka, Philippines, Queensland (Australia) and Florida (United States). Scattered trees are found at higher elevations in South-East Asia. Longan is also grown in the Reunion and Mauritius.

Agroecology

Longan is adapted to the warm subtropical areas, or at higher elevation in the tropics where there is a distinct fluctuations in temperatures for satisfactory flowering. Longan requires a short (2–3 months) of cool (mean temperature 15–22°C) winter season for prolific bloom or a short drought in winter may assist flowering, especially in the more tropical types. From fruit set onwards high temperatures do not hamper development, but nights should not be warmer than 20–25°C. Annual rainfall of 1,500–2,000 mm is probably required in the absence of irrigation. Ample soil moisture is needed from fruit set until maturity. Longan prefers rich well-drained sandy loams, it does well on oolitic limestone. Moderately acid sandy soils are more marginal and on organic muck soils flowering is deficient, probably because of protracted vegetative growth. In northern Thailand longan orchards are often situated on the lighter alluvial soils along former river courses.

Edible Plant Parts and Uses

The fruit pulp (ariloid) is edible, extremely sweet, juicy and succulent. It is best eaten fresh, out-of-hand or frozen, thawed and eaten. The fruit is also eaten cooked in various cuisines, dried or canned in its own juice or in syrup. Canned longan is usually used in various hot or cold desserts. Dried longan is commonly used in Asian herbal soups, as snacks, dessert, beverage and sweet-and-sour food. Dried longan is a *bupin* fruit used to make *bupin* which is equivalent to home-made, therapeutic, tonic food to revitalise and strengthen the body (Hu 2005). The dried longan is dark-brown to almost black, leathery

and smoky in flavor and is mainly used to prepare a cold or warm infusion drink for refreshment and vitality. A liqueur is made by macerating the longan flesh in alcohol. Canned and dried longans are mainly exported from China and Thailand to USA, Europe and elsewhere. Both lycee and longan are deemed as ‘warm fruit’.

Botany

An evergreen tree, growing to 20 m with a rough corky trunk with diameter reaching 1 m and dark-brown, lenticellate twigs. The leaves are alternate, petiolate 2–10 cm long, paripinnate with 2–6 jugate, leaflets opposite on 1.5–10 mm long petiolules. Leaflet is oblong-elliptic to oblong-lanceolate, 6–15 by 2.5–5 cm, upper surface glossy deep green, lower pale green, chartaceous, both surfaces glabrous, lateral veins 12–15 pairs, only prominent abaxially, base extremely asymmetrical, apex acute, blunt to obtuse (Plates 1 and 2). New growth is wine-colored and showy. Inflorescences terminal or axillary near apex, large, many branched, 8–40 cm long, densely tufted tomentose. Panicle comprise staminate, pistillate and hermaphrodite flowers. Cymules 3–5 flowered and distinctly stalked. Pedicels short 2–4 mm, bracts patent, 1.5–5 mm long; calyx lobes deltoid-ovate, 2–5 mm × 1–3 mm; petals 5, 1.5–6 mm × 0.6–2 mm, milky-white, lanceolate, nearly as long as sepals; stamens 6–8, filament 1–6 mm, hirsute in hermaphrodite flowers which



Plate 1 Foliage and developing longan fruits



Plate 2 Compound 3-6-jugate leaves and young fruits



Plate 3 Harvested ripe longan fruits



Plate 4 Ripe longan fruit with translucent flesh and glossy black seed

have bicarpellate, densely hairy ovary with a bilobed stigma. Stamens non-functional in pistillate flowers. Fruit drupaceous, 1.25–3 cm in diameter, subglobose, usually yellowish brown or sometimes grayish yellow, mostly pusticulate to granulate and nearly smooth (Plates 2–4). Seed

globular with shining blackish-brown testa and enveloped by a fleshy, translucent, white arilloid (Plates 3–4).

Nutritive/Medicinal Properties

The nutrient composition of raw longan (exclude 47% refuse of shell and seed) per 100 g edible portion is: water 82.75 g, energy 60 kcal (251 kJ), protein 1.31 g, fat 0.10 g, ash 0.70 g, carbohydrate 15.14 g, dietary fibre 1.1 g, Ca 1 mg, Fe 0.13 mg, Mg 10 mg, P 21 mg, K 266 mg, Na 0 mg, Zn 0.05 mg, Cu 0.169 mg, Mn 0.052 mg, vitamin C 84.0 mg, thiamine 0.031 mg, riboflavin 0.140 mg, niacin 0.3 mg, threonine 0.034 g, isoleucine 0.026 g, leucine 0.054 g, lysine 0.046 g, methionine 0.013 g, phenylalanine 0.030 g, tyrosine 0.025 g, valine 0.058 g, arginine 0.035 g, histidine 0.012 g, alanine 0.157 g, aspartic acid 0.126 g, glutamic acid 0.209 g, glycine 0.042 g, proline 0.042 g, and serine 0.048 g (USDA 2012).

Longan fruit had the highest vitamin C content (60.1 mg/100 g) among the three specialty fruit tested (lycee, longan and rambutan) (Wall 2006) and a range of 55.3–63.3 mg/100 g. Longan was found to compare favourably to fresh papayas (61.8 mg/ 100 g), oranges (53.2 mg/100 g), and strawberries (58.9 mg/100 g) for vitamin C content. Longans were found to be a good source of potassium (K) and copper (Cu). Fresh longans (100 g) can supply 7% of the DRI (Daily Recommendation Intake) for K and 29% of the DRI for Cu. Copper ranged from 0.23 to 0.30 mg/100 g in longan fruit. Longans also may provide 3–5% of the DRI for phosphorus (P), magnesium (Mg), iron (Fe), manganese (Mn), and zinc (Zn). Longan fruit had been reported to contain significant amounts of bioactive compounds such as corilagin, ellagic acid and its conjugates, 4-O-methylgallic acid, flavone glycosides, glycosides of quercetin and kaempferol, ethyl gallate 1- β -O-galloyl-D-glucopyranose, grevifolin and 4-O- α -L-rhamnopyranosyl-ellagic acid (Yang et al. 2011). Sun et al. (2007) extracted two polyphenol compounds identified as 4-O-methylgallic acid and (–)-epicatechin from longan fruit pericarp.

Longan fruit pericarp was found to contain 1.101 mg/mL of total flavanone (Huang et al. 2006). From the pulp of longan, three cerebroside molecular species have been isolated. Six known cerebrosides, soyacerebrosides I and II, 1-O- β -D-glucopyranosyl-(2S,3R,4E,8E)-2-(2'-lignoceroylamino)-4,8-octadecadiene-1,3-diol (longan cerebroside I) and its 8Z isomer (longan cerebroside II), momor-cerebroside I, and phytolacca cerebroside, were identified as major components of these cerebroside molecular species (Ryu et al. 2003). All the cerebrosides were shown to be a mixture of geometrical isomers (8E and 8Z) of sphingosine-type or phytosphingosine-type glucocerebrosides possessing 2-hydroxy fatty acids. Cerebrosides are important components in animal muscle and nerve cell membranes. HPLC analysis of acid hydrolyzed extracts of longan peel showed that the majority of the flavones were glycosides of quercetin and kaempferol (Jaitrong et al. 2006). Similar analyses also showed evidence of ellagic acid glycosides. Purified oligosaccharides extracted from longan fruit pericarp were found to comprise Gal (71.5%), Glc (24.6%), and GalA (3.9%) (Jiang et al. 2009). The analysis of glycosidic linkages showed that the backbone consisted of $\rightarrow 3$ -Gal-(1 $\rightarrow$, $\rightarrow 6$)-Gal-1 $\rightarrow$, Glc-(1 $\rightarrow$ and $\rightarrow 3$)-GalA-1 $\rightarrow$ with a molar proportion of 13:5:6:1. Longan fruit was found to contain the lowest total dietary fibre (0.19%) and the lowest phytate content (0.37%) compared to dragon fruit, durian, guava, mango, and pineapple (Nititham et al. 2004). Longan fruit arils also contained adenosine, adenine, uridine, and 5-methyluridine (Okuyama et al. 1999).

Phytochemicals extracted with 70% methanol from peel, pulp, and seed tissues of longan fruit, yielded the following major components gallic acid, corilagin (an ellagitannin), and ellagic acid (Rangkadilok et al. 2005). There was a large variation in the contents of gallic acid, corilagin, and ellagic acid in different plant tissues and cultivars. Seed contained the highest levels of the three phenolics, and pulp contained the lowest. Among commercial Thai cultivars, Biewkiew and Edor contained the highest levels of gallic and ellagic acid while Srichompoo contained the highest content of corilagin. The authors main-

tained that utilization of this byproduct material will support the use of thousands of tons of waste longan seeds after the production of canned longan pulp. Longan seed was found to contain a rich array of phenolic compounds which could be utilized as health-beneficial bioactive compounds rather than just discarded as waste (Soong and Barlow 2005). Gallic acid, ellagic acid, monogalloyl-glucose, monogalloyl-diglucose, digalloyl-diglucose, penta- to heptagalloyl-glucose, ellagic acid-pentose conjugate, galloyl-HHDP (Hexahydroxydiphenoyl)-glucopyranose, penta-galloy-HHDP-glucopyranose, procyanidin A-type dimer, procyanidin B2 and quercetin-3-O-rhamnoside were found to be present in longan seed along with a number of, unidentified compounds. The hexane extract of longan seeds was found to be predominated by long-chain fatty acids with major levels of palmitic (35%) and oleic (28%) acids (Sudjaroen et al. 2012). The polyphenolic fraction (80.90 g/kg dry weight) was dominated by ellagic acid (25.84 g/kg) and the known ellagitannins corilagin (13.31 g/kg), chebulagic acid (13.06 g/kg), ellagic acid 4-O- α -L-arabinofuranoside (9.93 g/kg), isomallotinic acid (8.56 g/kg) and geraniin (5.79 g/kg).

The seed oil of longan, was found to contain 17.4% of 9,10-methyleneoctadecanoic (dihydrosterculic) acid, 16:0 (19%), 18:0 (7%), 18 Δ 1 (36%), 18:2 (6%), 18:3 (5%) and 20:0 (4%) and less than 1%, of cyclopropanoid fatty acids (Kleiman et al. 1969). Sixty-one volatile compounds were identified in longan fruit (Wong et al. 1996). Esters (68.4%) and terpenoids (27.1%) were quantitatively the most significant among longan volatiles, and ethyl acetate (66.2%) and (E)-ocimene (26.7%) were clearly dominant.

Three acetylenic amino acids: 2-amino-4-methylhex-5-ynoic acid, 2-amino-4-hydroxymethylhex-5-ynoic acid, and 2-amino-4-hydroxyhept-6-ynoic acid were characterised from longan seeds (Sung et al. 1969).

In recent years, some pharmacological activities such as anti-tyrosinase, anti-glycated and anticancer activities, and memory-enhancing effects of longan aril, pericarp or seed extract have been found, implicating a significant contribution to human health (Yang et al. 2011). Other

pharmacological properties that have been reported on the fruit, seeds, flowers and leaves include antioxidant, hypolipidemic, antiobesity, antihypertensive, immunomodulatory, antibacterial, cytotoxic, anxiolytic, analgesic, antimutagenic, neuroprotective, osteoclastogenic, adaptive and antifatigue activities.

Antioxidant Activity

In DPPH (2,2-diphenyl-1-picrylhydrazyl) and superoxide radicals scavenging activity, longan seed extract was found to be as effective as Japanese green tea extract while dried longan pulp and mulberry green tea extracts showed the least scavenging activities (Rangkadilok et al. 2007). In the ORAC assay, both fresh and dried longan seed also exerted higher activity than dried pulp and whole fruit. Longan extracts contained corilagin ranging from zero to 50.64 mg/g DW, gallic acid from 9.18 to 23.04 mg/g DW, and ellagic acid from 8.13 to 12.65 mg/g DW depending on the cultivars. However, the results demonstrated that these three polyphenolics may not be the major contributors of the high antioxidant activity of longan water extracts but this high activity may be due to other phenolic/flavonoid glycosides and ellagitannins present in longan fruit. Of the two polyphenols extracted from longan pericarp, 4-O-methylgallic acid exerted higher reducing power and DPPH-, hydroxyl radical-, and superoxide radical-scavenging activities than (–)-epicatechin (Sun et al. 2007). He et al. (2009) reported that the ferric reducing antioxidant activity of longan pericarp was highly correlated to polyphenol content of which 52.9 mg/g (dry matter) polyphenol was extracted. Their results suggested that gallic and ellagic acids were not the main contributors; 15 other phenolic compounds were found in longan pericarp, all contributing to a synergistic defence system against oxidation. High pressure-assisted extract of longan fruit pericarp exhibited excellent antioxidant activity as assessed by DPPH radical scavenging activity, superoxide anion radical activity, total antioxidant and lipid peroxidation inhibitory activity (Prasad et al. 2009). It contained higher level of total phenolic contents 20.8 mg/g gallic acid equivalent/g dw compared

to conventional extract of longan with 14.6 mg gallic acid equivalent/g. Similarly longan fruit pericarp extract from ultra-high-pressure-assisted extraction at 500 MPa (UHPE-500) showed the highest antioxidant activities as assayed using similar antioxidant models (Prasad et al. 2010). Three phenolic acids, namely gallic acid, ellagic acid, and corilagin were identified. Oligosaccharides extracted from longan fruit pericarp exhibited strong and dose-dependent antioxidant activities as evaluated using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) and superoxide anion radical scavenging assays (Jiang et al. 2009).

The methanol extract of longan seeds exhibited potent antioxidant capacities with an IC_{50} of 154 μ g/mL for reactive oxygen species scavenge on salicylic acid and 78 μ g/mL for inhibition of xanthine oxidase in the hypoxanthine/xanthine oxidase assay (Sudjaroen et al. 2012). The extracts were less effective in the 2-deoxyguanosine assay (IC_{50} = 2.46 mg/mL), indicating that gallates along with ellagic acid and its congeners exerted their potential antioxidant effects predominantly by precipitation of proteins such as xanthine oxidase. This was confirmed for the pure compounds gallic acid, methyl gallate, ellagic acid and corilagin.

The total phenolic content of longan fruit peel extracted with 95% ethanol using microwave-assisted extract of longan peel (MEL) and Soxhlet extract of longan peel (SEL) reached 96.78 mg/g and 90.35 mg/g dry weight, respectively, expressed as pyrocatechol equivalents (Pan et al. 2008). MEL and SEL showed excellent antioxidant compared to synthetic antioxidant 2,6-di-ter-butyl-4-methylphenol (BHT) in all test systems employing various established systems in-vitro including DPPH radical scavenging assay, hydroxyl radical scavenging assay using a new resonance scattering (RS) method, reducing power and total antioxidant capacity. The antioxidant activities of MEL were all superior to those of SEL. MEL and SEL treatment significantly reduced lipid oxidation in peanut oil compared to the control.

Longan flowers exhibited suppressive effects in lipopolysaccharide-stimulated RAW 264.7 macrophage cells (Ho et al. 2007). Abundant levels

of phenolic compounds including flavonoids, condensed tannins, and proanthocyanidins were found in water or ethanolic extracts prepared from dried longan flowers. The antioxidative effect of longan flower extract was similar to the effect exhibited by pure antioxidants (gallic acid, myricetin, and epigallocatechin gallate). Longan flower extract also showed prominent inhibitory effects on prostaglandin E₂ production. Significant concentration-dependent inhibition of nitric oxide production was detected when cells were cotreated with lipopolysaccharide and various concentrations of longan flower extracts. These inhibitory effects were further attributed to suppression of inducible nitric oxide synthase protein expression and not to reduced enzymatic activity. These results suggested that longan flower crude extracts, especially ethanolic extract, had antioxidant and anti-inflammatory effects, and the mechanism may involve inhibition of inflammation by proanthocyanidins. Hiesh et al. (2008) reported that the methanol extract of longan flowers exerted the highest antioxidant activity, followed by ethyl acetate and n-hexane extracts as evaluated using the DPPH free radical scavenging effect, the oxygen radical absorbance capacity (ORAC) assay, and the inhibition of Cu(2+)-induced oxidation of human low-density lipoprotein (LDL) assays. On further fractionation of the methanol extract, the ethyl acetate fraction was found to have the highest activity of delaying LDL oxidation and to contain two major compounds, (–)-epicatechin and proanthocyanidin A2.

The petroleum ether, chloroform and ethyl acetate fractions of ethanol extract of longan leaf and stem exhibited potent antioxidant activity with the ethyl acetate and chloroform leaf fractions displaying the highest with IC₅₀ values of 44.28 and 44.31 µg/mL respectively (Ripa et al. 2010).

Anticancer Activity

High pressure-assisted extract of longan fruit pericarp exhibited higher anticancer activity on HepG2 (Human hepatocellular liver carcinoma), A549 (Human lung adenocarcinoma epithelial

cell line) and SGC 7901 (human gastric carcinoma) cancer cell lines than conventional extracted longan (Prasad et al. 2009). Three phenolic compounds identified gallic acid, ellagic acid and corilagin were identified in the extract. Studies by Chung et al. (2010) showed that longan seed polyphenols (LSP) (25–200 µg/mL) inhibited the proliferation of 3 human colorectal carcinoma cells Colo 320DM, SW480 and HT-29, but not LoVo. LSP induced S phase arrest of the cell cycle and apoptotic death in three CRC cell lines by reducing the expression of cyclin A and cyclin D1. Longan flower extract (LFE) (25–400 µg/mL) inhibited proliferation of two colorectal cancer cell lines, SW-480 and Colo 320DM in a dose- and time-dependent manner by inducing S phase arrest of the cell cycle (Hsu et al. 2010). An apoptotic mechanism induced by LFE involving a loss of mitochondrial membrane potential and caspase 3 activation was found in Colo 320DM cells but not in SW480 cells.

Anti-tyrosinase/Skin-Whitening Activity

Longan seed extract showed tyrosinase inhibitory activity with IC₅₀ values of 2.9–3.2 mg/mL (Rangkadilok et al. 2007) and may have potential as a new natural skin-whitening agent. Yang et al. (2008) reported that polysaccharides extracted from longan fruit pericarp (PLFP) acted as non-competitive inhibitor of tyrosinase. They found that ultrasonic treatment of PLFP increased the inhibition of tyrosinase activity. Longan fruit pericarp extract from ultra-high-pressure-assisted extraction at 500 MPa (UHPE-500) showed moderate tyrosinase inhibitory activity (Prasad et al. 2010).

Anti-glycated Activity

Studies showed that longan pericarp had anti-glycation activity. An anti-glycation agent inhibits the glycation process and prevents the formation of AGEs, advanced glycation end products (e.g. free radicals, α-dicarbonyl species,

protein cross-links, etc.) associated with deleterious health effects. Yang et al. (2009) reported that ultrasonic extraction of polysaccharides of longan fruit pericarp impacted on its anti-glycated activity. The optimal ultrasonic conditions for obtaining the highest anti-glycated activity were predicted to be 276 W, 24 min and 69°C. The predicted anti-glycated activity was 60.4%.

Antihypertensive Activity

Acetylgeraniin, an active principle isolated from the seeds of longan reversed the fall in arterial blood pressure in conscious hypertensive rats (SHRs) with orthostatic hypotension induced by injection of hexamethonium into animals (Hsu et al. 1994). However, acetylgeraniin failed to affect prazosin-induced orthostatic hypotension. Plasma noradrenaline (NA) and mean blood pressure were elevated dose-dependently by an intravenous injection of acetylgeraniin into the rats; this increase in blood pressure was totally abolished by prazosin. Results showed that a direct release of noradrenaline from the noradrenergic nerve terminals by acetylgeraniin seems responsible for the reversing of orthostatic hypotension. In an additional study, administration of corilagin, one of the ellagitannins purified from longan seeds, into conscious spontaneously hypertensive rat (SHR) at 5 mg/kg produced an antihypertensive effect equivalent to that induced by 1 mg/kg of guanethidine (Cheng et al. 1995). This dose-dependent hypotensive effect was comparable with that observed in anesthetized SHR rats. Corilagin reduced plasma noradrenaline in a dose-dependent fashion, an effect that was maintained in adrenalectomized rats. Moreover, corilagin attenuated the pressor effects of methoxamine and Bay K8644 to a similar degree, indicating the direct effect of corilagin on vascular activity in rats. These results suggested that corilagin possessed the ability to lower blood pressure through the reduction of noradrenaline release and (or) direct vasorelaxation.

Tsai et al. (2008) showed that male Sprague-Dawley rats fed with high-fructose diet resulted in oxidative stress and affected the antioxidant

status including plasma thiobarbituric acid and liver antioxidant enzyme activity. Treatment with longan flower water extract significantly increased the antioxidant system. High fructose diet caused insulin resistance and elevation of the blood pressure. Logan flower extract treatment ameliorated insulin resistance by enhancing the expression of insulin signalling pathway related proteins, including insulin receptor substrate-1 and glucose transporter 4 and decreased systolic blood pressure.

Hypolipidemic/Antiobesity Activity

Studies showed that longan flower extract rich in polyphenols (phenolic acids and flavonoids) exhibited antiobesity and hypolipidemic effects in hypercaloric-dietary rats (Yang et al. 2010). Ingestion of the extract for 9 weeks by hypercaloric-dietary rats reduced significantly body weight, size of epididymal fat, serum triglyceride level and atherogenic index, and hepatic lipids. This was postulated to result from down-regulation of pancreatic lipase activity, sterol regulatory element binding protein-1c (SREBP-1c) and fatty acid synthase (FAS) gene expressions, and upregulation of LDL receptor (LDLR) and peroxisome proliferator-activated-receptor-alpha (PPAR-alpha) gene expressions. Faecal triglyceride excretions were also increased.

Anxiolytic/Analgesic Activity

The longan aril extract exhibited significant anxiolytic activity at a dose of 2 g/kg, s.c. in mice, and results of the bioassay-oriented isolation revealed adenosine to be the active principle (Okuyama et al. 1999). Adenosine produced the anti-conflict effect significantly at a dose of 30 mg/kg, s.c. Adenine, uridine, and 5-methyluridine did not exhibit the effect, although these compounds were isolated from the extract. Some other related compounds such as AMP and c-AMP showed no effect, except for inosine. Adenosine also contributed to the analgesic effect which was observed in the extract by the writhing method.

Immunomodulatory Activity

Polysaccharides from longan pulp at doses of 100–200 mg/kg exhibited potent immunomodulatory effects in S180 tumour mice model and also displayed marked effect on delayed-type hypersensitivity (DTH) response, macrophage phagocytosis and ConA-stimulated splenocyte proliferation as compared with the control treatment (Zhong et al. 2010). Longan pulp polysaccharides also exhibited excellent scavenging activity on hydroxyl and DPPH radicals. Yi et al. (2011a, b) found the three polysaccharide-protein complexes of longan pulp (LP1-3) to be principally composed of glucose, arabinose and mannose. LP3 displayed maximal moisture absorption, and thermal stability of LP2 was higher than that of LP1 and LP3. Oral administration of 100 mg/kg/day of longan pulp polysaccharide-protein complex (LP3) significantly increased against chicken red blood cell, concanavalin A (ConA)-induced splenocyte proliferation, macrophage phagocytosis, NK cell cytotoxicity against YAC-1 lymphoma cell, and interferon-gamma (INF- γ) and interleukin-2 (IL-2) secretion in the serum (Yi et al. 2011b). The beneficial immunomodulatory effects of 50–100 mg/kg/day LP3 were comparable to those of 50 mg/kg/day ganoderan, confirming longan pulp polysaccharide to have good potential as an immunotherapeutic adjuvant due to their immunomodulatory activities.

Antibacterial and Cytotoxic Activities

Longan seed but not the pulp nor whole fruit exhibited antifungal activity against the opportunistic yeasts (*Candida* species and *Cryptococcus neoformans*) (Rangkadilok et al. 2012). Of the seed polyphenols, ellagic acid showed the most potent antifungal activity followed by corilagin and gallic acid, respectively. Ellagic acid was more effective against *Candida parapsilosis* and *C. neoformans* than against *Candida krusei* and some *Candida albicans* clinical strains. The Baidam cultivar possessed higher antifungal activity (MIC = 500–4,000 $\mu\text{g/mL}$) as it contained higher contents of ellagic acid

and gallic acid than the Edor cultivar (MIC = 1,000–8,000 $\mu\text{g/mL}$). For antibacterial activity, only corilagin and gallic acid demonstrated weak to moderate inhibitory effects against *Staphylococcus aureus* and *Streptococcus mutans*, respectively.

Chloroform crude extracts of longan leaf and stem (500 $\mu\text{g/disc}$) showed excellent antibacterial activity with the average zone of inhibition of 13–21 mm among the tested bacteria (Ripa et al. 2010). In contrast the petroleum ether extracts showed activity only against *Escherichia coli*. The ethyl acetate crude extracts showed good activity against the growth of *Sarcina lutea* (20 mm), *Vibrio mimicus* (18 mm), *Salmonella typhi* (18 mm), *E. coli* (17 mm) and *Staphylococcus aureus* (14 mm).

In the brine shrimp lethality bioassay, all the crude extracts of longan leaf and stem displayed considerable cytotoxic activity. The chloroform and ethyl acetate extracts of leaf and stem had significant cytotoxic potentials with the LC_{50} values of 8.802, 9.587, 9.248 and 10.45 $\mu\text{g/mL}$ respectively.

Neuroprotective Activity

Studies by Chen et al. (2011) found that longan fruit polysaccharides were capable of alleviating cerebral ischemia/reperfusion injury in rats by a mechanism that may involve decreasing oxidative stress. Longan polysaccharides were found to reduce the neurological score, the infarct volume, the brain water content, malondialdehyde content, myeloperoxidase activity, tumour necrosis factor- α and interleukin -1 β level, expression of Bax, and increase superoxide dismutase, glutathione, glutathione peroxidase activity and expression of Bcl-2.

Antifatigue Activity

Studies by Zheng et al. (2010) demonstrated that longan seed polysaccharides (50 to 100 mg/kg doses), extended swimming time, increased hepatic glycogen, reduced blood urea nitrogen

and decreased blood lactic acid in mice. The result indicated that longan seed polysaccharides may have potential as an antifatigue agent.

Antimutagenic Activity

Three unusual amino acids were identified as anti-mutagens against spontaneous mutation of *Salmonella typhimurium* TA100 from longan seeds: 2-amino-4-methylhex-5-ynoic acid (3), hypoglycin A (4), and (2S,4R)-2-amino-4-hydroxyhept-6-ynoic acid (Minakata et al. 1985).

Osteoclastogenic Activity

Methanol extract of *D. longan* was one of the dozen Korean medicinal plants screened samples exhibited ability to induce osteoclast differentiation (Youn et al. 2008). Bone resorption and loss are generally attributed to osteoclasts. Differentiation of osteoclasts is regulated by receptor activator of nuclear factor NF- κ B ligand (RANKL), a member of tumor necrosis factor family. When the balance is disturbed, pathological bone abnormality ensues.

Memory-Enhancing Activity

Results of studies by Park et al. (2010) suggested that subchronic administration of aqueous extract longan fruit enhanced learning and memory in mice. Its beneficial cognitive activity was found to be mediated partly by increase in BDNF, pCREB, or pERK 1/2 expressions in the hippocampal dentate gyrus and CA1 regions, and by immature neuronal survival.

Adaptogenic Activity

ALG an extract from longan arils and gecko at a dose of 20 ml/kg/day for 10 days administered by gastric intubation (i.g.) significantly enhanced mice tolerance to low and high temperatures and anoxia (Nong and Li 1989). The extract also

increased the body-weight of normal mice, while ALG at 15 ml/kg/day (i.g.) for 2 weeks protected body-weight from decreasing in reserpinized mice. ALG ig 15 ml/kg/day for 10 days elevated the clearance rate of iv (intra-venous) charcoal particles in normal mice.

Prostaglandin E2 Enhancing Activity

Studies found that water extracts of the 'heating foods', litchi, longan, or dried longan applied to RAW264.7 macrophages in absence of LPS (lipopolysaccharide) had a dose-dependent enhancing effect on PGE(2) prostaglandin E2 (well-known proinflammatory mediator) production, with EC50 values of 8.4, 16, and 11 mg/mL respectively (Huang and Wu 2002). In contrast, LPS-induced PGE(2) production was inhibited in a dose-dependent manner by the water extracts of the 'cooling foods', chrysanthemum flower, bitter gourd, and lotus seed plumule. It was concluded that water-soluble extracts of foods traditionally regarded as 'heating' enhanced basal PGE(2) production, while those from 'cooling' foods significantly inhibited LPS-induced PGE(2) production by the macrophage cell line.

Traditional Medicinal Uses

In traditional herbal medicine, the dried flesh of the fruit is administered as a stomachic, febrifuge and vermifuge, and is regarded as an antidote for poison. A decoction of the dried flesh is taken as a tonic and treatment for insomnia and neurasthenic neurosis. In both North and South Vietnam, the "eye" of the longan seed is pressed against a snake bite in the belief that it will absorb the venom. Longan fruit has been used in the traditional Chinese medicinal formulation, serving as an agent in relief of neural pain and swelling (Yang et al. 2011).

Leaves and flowers are sold in Chinese herb markets. The leaves contain quercetin and quercitrin. Dried flowers are exported to Malaysia for medicinal purposes. The seeds are administered to counteract heavy sweating and the pulverized kernel, which contains saponin, tannin and fat, serves as a styptic.

Other Uses

The seeds are rich in saponins and are used as hair shampoo. Both the seed and the fruit flesh of longan have several medicinal uses. The leaves, which contain quercetin and quercitrin, and flowers are sold in Chinese herb markets. The red, hard longan timber is not often cut for timber; the wood is used for posts, agricultural implements, furniture and construction. The heartwood is red, hard, and takes a fine polish.

Studies found longan fruit shell to have stronger adsorbability toward Pb(II) and Hg(II) ions than most natural sorbents reported and to be more low cost effective and more environmental friendly than all synthetic and even seminatural sorbents (Huang et al. 2010), making longan shell attractive as a highly cost-efficient sorbent for the selective removal of hazardous heavy metal ions. Longan fruit shell displayed highly selective sorption to Pb(II) over light metal ions with an adsorbability order of Pb(II) > Hg(II) >> Zn(II) > Cu(II) > Ca(II) > Mg(II) >> Fe(III,II), indicating that the shell could efficiently purify drinking water and nutritious liquids by just eliminating the harmful metal ions and still retaining the nutritious metal ions.

Comments

Leenhouts divided the species *Dimocarpus longan* Lour. into two subspecies, ssp. *longan* and ssp. *malesianus* each with several varieties. The former was revised into 3 varieties, var. *longan*, the commercially cultivated taxon, var. *longepetiolatus* found in Vietnam, and var. *obtus* found in Thailand. All three varieties are also found wild in southern China. The later subspecies *malesianus* encompasses the more tropical assemblage and was further subdivided into var. *echinatus* and var. *malesianus* which is covered in greater detail in a separate chapter.

Three edible longan types are distinguished in Thailand, which presumably all belong to ssp. *longan* (Subhadrabandhu 1990). The first one is a large forest tree with small fruits and a very thin aril, possibly of interest for breeding purposes.

The second one is the common longan ('lamyai kraduk'), growing in the northern part of the country as an erect tree, producing small fruits with large seeds and is recommended as a root-stock for commercial cultivars. The third type is formed by the commercial cultivars ('lamyai kraloke') which produce large fruits and small seeds.

Selected References

- Adema F, Leenhouts PW, van Welzen PC (1994) Sapindaceae. Flora Malesiana, Ser 1, vol 11, Part 3 Noordhoff-Kolff Jakarta, pp 419–768
- Anonymous (1986) *Dimocarpus longan* (longan). In: Genetic resources of tropical and subtropical fruits and nuts (excluding Musa). International Board for Plant Genetic Resources, Rome, pp 120–122
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula. Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, Malaysia, vol 1 (A–H), pp 1–1240, Vol 2 (I–Z), pp 1241–2444
- Chen J, Chen X, Qin J (2011) Effects of polysaccharides of the *Euphoria Longan* (Lour.) Steud on focal cerebral ischemia/reperfusion injury and its underlying mechanism. *Brain Inj* 25(3):292–299
- Cheng JT, Lin TC, Hsu FL (1995) Antihypertensive effect of corilagin in the rat. *Can J Physiol Pharmacol* 73(10):1425–1429
- Chung YC, Lin CC, Chou CC, Hsu CP (2010) The effect of longan seed polyphenols on colorectal carcinoma cells. *Eur J Clin Invest* 40(8):713–721
- Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand, 44 pp
- He N, Wang Z, Yang C, Lu Y, Sun D, Wang Y, Shao W, Li Q (2009) Isolation and identification of polyphenolic compounds in longan pericarp. *Separ Purif Technol* 70(2):219–224
- Ho SC, Hwang LS, Shen YJ, Lin CC (2007) Suppressive effect of a proanthocyanidin-rich extract from longan (*Dimocarpus longan* Lour.) flowers on nitric oxide production in LPS-stimulated macrophage cells. *J Agric Food Chem* 55(26):10664–10670
- Hsieh MC, Shen YJ, Kuo YH, Hwang LS (2008) Antioxidative activity and active components of longan (*Dimocarpus longan* Lour.) flower extracts. *J Agric Food Chem* 56(16):7010–7016
- Hsu FL, Lu FH, Cheng JT (1994) Influence of aceto-nylgeraniin, a hydrolyzable tannin from *Euphoria longana*, on orthostatic hypotension in a rat model. *Planta Med* 60(4):297–300
- Hsu CP, Lin YH, Zhou SP, Chung YC, Lin CC, Wang SC (2010) Longan flower extract inhibits the growth of colorectal carcinoma. *Nutr Cancer* 62(2):229–236

- Hu SY (2005) Food plants of China. The Chinese University Press, Hong Kong, 844 pp
- Huang CJ, Wu MC (2002) Differential effects of foods traditionally regarded as 'heating' and 'cooling' on prostaglandin E(2) production by a macrophage cell line. *J Biomed Sci* 9(6 Pt 2):596–606
- Huang SY, Tang YL, Li HN, Li R (2006) The extraction and identification of total flavanone from longan pericarp. *Zhong Yao Cai* 29(8):767–769 (In Chinese)
- Huang MR, Li S, Li XG (2010) Longan shell as novel biomacromolecular sorbent for highly selective removal of lead and mercury ions. *J Phys Chem B* 114(10):3534–3542
- Jaitrong S, Rattanapanone N, Manthey JA (2006) Analysis of the phenolic compounds in longan (*Dimocarpus longan* Lour.) peel. *Proc Fla State Hort Soc* 119:371–375
- Jiang G, Jiang Y, Yang B, Yu C, Tsao R, Zhang H, Chen F (2009) Structural characteristics and antioxidant activities of oligosaccharides from longan fruit pericarp. *J Agric Food Chem* 57(19):9293–9298
- Kleiman R, Earle FR, Wolff IA (1969) Dihydrosterculic acid, a major fatty acid component of *Euphoria longana* seed oil. *Lipids* 4(5):317–320
- Leenhouts PW (1971) A revision of *Dimocarpus* (Sapindaceae). *Blumea* 19:113–131
- Leenhouts PW (1973) A new species of *Dimocarpus* (Sapindaceae) from Australia. *Blumea* 21:377–380
- Menzel CM, McConchie CA (1998) Lychee and longan. In: Hyde KW (ed) The new rural industries. Rural Industries Research and Development Corporation, Canberra, pp 288–295
- Menzel CM, Watson BJ, Simpson DR (1989) Longans – a place in Queensland's horticulture? *Queensl Agric J* 113(5):251–65
- Minakata H, Komura H, Tamura SY, Ohfuné Y, Nakanishi K, Kada T (1985) Antimutagenic unusual amino acids from plants. *Experientia* 41(12):1622–1623
- Morton J (1987) Longan. In: Fruits of warm climates. Julia F. Morton, Miami, FL, pp 259–262
- Nititham S, Komindr S, Nichachotsalid A (2004) Phytate and fiber content in Thai fruits commonly consumed by diabetic patients. *J Med Assoc Thai* 87(12):1444–1446
- Nong XX, Li M (1989) Pharmacologic effects of an extract of arillus longan (Lour.) Steud. and gecko. *Zhongguo Zhong Yao Za Zhi* 14(6):365–367, 383 (In Chinese)
- Okuyama E, Ebihara H, Takeuchi H, Yamazaki M (1999) Adenosine, the anxiolytic-like principle of the Arillus of *Euphoria longana*. *Planta Med* 65(2):115–119
- Pan Y, Wang K, Huang S, Wang H, Mu X, He C, Ji X, Zhang J, Huang F (2008) Antioxidant activity of microwave-assisted extract of longan (*Dimocarpus longan* Lour.) peel. *Food Chem* 106(3):1264–1270
- Park SJ, Park DH, Kim DH, Lee S, Yoon BH, Jung WY, Lee KT, Cheong JH, Ryu JH (2010) The memory-enhancing effects of *Euphoria longan* fruit extract in mice. *J Ethnopharmacol* 128(1):160–165
- Prasad KN, Hao J, Shi J, Liu T, Li J, Wei X, Qui S, Xue S, Jiang Y (2009) Antioxidant and anticancer activities of high pressure-assisted extract of longan (*Dimocarpus longan* Lour.) fruit pericarp. *Innov Food Sci Emerg Technol* 10(4):413–419
- Prasad KN, Yang B, Shi J, Yu C, Zhao M, Xue S, Jiang Y (2010) Enhanced antioxidant and antityrosinase activities of longan fruit pericarp by ultra-high-pressure-assisted extraction. *J Pharm Biomed Anal* 51(2):471–477
- Rangkadilok N, Worasuttayangkurn L, Bennett RN, Satayavivad J (2005) Identification and quantification of polyphenolic compounds in Longan (*Euphoria longana* Lam.) fruit. *J Agric Food Chem* 53(5):1387–1392
- Rangkadilok N, Sithimonchai S, Worasuttayangkurn L, Mahidol C, Ruchirawat M, Satayavivad J (2007) Evaluation of free radical scavenging and antityrosinase activities of standardized longan fruit extract. *Food Chem Toxicol* 45(2):328–336
- Rangkadilok N, Tongchusak S, Boonhok R, Chaiyaroj SC, Junyaprasert VB, Buajeeb W, Akanimanee J, Raksasuk T, Suddhasthira T, Satayavivad J (2012) In vitro antifungal activities of longan (*Dimocarpus longan* Lour.) seed extract. *Fitoterapia* 83(3):545–553
- Ripa FA, Haque M, Bulbul IJ (2010) In vitro antibacterial, cytotoxic and antioxidant activities of plant *Nephelium longan*. *Pakistan J Biol Sci* 13(1):22–27
- Ryu J, Kim JS, Kang SS (2003) Cerebrosides from longan arillus. *Arch Pharm Res* 26(2):138–142
- Soong YY, Barlow PJ (2005) Isolation and structure elucidation of phenolic compounds from longan (*Dimocarpus longan* Lour.) seed by high-performance liquid chromatography-electrospray ionization mass spectrometry. *J Chromatogr A* 1085(2):270–277
- Subhadrabandhu S (1990) Lychee and longan cultivation in Thailand. Rumthai Publication, Bangkok, Thailand, 40 pp
- Sudjaroen Y, Hull WE, Erben G, Würtele G, Changbumrung S, Ulrich CM, Owen RW (2012) Isolation and characterization of ellagitannins as the major polyphenolic components of longan (*Dimocarpus longan* Lour.) seeds. *Phytochemistry* 77:226–237
- Sun J, Shi J, Jiang Y, Xue SJ, Wei X (2007) Identification of two polyphenolic compounds with antioxidant activities in longan pericarp tissues. *J Agric Food Chem* 55(14):5864–5868
- Sung ML, Fowden L, Millington DS, Sheppard RC (1969) Acetylenic amino acids from *Euphoria longan*. *Phytochemistry* 8(7):1227–1233
- Tsai HY, Wu LY, Hwang LS (2008) Effect of a proanthocyanidin-rich extract from longan flower on markers of metabolic syndrome in fructose-fed rats. *J Agric Food Chem* 56(22):11018–11024
- U.S. Department of Agriculture, Agricultural Research Service (2012) USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory Home Page, <http://www.ars.usda.gov/ba/bhnrc/ndl>
- Van Welzen PC, Lamb A, Wong WWW (1988) Edible Sapindaceae in Sabah. *Nat Malaysiana* 13:10–25
- Wall M (2006) Ascorbic acid and mineral composition of longan (*Dimocarpus longan*), lychee (*Litchi chinensis*) and rambutan (*Nephelium lappaceum*)

- cultivars grown in Hawaii. *J Food Comp Anal* 19(6–7):655–663
- Wong KC (2000) Longan Production in Asia. RAP Publication: 2000/20
- Wong KC, Gan YY (1992) The diversity of *Dimocarpus longan* ssp. *malesianus* var. *malesianus* in Sarawak. *Acta Hort* 292:29–39
- Wong KC, Ketsa S (1992) *Dimocarpus longan* Lour. In: Verheij EWM, Coronel RE (eds) Plant resources of Southeast Asia No. 2. Edible fruits and nuts. Prosea Foundation, Bogor, Indonesia, pp 146–151
- Wong KC, Saichol K (1991) *Dimocarpus longan* Lour. In: Coronel RE, Verheij EWM (eds) Edible fruits and nuts. Plant Resources of Southeast Asia, Pudoc, Wageningen, pp 146–151
- Wong KC, Wong SN, Loi HK, Lim CL (1996) Volatile constituents from the fruits of four edible Sapindaceae: Rambutan (*Nephelium lappaceum* L.), Pulasan (*N. ramboutan-ake* (Labill.) Leenh.), Longan (*Dimocarpus longan* Lour.), and Mata Kucing (*D. longan* ssp. *malesianus* Leenh.). *Flav Fragr J* 11(4):223–229
- Xia N, Gadek PA (2007) Sapindaceae. In: Wu ZY, Raven PH, Hong DY (eds) Flora of China, vol 12 (Hippocastanaceae through Theaceae). Science Press/Missouri Botanical Garden Press, Beijing/St. Louis
- Yang B, Zhao M, Jiang Y (2008) Optimization of tyrosinase inhibition activity of ultrasonic-extracted polysaccharides from longan fruit pericarp. *Food Chem* 110(2):294–300
- Yang B, Zhao M, Jiang Y (2009) Anti-glycated activity of polysaccharides of longan (*Dimocarpus longan* Lour.) fruit pericarp. *Food Chem* 114(2):629–633
- Yang DJ, Chang YY, Hsu CL, Liu CW, Lin YL, Lin YH, Liu KC, Chen YC (2010) Antiobesity and hypolipidemic effects of polyphenol-rich longan (*Dimocarpus longan* Lour.) flower water extract in hypercaloric-dietary rats. *J Agric Food Chem* 58(3):2020–2027
- Yang B, Jiang Y, Shi J, Chen F, Ashraf M (2011) Extraction and pharmacological properties of bioactive compounds from longan (*Dimocarpus longan* Lour.) fruit—a review. *Food Res Int* 44(7):1837–1842
- Yi Y, Liao ST, Zhang MW, Shi J, Zhang RF, Deng YY, Wei ZC (2011a) Physicochemical characteristics and immunomodulatory activities of three polysaccharide-protein complexes of longan pulp. *Molecules* 16(7):6148–6164
- Yi Y, Liao ST, Zhang MW, Zhang RF, Deng YY, Yang B, Wei ZC (2011b) Immunomodulatory activity of polysaccharide-protein complex of longan (*Dimocarpus longan* Lour.) pulp. *Molecules* 16(12):10324–10336
- Youn YN, Lim E, Lee N, Kim YS, Koo MS, Choi SY (2008) Screening of Korean medicinal plants for possible osteoclastogenesis effects in vitro. *Genes Nutr* 2(4):375–380
- Zheng SQ, Jiang F, Gao HY, Zheng JG (2010) Preliminary observations on the antifatigue effects of longan (*Dimocarpus longan* Lour.) seed polysaccharides. *Phytother Res* 24(4):622–624
- Zhong K, Wang Q, He Y, He X (2010) Evaluation of radicals scavenging, immunity-modulatory and antitumor activities of longan polysaccharides with ultrasonic extraction on in S180 tumor mice models. *Int J Biol Macromol* 47(3):356–360

Dimocarpus longan subsp. *malesianus* var. *echinatus*

Scientific Name

Dimocarpus longan subsp. *malesianus* var. *echinatus* Leenh.

Synonyms

Euphoria microcarpa Radlk., *Euphoria nephelioides* Radlk., *Nephelium schneideri* Merr.

Family

Sapindaceae

Common/English Names

Spiny Longan, Spiny Mata Kuching.

Vernacular Names

Philippines: Alupag-Amo.

Origin/Distribution

The fruit is native to Malesia: Borneo, south Philippines (Mindanao and Basilan).

Agroecology

Spiny longan occurs in primary and secondary tropical forest on blackish or sandy soil at 20–250 m altitude.

Edible Plant Parts and Uses

The sweet to acid-sweet arillode is edible fresh. The fruit is very attractive looking and the sweet varieties may have potential for commercial exploitation as fresh and canned fruit like the rambutan.

Botany

Tree reaching heights of 9–30 m high, with bole of 30–80 cm, buttresses up to 1–2 m high and subterete, pale-greyish branches. Leaf on a long petiole, 3–5 jugate, 25–35 cm long (Plates 1–2). Young leaf flushes reddish-brown, Leaflets on 3–15 mm long petiolule, oblong to elliptic-obovate, 15–20 cm long by 5–8 cm wide, acuminate apex and cuneate base and entire margin, dark-green and glabrous above, paler green below with impressed mid-rib and 1–12 pairs of lateral veins. Panicle terminal, densely pubescent, flowers as in var. *malesianus* with minute ovate petals. Fruit globose densely covered with



Plate 1 Cluster of spiny longan fruit and leaves



Plate 3 Spiny longan fruit with thin translucent arillode and one black seed

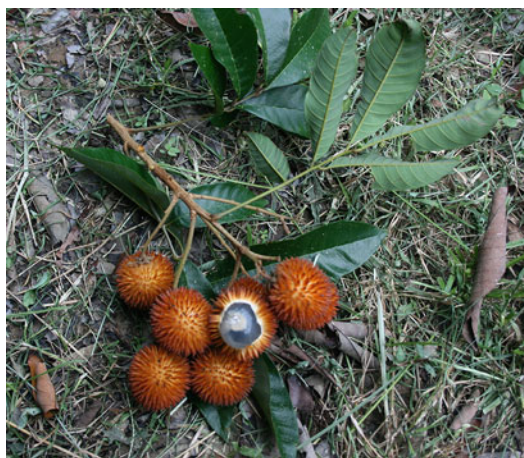


Plate 2 Spiny longan fruit with 3-jugate leaf

orangey-brown conical, flexuous, blunt, tapering soft spinterns, the white basal epicarp encloses the 2–4 mm thick, transparent, juicy sweet to acid sweet arillode which in turn encloses a globose large glossy, dark brown seed (Plates 1–3). The fruits occur in terminal bunches.

Nutritive/Medicinal Properties

No information on the nutritive value of the edible fruit or medicinal properties of the plant and uses have been published.

Other Uses

It may have similar uses as *Dimocarpus longan* ssp. *malesianus* var. *malesianus* in that the seeds can be used for shampoo and its timber for light construction, fuel and charcoal.

Comments

Dimocarpus longan ssp. *malesianus* var. *echinatus*, called ‘alupag-amò’ and *Dimocarpus longan* ssp. *malesianus* var. *malesianus* called ‘alupag lalaki’ have been listed as endangered species in the Philippines (Fernando et al. 2008).

Selected References

- Adema F, Leenhouts P W, van Welzen PC (1994) Sapindaceae. Flora Malesiana, Ser 1, vol 11, Part 3, Noordhoff-Kolff Djakarta, pp 419–768
- Fernando ES, Co LL, Lagunzad DA, Gruèzo WS, Barcelona JF, Madulid DA, Lapis AB, Texon GI, Manila AC, Zamora PM (2008) Threatened plants of the Philippines – a preliminary assessment. Philippine Plant Conservation Committee, Department of Environment and Natural Resources, Republic of the Philippines. http://www.pawb.gov.ph/index.php?option=com_docman&task=doc_download&gid=218&Itemid=235
- Leenhouts PW (1971) A revision of *Dimocarpus* (Sapindaceae). Blumea 19:113–131

-
- Van Welzen PC, Lamb A, Wong WWW (1988) Edible Sapindaceae in Sabah. *Nat Malaysiana* 13(1):10–25
- Wong KC, Gan YY (1992) The diversity of *Dimocarpus longan* ssp. *malesianus* var. *malesianus* in Sarawak. *Acta Horti* 292:29–39
- Wong KC, Saichol K (1991) *Dimocarpus longan* Lour. In: Coronel RE, Verheij EWM (eds) *Edible fruits and nuts. Plant Resources of Southeast Asia*, Pudoc, Wageningen, pp 146–151

Dimocarpus longan subsp. *malesianus* var. *malesianus*

Scientific Name

Dimocarpus longan Lour. subsp. *malesianus* Leenh. var. *malesianus* Leenh.

Common/English Names

Cat's Eye, Guring, Isau, Kakus, Mata Kucing, Sau.

Synonyms

Euphoria cambodiana Lecomte, *Euphoria fragifera* Gagnep, *Euphoria didyma* Auct. non Balnco, *Euphoria elongata* Radlk., *Euphoria gracilis* Radlk., *Euphoria malaiensis* f. *declavata* Radlk., *Euphoria microcarpa* Radlk., *Euphoria pallens*, *Euphoria sclerocarpa* Radlk., *Euphoria setosa* Radlk., *Euphoria* sp. Ceron, *Euphoria succulenta* Radlk., *Dimocarpus litchi* Lour., *Nephelium longana* Auct. non Cambess., *Nephelium malaiense* Griff., *Pometia curtisii* King, *Sapindus cinereus* Turcz. var. *malesianus* (basionym), *Xerospermum ferrugineum* C.E.C. Fischer.

Vernacular Names

East Malaysia: Sau, Isau, Kakus, Guring (Iban, Sarawak), Bauh Arut, Buah Binkoi (Murut, Sabah);

Peninsular Malaysia: Mata Kucing (Malay);

Indonesia: Buku, Ihau (Kalimantan), Isau Bala, Isau Beleng (Kenyah Badeng, Kalimantan Timor), Jilen, Sau (Penan Benalui, Kalimantan Timor); Nyau Belah, Nyau Bong, Nyau Lucih (Punan Tubu, Kalimantan Timor), Medaru (Sumatra).

Family

Sapindaceae

Origin/Distribution

The subspecies *Dimocarpus longan* Lour. ssp. *malesianus* is native to Southeast Asia. It is subdivided into a few varieties: var. *malesianus* and var. *echinatus*. The greatest diversity of the

former is found in Borneo where it might be possible to distinguish between 30 and 40 local races while the latter is found in Sabah and the Philippines (Leenhouts 1971; van Welzen et al. 1988). The diversity of this subspecies in Sarawak in the Borneo island has been documented by Wong and Gan (1992) and Wong (2000).

Agroecology

This subspecies *malesianus* is truly a tropical species that is fully adapted to the unchanging heat, high humidity, high rainfall, daylength and other conditions of the equatorial zone in its native range. In its native range, rainfall hovers from 2,500 mm to more than 4,000 mm per year associated with a mean air temperature of 25–32°C and a relative humidity of 80–95%. Trees occur mainly in the substage or understorey in primary mixed Dipterocarp forests or sometimes secondary forests at low altitudes near sea level and as high as 1,000 m above sea level. Trees are also common in abandoned villages. Trees grow on a wide range of soil types from pH 4.5 to 8.0, alluvial soils in riverine habitats, loams, limestone soils and fertile clay soils. Many productive and good eating races are being cultivated on small scales in villages and small orchards.

Edible Plant Parts and Uses

The pulp (arillode) of the fruits of this subspecies is eaten fresh, frozen or made into drinks and dessert like the true longan. The sweet, juicy fruits of the many races are relished by the locals and during the fruiting season they are sold in local markets. They are sweet and juicy with a delicious musky or melon like flavour.

Botany

Evergreen tree to 20 m tall with mostly smooth, glabrescent twigs of 3.5–9.2 mm diameters. Leaves compound, 2–4–6 jugate, petiole 5–16.2 mm, petiolule usually grooved above.

Leaflets, 9.9–22 cm long by 2.7–10 cm wide, medium green with hair-covered glands in nerve axils on lower surface, mostly symmetrical base, acuminate apex, entire margin, mid-rib sunken; veins, 10–25, mostly transverse. Young leaf flushes are deep red in colour. Flowers in subsessile cymes. Flowers monoecious, two types: male flowers with rudimentary pistil and hermaphrodite with poorly developed stamens, small, 3.5–6.5 by 4.5–5.5 mm. Calyx 5-lobed, imbricate, yellowish green to brown; petals 5, free, spatulate, densely woolly, longer than sepals; stamens 8 with basifixed anther on filament that is sparsely woolly at the base; ovary bilobed, puberulous to velutinous with extended style, 3–5.5 mm long. Fruit drupaceous, subglobose to broad-ellipsoid, 2–3 cm across, smooth to warty, colliculate, ripened green, yellowish-green, yellowish brown to brown. Seed round to ellipsoid, dark brown to black, enveloped by opalescent, fleshy, moderately thick to thin, sweet, edible, whitish arillode.

Four races of *Dimocarpus longan* ssp. *malesianus* var. *malesianus* have been distinguished in Sarawak (Wong 2001; Wong and Ketsa 1992; Wong and Gan 1992) based on vegetative, floral and fruit characteristics:

Mata Kuching (Plates 1–2): produces fruit of similar size to longan, with glabrous, smooth yellowish brown to brown, thick skin, large round seed and usually thin arillode, poor aril recovery. Mata Kuching is commonly found in Peninsular Malaysia, Celebes, Sumatra and the Philippines.

Isau (Plates 4–7): with heavily warty, colliculate, globular fruits, smaller than sau or kakus which remain green when ripe and with lower vegetative characteristic (lower leaflet number, small leaflets, shorter petiole, smaller twig diameter, less nerve number), smaller flower size, yellowish-green calyx, smaller, seed with pointed end, but the fruits are sweeter with high brix value (22.5%), higher vitamin C, Calcium, Fe, thicker, less watery and firmer arillode. Isua has higher aril recovery percentage attributable to its greater brix, nutritive content, smaller seed size and thinner pericarp.

Sau (Plates 8–9): with warty, broad ellipsoid fruit, which remains green or yellowish-green when



Plate 1 Thick lush foliage of Mata Kucing with 2-3 juagte compound leaves



Plate 4 Leaflets and small cluster of developing Isau fruits



Plate 2 Harvested detached ripe Mata Kucing fruits



Plate 5 Close-up of Isau fruits



Plate 3 Clusters of ripe Mata Kucing fruits



Plate 6 Detached Isau fruits



Plate 7 Ripe Isau fruit with thin peel and translucent arillode



Plate 8 Young and mature leaflets of Sau

ripe, with larger flower, ellipsoid seed and higher vegetative characteristic than Isau, but comparatively less sweet (17% brix) than Isau or Kakus;

Kakus (Plates 10–11): warty, globular fruit which turn brown when ripe, with larger flower, brownish calyx, round seed and higher vegetative characteristic than Isau, but comparatively less sweet (19% brix) than Isau but sweeter than Sau.

Nutritive/Medicinal Properties

Proximate nutrient composition had been reported for the three races: Isau, Sau and Kakus (Wong 2001): Isau: moisture 78.8%, protein (%Nx6.25) 1.2%, crude fibre 0.7%, ash 0.6%, brix 22.5%, vitamin C 2.9 mg/100 g, Ca 52.1 ppm, Fe



Plate 9 Clusters of ripe Sau fruits



Plate 10 Leaflets and developing Kakus fruits

2.5 ppm; sau: moisture 82.8%, protein (%Nx6.25) 1.1%, crude fibre 1.4%, ash 0.6%, brix 17%, vitamin C 1.9 mg/100 g, Ca 41 ppm, Fe 1.6 ppm; Kakus: moisture 82.9%, protein (%Nx6.25) 1.1%, crude fibre 1.1%, ash 0.6%, brix 19%, vitamin C 0.9 mg/100 g, Ca 28.5 ppm, Fe 1.3 ppm;

The Isau type has more superior fruit quality than the sau or kakus type in terms of its sweetness (highest brix value), comparatively higher



Plate 11 Sparse cluster of ripening Kakus fruits

vitamin C, calcium and iron content and much thicker and less watery aril (Wong 2001). Forty-four volatile compounds were identified in mat kucing fruit (Wong et al. 1996). Mata kucing differs from longan in producing much lower levels of esters (0.5%) and terpenoids (4.7%) but significantly larger proportions of aliphatic alcohols (53.2%) and carbonyl compounds (34.7%).

Dimocarpus longan malesianus (ripe fruit peels and leaves) extracts at a dose of 100 µg/mL exhibited xanthine oxidase inhibitory activity (Azmi et al. 2012). The distilled water extract of the ripe fruit peel and leaves exhibited 3.59 and 15.77% xanthine oxidase inhibition respectively; the methanol extracts exhibited higher inhibitory activity of 10.85 and 39.42% respectively; whilst the ethanol extracts exhibited 13.41 and 46.88% inhibition receptively. Xanthine oxidase (XO) is an enzyme responsible for catalysing the oxidation of hypoxanthine to xanthine and of xanthine to formation of uric acid (Owen and Johns 1999; Ramallo et al. 2006). The treatment of gout involves the use of therapeutic agents such as xanthine oxidase inhibitors (XOI) which acts by blocking the biosynthesis of uric acid from purine in the body (Unno et al. 2004).

Other Uses

The timber is fairly hard, moderately heavy, light brown or yellowish colour and does not split on drying.

Comments

In Kalimantan Timor, “isau bala” (red mata kucing) has globular fruits that turn light brown with reddish dipples when ripe and “isau belong” (green mata kucing); globular to slightly oblong fruits that stay green when ripe (Puri 1998). The former appear to be similar to Kakus and the latter to Sua or Isau. *Dimocarpus longan* ssp. *malesianus* var. *echinatus* differs from var. *malesianus* in that the small round fruits have rather spines resembling the rambutan (*Nephelium lappaceum* L.). This variety is found in Sabah where the ‘kakus’ also exists.

Choo (1992) found patch budding on seedling stock to be a suitable method of propagating *D. longan* ssp. *malesianus* varieties. Isau can also be propagated by micropropagation of explants taken from buds of epicormic shoots emerging from 40 cm section branches (3–7 cm in diameter) planted in moist sand (Kho et al. 2010).

Selected References

- Azmi SMN, Jamal P, Amid A (2012) Xanthine oxidase inhibitory activity from potential Malaysian medicinal plant as remedies for gout. *Int Food Res J* 19(1):159–165
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula. Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, Malaysia, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Choo W (1992) Studies on the propagation, seed storage and fruit storage of *Dimocarpus longan* subspecies *malesianus* variety *malesianus*. *Acta Horti (ISHS)* 292:69–72
- Kho SL, Lau CY, Sim SL (2010) Induction of epicormic shoots from branches of isau (*Dimocarpus longan* Lour. subspecies *malesianus* Leenh. var. *malesianus*) for use in micropropagation. *Asia Pac J Mol Biol Biotechnol* 18(1):123–125
- Leenhouts PW (1971) A revision of *Dimocarpus* (Sapindaceae). *Blumea* 19:113–131
- Leenhouts PW (1973) A new species of *Dimocarpus* (Sapindaceae) from Australia. *Blumea* 21:377–380
- Molesworth Allen B (1967) Malayan fruits. An introduction to the cultivated species. Moore, Singapore, 245 pp
- Owen PL, Johns T (1999) Xanthine oxidase inhibitory activity of northeastern North American plant remedies used for gout. *J Ethnopharmacol* 64:149–160

- Puri RK (1998) Local knowledge and manipulation of the fruit 'mata kucing' (*Dimocarpus longan*) in East Kalimantan. Paper presented at international seminar on cultivating forests: alternative forest management practices and techniques for community forestry, Rama Gardens Hotel, Bangkok, Thailand, 23–25 Sept 1998
- Ramallo IA, Zacchino SA, Furlan RLE (2006) A rapid TLC autographic method for the detection of xanthine oxidase inhibitors and superoxide scavengers. *Phytochem Anal* 17(1):15–19
- Unno T, Sugimoto A, Kakuda T (2004) Xanthine oxidase inhibitors from the leaves of *Lagerstroemia speciosa* (L.). *Pers. J Ethnopharmacol* 93:391–395
- Van Welzen PC, Lamb A, Wong WWW (1988) Edible Sapindaceae in Sabah. *Nat Malaysiana* 13:10–25
- Voon BH, Chin TH, Sim CY, Sabariah P (1988) Wild Fruits and Vegetables in Sarawak. Sarawak Department of Agriculture, 114 pp
- Wong KC (2000) Longan production in Asia. RAP Publication: 2000/20, Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand, 44 pp
- Wong KC (2001) Variations of local longan in Malaysia. *Acta Horti* (ISHS) 558:103–106
- Wong KC, Gan YY (1992) The diversity of *Dimocarpus longan* ssp. *malesianus* var. *malesianus* in Sarawak. *Acta Horti* 292:29–39
- Wong KC, Ketsa S (1992) *Dimocarpus longan* Lour. In: Verheij EWM, Coronel RE (eds) Plant resources of Southeast Asia No. 2. Edible fruits and nuts. Prosea Foundation, Bogor, Indonesia, pp 146–151
- Wong KC, Wong SN, Loi HK, Lim CL (1996) Volatile constituents from the fruits of four edible Sapindaceae: rambutan (*Nephelium lappaceum* L.), pulasan (*N. ramboutan-ake* (Labill.) Leenh.), longan (*Dimocarpus longan* Lour.), and mata kucing (*D. longan* ssp. *malesianus* Leenh.). *Flav Fragr J* 11(4):223–229

Lepisanthes alata

Scientific Name

Lepisanthes alata (Blume) Leenh.

Synonyms

Capura alata (Blume) Teijsm. & Binn., *Otolepis alata* (Blume) Kuntze, *Otophora alata* Blume, *Otophora edulis* C.E.C. Fischer.

Family

Sapindaceae

Common/English Names

Chinese Averrhoe, Johore Fruit, Malaysian Lepisanthes, Trengganu Cherry.

Vernacular Names

Indonesia: Blimbing Cina (Javanese), Kurumei (Kalimantan), Cereme Landa, Kiangir (Sundanese);

Malaysia: Engkili (Sarawak), Ceri Trengganu, Buah Johor, Perupok, Rambai Istana (Peninsular Malaysia);

Thailand: Ya Ho (Southern).

Origin/Distribution

The species is indigenous to southeast Asia – Peninsular Malaysia, Sarawak, and Sabah in Malaysia; Kalimantan and Java in Indonesia and the Philippines (Plate 5). It is commonly cultivated in villages and house gardens in the east coast of Peninsular Malaysia in the states of Terengganu, Pahang and Johore.

Agroecology

Lepisanthes alata is strictly a tropical species that occurs wild along rivers, streams in the humid, lowland tropical forests up to 500 m elevation.

Edible Plant Parts and Uses

The aril of the fruit can be eaten fresh, as it is fairly sweet when ripe. Young leaves are cooked and eaten as vegetables in South Thailand.

Botany

A small tree, usually 4–5 (–14) m tall with glabrous, brownish-grey twigs. Leaves are pinkish-purplish when young turning to green with age. Leaves are usually imparipinnate, 8–12



Plate 1 Juvenile and mature leaflets



Plate 2 Inflorescence with widely spaced reddish flowers

jugate, terminal leaflets much reduced, rachis glabrous and distinctly winged on both sides. Pseudo-stipules oblique-ovate. Leaflets opposite to sub-opposite, sessile to sub-sessile, narrowly elliptic to lanceolate, 8.5 cm long by 2 cm wide, apex tapering long acuminate, base obtuse to oblique, upper surface glaucous, mid rib prominent below, 10–13 pairs of nerves, margin entire (Plate 1). Inflorescences are axillary sometimes cauliflorous, simple with short branches (Plate 2). Flowers scentless, mostly unisexual, male and female on same plant, 8 mm across with 5 imbricate, glabrous, oval to obovate sepals; 5 wine-red, obovate, glabrous petals with entire, hood-shaped scales; 7–8 stamens with short hairy filaments, yellow anthers; glabrous ellipsoid, 3–4-celled ovary, with a very short style and a white, stout, dome-shaped, stigma. Fruit shortly stipitate, trigonous-obovoid, trigonous-subglobose to squarish-subglobose 2.5–4 cm by



Plate 3 Dense clusters of unripe fruits

2.2–3 cm (Plates 3–4), apiculate, dark reddish purple to nearly black when ripe. Seeds 3, ellipsoid with soft, white, translucent, thick and fleshy, fairly sweet aril.

Nutritive/Medicinal Properties

Nutrient value reported for the ripe fruit was reported as: moisture 77.7%, dietary fibre 9.5%, ash 0.8%, total sugar 9.8% and vitamin C 16 mg/100 g (Upho 2005).

No published information on its medicinal value and uses have been reported.

Other Uses

It may be used as an ornamental plant in landscaping due to its attractive form.



Plate 4 Single cluster of squarish-subglobose fruits



Plate 5 Tree label

Comments

Ceri Trengganu is featured in a stamp on a series of stamps on rare fruits in Malaysia.

Selected References

- Adema F, Leenhouts P W, van Welzen PC (1994) Sapindaceae. Flora Malesiana, ser 1, vol 11, Part 3. Noordhoff-Kolff, Djakarta, pp 419–768
- Backer CA, Bakhuizen van den Brink Jr RC (1965) Flora of Java (Spermatophytes Only), vol 2. Wolters-Noordhoff, Groningen, 641 pp
- Chai PPK (2006) Medicinal plants of Sarawak. Lee Ming Press, Kuching, Sarawak, 212 pp
- Jansen PCM, Jukema J, Oyen LPA, van Lingem TG (1991) *Lepisanthes alata* (Blume) Leenh. In: Verheij EWM, Coronel RE (eds) Plant resources of South-East Asia, No. 2. Edible fruits and nuts. Prosea Foundation, Bogor, p 343
- Leenhouts PW (1969) A revision of *Lepisanthes* (Sapindaceae). Blumea 17:33–91
- Ochse JJ (1927) Indische Vruchten. Volkslectuur, Weltevreden, 330 pp
- Porcher MH et al (1995–2020) Searchable World Wide Web Multilingual Multiscript Plant Name Database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Upho U (2005) Ethnobotany of Buddhist and Muslim Thais in some locations in the lower part of Southern Thailand. PhD thesis. Chiang Mai University, Thailand, 542 pp
- Xia N, Gadek PA (2007) *Lepisanthes*. In: Wu ZY, Raven PH, Hong DY (eds) Flora of China, vol 12 (Hippocastanaceae through Theaceae). Science Press/Missouri Botanical Garden Press, Beijing/St Louis
- Yap SK (1989) Sapindaceae. In: Ng FSP (ed) Tree flora of Malaya, vol 4. Longman, Malaysia, pp 434–461

Lepisanthes fruticosa

Scientific Name

Lepisanthes fruticosa (Roxb.) Leenh.

Synonyms

Capura fruticosa (Roxb.) Vidal, *Koelreuteria edulis* Blanco, *Otolepis cambodiana* Pierre, *Otolepis erythrocalyx* (Hiern) Kuntze, *Otolepis furcata* Pierre, *Otolepis fruticosa* (Roxb.) Kuntze, *Otolepis nodosa* Pierre, *Otolepis sessilis* King, *Otophora acuminata* Radlk., *Otophora blancoi* Blume, *Otophora cambodiana* Pierre ex Lecomte, *Otophora eberhardtii* Ganep, *Otophora erythrocalyx* Hiern, *Otophora fruticosa* (Roxb.) Blume, *Otophora furcata* Pierre ex Lecomte, *Otophora glandulosa* Radlk., *Otophora glandulosa* Radlk. ex Ridley, *Otophora latifolia* Ridl., *Otophora nodosa* Pierre ex Lecomte, *Otophora resecta* Radlk., *Sapindus baccata* Blanco, *Sapindus fruticosa* Roxb.

Family

Sapindaceae

Common/English Names

Luna Nut.

Vernacular Names

Borneo: Kilinga;

Indonesia: Blimbing Cina, Cereme Cina, Mojowontu,

Khmer: Kandak, Kândâk;

Laos: Kwad Khaaz;

Malaysia: Setengok (Peninsular), Talikasan (Timugon, Sabah), Palingsan Bukit, Petagar Tulang (Kedayan, Sarawak);

Philippines: Buli-Buli (Bisaya), Ara (Ibanag), Balinaunau, Linaunau (Tagalog);

Thailand: Chammaliang, Chammaliang Baan, Khomriang, Phumriang, Phum Rieng Suan, Phuuwiang (Central), Mathao (North);

Vietnam: Bắp muôi.

Origin/Distribution

The plant is indigenous to southeast Asia: Myanmar, Indo-China, Thailand, Malaysia, Philippines, Indonesia – Kalimantan, Sumatra, Java to the Moluccas.

Agroecology

The species is found as understorey in undisturbed to slightly disturbed (open sites) mixed dipterocarp, keranga and sub-montane tropical forests up to 1,400 m altitude. It usually occurs along

rivers and streams, swamp edges, moist thickets and on ridges. It grows on rich as well as poor, clayey, sandy, acid as well as basic soils. In secondary forests, it is usually present as a pre-disturbance remnant.

Edible Plant Parts and Uses

The fruit can be eaten fresh, as it is sweet when ripe. The seeds are eaten roasted. Young leaves eaten cooked as vegetables in southern Thailand.

Botany

An erect shrub or small tree, usually 1.5–10 m high but may reach 14 m high with a diameter at breast height (dbh) of 2–15 cm. Twigs are reddish when young (Plate 2) becoming brown to silvery grey, smooth or lenticellate and glabrescent. Leaves alternate, paripinnate, 2–8(14)-jugate, penninerved, coracious, glossy and glabrous, young leaves pinkish (Plate 2) becoming green with age, rachis not winged. Pseudostipules present, ovate to elliptic and persistent. Leaflets opposite to sub-opposite, elliptic to lanceolate, apex obtuse to acuminate, margin entire (Plate 1). Inflorescence axillary or terminal, sometimes ramiflorous and cauliflorous. Flowers scentless, bisexual, 0.3–0.4×0.5–0.6 cm, with of 4–5 elliptic, ovate, or obovate, reddish sepals, 4–5 elliptic to obovate dark red, glabrous petals, stamens 5–8 with yellow or white anthers, ovary 2–3(–4) locules, glabrous, stigma slightly lobed and sessile. Fruit is subglobose to ovoid (-ellipsoid), 3–4 cm diameter, glossy, dark red to reddish-black when ripe (Plates 1–2), thin-walled, with sweet, translucent, fleshy aril. Seeds usually 2, brown, subglobose to ellipsoid, flattened on the axial side.

Nutritive/Medicinal Properties

No information on its nutritive value has been published.

In traditional Malay medicine, the root is used in a compound poultice to relieve itching and to



Plate 1 Cluster of pendant, glossy, dark red, sub-globose fruit and elliptic-lanceolate leaves



Plate 2 Reddish twigs, pinkish juvenile leaves and ripe dark red, glossy fruits

lower temperature during fever. The Kedayan in Sarawak use a tea infusion of the root regularly against rheumatism or impotence. A tea is made from its roots and the roots of pasak nagi (Euphorbiaceae) and drunk to relieve backache and to enhance sexual desires.

Other Uses

The tree is used as an ornamental plant in landscaping due to its attractive form. The wood is hard, durable, and heavy and is used for house-building in Malacca and also used for firewood. The shoots are used in a preharvest rice ritual in southern Thailand.

Comments

Lepisanthes fruticosa is a rather variable species and some local races have been distinguished (Adema et al. 1994).

In Peninsular Malaysia there are two races: ‘erythrocalyx’, characterized by distinctly stalked leaflets, pentamerous flowers, and completely 3-celled fruits; and ‘resecta’ (including also *O. sessilis*) with (sub)sessile leaflets, 4-merous flowers, and incompletely 2-celled fruits.

In Borneo there are three main races: ‘acuminata’, ‘fruticosa’ and ‘glandulosa’. The latter have 2 ecotypes. Race ‘acuminata’ has acute leaflets, ramiflorous or cauliflorous inflorescences, pentamerous flowers, completely 3-celled fruits; it is restricted to the Kapuas basin. Race ‘fruticosa’ has obtuse leaflets, axillary or sometimes terminal inflorescence, incompletely 2-celled fruits; it is mostly restricted to N Borneo. Race ‘glandulosa’ has obtuse leaflets, axillary and ramiflorous or cauliflorous inflorescences, pentamerous flowers, densely short-hairy anthers, and very incompletely 2-celled fruits. The lowland form is rather wide-spread, a mountain form, mainly restricted to Mount Kinabalu, differs in the more slender petiole and rachis (the latter may be narrowly winged), smaller and more

caducous pseudo-stipules, narrower leaflets with a longer attenuate apex, and the mid-rib more often rounded beneath.

Selected References

- Adema F, Leenhouts P W, van Welzen PC (1994) Sapindaceae. Flora Malesiana., Ser 1, vol 11, Part 3, Noordhoff-Kolff Djakarta, pp 419–768
- Backer CA, Bakhuizen van den Brink Jr RC (1965) Flora of Java (Spermatophytes only), vol 2. Wolters-Noordhoff, Groningen, 641 pp
- Chai PPK (2006) Medicinal plants of Sarawak. Lee Ming Press, Kuching, Sarawak, 212 pp
- Jansen PCM, Jukema J, Oyen LPA, van Lingem TG (1991) *Lepisanthes fruticosa* (Roxb.) Leenh. In: Verheij EWM, Coronel RE (eds) Plant resources of South-East Asia, No. 2. Edible fruits and nuts. Prosea Foundation, Bogor, pp 343–4
- Kulip J (2003) An ethnobotanical survey of medicinal and other useful plants of Muruts in Sabah, Malaysia. Telopea 10(1):81–98
- Leenhouts PW (1969) A revision of *Lepisanthes* (Sapindaceae). Blumea 17:33–91
- Ochse JJ (1927) Indische Vruchten. Volkslectuur, Weltevreden, 330 pp
- Porcher MH et al (1995–2020) Searchable World Wide Web Multilingual Multiscript Plant Name Database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Rojo JP (1999) Revised Lexicon of Philippine Trees. Forest Products Research and Development Institute, Philippines, 484 pp
- Slik JWF (2006) Trees of Sungai Wain. Nationaal Herbarium Nederland. <http://www.nationaalherbarium.nl/sungaiwain/>
- Subhadrabandhu S (2001) Under utilized tropical fruits of Thailand. FAO Rap publication 2001/26, 70 pp
- Upho U (2005) Ethnobotany of Buddhist and Muslim Thais in some locations in the lower part of Southern Thailand. PhD thesis. Chiang Mai University, Thailand, 542 pp
- Yap SK (1989) Sapindaceae. In: Ng FSP (ed) Tree flora of Malaya, vol 4. Longman, Malaysia, pp 434–461

Litchi chinensis

Scientific Name

Litchi chinensis Sonnerat.

Synonyms

Corvinia litchi Stadm. ex Willem., *Dimocarpus litchi* Loureiro, *Euphoria didyma* Blanco, *Euphoria lit-chi* Desf., *Litchi chinensis* var. *euspontanea* H. H. Hsue, *Litchi litchi* Britt., *Litchi philippinensis* Radlk., *Nephelium chinense* (Sonnerat) Druce, *Nephelium litchi* (Desf.) Cambessèdes nom. illeg., *Sapindus edulis* Aiton, *Scytalia chinensis* (Sonnerat) Gaertn., *Scytalia litchi* Roxb.

Family

Sapindaceae

Common/English Names

Chinese Cherry, Leechee, Lichee, Litchi, Lychee, Mountain Lychee, Water Lychee.

Vernacular Names

Brazil: Lichia;
Burmese: Kyet Mouk, Lam Yai, Lin Chi;
Chinese: Li Zhi (Li Chi), Li Zhi Guo, Ma Gie;
Czech: Liči čínské;

Danish: Kinesisk Blomme, Litchiblonne;

Dutch: Lychee

French: Cerisier De Chine, Litchi, Litchi De Chine, Litchie, Litchier;

Haiti: Quenepe Chinois (**French**);

Hungarian: Licsi;

India: Lichi (**Bengali**), Lichi (Hindu), Lichi Hannu (Kannada), Lichi (**Manipuri**), Lichi (**Marathi**), Lachu (**Mizoram**), Lachu, Lichi (**Oriya**);

Indonesia: Mengkuris(**Kalimantan**), Kelengkang, Kelengkang, Laici, Lici, Litsi;

Italian: Litchi;

German: Litchi, Litschi, Litchiplanze, Litschiplaume, Litschibaum;

Greek: Litsi;

Japanese: Reishi, Reishi;

Khmer: Kuléén;

Laotian: Ngèèw;

Malaysia: Kelengkang, Laici;

Nepali: Litchi;

Philippines: Alupag-Amo, Letsias, Licheas (**Tagalog**);

Polish: Liczi chińskie;

Portuguese: Lechia, Lichia, Litchia;

Reunion: Letchi, Pied De Letchi (**French**);

Russian: Lichi Kitaiskaia, Lichi Lichi, Lichi Kitaiskoe, Lidzhi Kitaiskoe, Nefelium, Nefelium Lichi;

Slovačina: Liči;

Spanish: Lechia, Mamoncillo Chino;

Swedish: Kinesiska Plommon, Litchiplommon;

Thai: Lin Chi, Lin Chi Pa, Si Raman, Si Raman Kha;

Vietnamese: Cây Vải, Giồng Vải, Ngan Xanh, Quả Vải, Tu Hú, Vải.

Origin/Distribution

The lychee is native to low elevations of the provinces of Kwangtung and Fukien in southern China, Hainan Island and possibly in northern Vietnam, where it flourishes especially along rivers and near the seacoast. Lychee trees grow wild in abundance on Hainan Island near northern Vietnam mainly at an elevation of 600–800 m, and below 500 metres in hilly areas in Leizhou Peninsula, in the west of Guangdong and the east of Guangxi (Menzel 1995). Wild lychees are a major species in several lowland rainforest areas on Hainan Island and may account for 50% of the virgin forest composition.

Agroecology

Lychees are grown commercially from 17° N to 30° N latitude, and are usually found at low elevation in the subtropics and from 300 to 600 m in tropical locations, with cool or cold winters and warm to hot summers. Rainfall is generally highest in summer and least in winter or spring. There are a few exceptions to this pattern such as Cairns in northern Australia (latitude 17°S) where they are grown along the coastal flats and in some areas of South Africa (latitude 25°S) where they are found at 600–800 m. In both these locations, winters are dry and the Tai So or Mauritius cultivar is grown. Production is very erratic for many cultivars in coastal northern Queensland, but more consistent at elevation in South Africa. Most of the lychee growing areas have winter minima below 20°C and usually below 15°C or 10°C. Winters are usually dry with rainfall of less than 25 mm or between 25 and 50 mm. Temperatures below 20°C and cloud cover during flowering can reduce fruit set.

Most orchards in South-East Asia are under dryland conditions. Annual rainfall of about 1,200–1,500 mm usually provides sufficient moisture for cropping. A few weeks of drought in

winter may assist flower initiation, however drought at other stages of the growth cycle can reduce yield or fruit quality. Well-grown trees can have roots below 1.5 m. This can help the trees buffer short-term droughts. Good protection from wind is also essential for cropping.

Lychee is a fastidiously sensitive crop to fluctuations in the environmental growing conditions. The lychee is adapted to the high elevation of 400–800 m in the tropics and the lowlands in the warm subtropics (between 13°N–32°N and 6°S–29°S). It thrives best in regions with winters that are short, dry (with rainfall of less than 50–80 mm) and cool (daily maximum below 20–22°C and minima of 10–15 °C) but frost free and summers that are long and warm (daily maximum above 25°C) with high rainfall (1,200–1,500 mm) and high humidity. Temperatures below 20°C and cloud cover or misty conditions and heavy rain during flowering can reduce fruit set as pollen and bee activity are reduced. Warm humid conditions are ideal for fruit development and vegetative growth. Low humidity, hot dry winds and fluctuating soil moisture can devastate yields or cause fruit splitting. Lychee needs protection such as wind-breaks against strong wind for good cropping as strong wind causes flower and fruit drop, limb damage and stunted growth.

The lychee grows well on a wide range of soils. In China it is cultivated in sandy or clayey loam, “river mud”, moist sandy clay, and even heavy clay. The lychee attains maximum growth and productivity on well-drained, deep alluvial loam or sandy loams rich in organic matter. It also grows in calcareous soil as in oolitic limestone in southern Florida provided it is well-irrigated in the dry seasons. The soil pH should be between 5.5 and 7.5. Lychee cannot tolerate prolonged water-logging and have low tolerance to salinity and extremes of pH.

Edible Plant Parts and Uses

Fleshy sweet lychee arils are best consumed fresh, out-of-hand. The strong appeal of lychee lies in the exquisite aroma of the fruit. Peeled and pitted, they are commonly added to fruit cups and

fruit salads. Lychee arils stuffed with cottage cheese are served as salad topped with dressing and pecans. Lychee arils may be stuffed with a mixture of cream cheese and mayonnaise, or stuffed with pecan meats, and embellished with whipped cream. Sliced lychee arils, set in lime gelatin, are served on lettuce with whipped cream or mayonnaise. The arils may be layered with pistachio ice cream and whipped cream in parfait glasses, as dessert. Halved lychee arils have been placed on top of ham during the last hour of baking, or grilled on top of steak. Pureed lychee arils are added to ice cream mix. Sherbet is made by extracting the juice from fresh, lychee arils and adding it to a mixture of prepared plain gelatin, hot milk, light cream, sugar and a little lemon juice, and freezing. Whole frozen lychees are thawed in luke-warm water. They must be consumed very soon, as they turn brown and spoil quickly.

Peeled, pitted lychee are canned in sugar syrup in India, Thailand and China and have been exported from China and Thailand for many years. To a small extent, lychees are also spiced or pickled, or made into sauce, preserves or processed into wine. Lychee jelly has been made from blanched, crushed lychee arils and their accompanying juice, with 1% pectin, and combined phosphoric and citric acid added to enhance the flavor.

The arils of dried lychees are eaten like raisins. Chinese people relish the dried arils in tea as a sweetener in place of sugar. Lychee arils can be fermented and processed into wine. Alves et al. (2011) found that lychee wine produced by inoculation with the yeast strain UFLA CA1183 for fermentation of the arils was the most suitable for the production of lychee wines.

Botany

An evergreen, medium-sized tree, usually less than 10 m tall sometimes reaching 15 high or more, with a short stocky trunk, dark greyish bark (Plate 1) and terete, brownish-red, lenticellate branches and round-headed canopy (Plate 2). Leaves are alternate, pinnate and borne on



Plate 1 A grafted lychee tree with short stocky trunk



Plate 2 Tree with rounded dense canopy

10–25 cm long petioles. Leaflets occur in 2–4 pairs on 7–8 mm petiolules, lamina elliptic-oblong to lanceolate, 6–15 by 2–4 cm, acuminate apex, acute base, entire margin, adaxially deep green and glossy, abaxially greyish-green and



Plate 3 Harvested lychee fruits

glaucous, somewhat leathery. Young flushes are reddish. Inflorescences terminal, large, 75 cm long, much-branched panicle bearing hundreds of small, apetalous, greenish-white to yellowish flowers which are basically male (only stamens well developed) or hermaphrodite which function effectively as female (stamens small, anthers not dehiscing) or male (rudimentary, undeveloped ovary). The proportion of different flower types varies with cultivar and temperature conditions during flower differentiation. Flowers small, on short, stout, slender pedicels 2–4 mm long with golden tomentose, tetramerous calyx, 6–8 stamens with hairy stamens and densely tuberculate, hispid, 2-lobed ovary. Fruits drupaceous in loose, pendant clusters of 3–30, strawberry-red, sometimes rose, pinkish or amber, and some types tinged with green. Most are aromatic, subglobose, ovoid, or heart shaped, to 4 cm long by 2.5 cm wide, with a thin leathery, rough pericarp smooth inside and outside with hexagonal-conic shields with a minute warty protuberance (Plates 3, 4), brittle and easily peeled. Seed – one



Plate 4 Close-up of lychee fruit cluster

per fruit, is ellipsoid-oblong, up to 20 mm long, hard, with a shiny, dark-brown coat (depending on pollination seed may be small and atrophied) and is white internally, enveloped by glossy, succulent, thick, translucent-white to greyish or pinkish fleshy arillode (or aril) which usually separates readily from the seed.

Nutritive/Medicinal Properties

The nutrient composition of raw litchi (exclude 40% refuse of shell and seed) per 100 g edible portion was reported as: water 81.76 g, energy 66 kcal (276 kJ), protein 0.83 g, fat 0.44 g, ash 0.44 g, carbohydrate 16.53 g, dietary fibre 1.3 g, Ca 5 mg, Fe 0.31 mg, Mg 10 mg, P 31 mg, K 171 mg, Na 1 mg, Zn 0.07 mg, Cu 0.148 mg, Mn 0.055 mg, Se 0.6 µg, vitamin C 71.5 mg, thiamine 0.011 mg, riboflavin 0.065 mg, niacin 0.603 mg, vitamin B-6 0.100 mg, total folate

14 µg, choline 7.1 mg, vitamin E (α-tocopherol) 0.07 mg, vitamin K (phylloquinone) 0.4 µg, total saturated fatty acids 0.099 g, 14:0 (myristic acid) 0.002 g, 16:0 (palmitic acid) 0.070 g, 18:0 (stearic acid) 0.024 g; total monounsaturated fatty acids 0.120 g, 16:1 undifferentiated (palmitoleic acid) 0.001 g, 18:1 undifferentiated (oleic acid) 0.119 g; total polyunsaturated fatty acids 0.132 g, 18:2 undifferentiated (linoleic acid) 0.067 g, 18:3 undifferentiated (linolenic acid) 0.065 g; tryptophan 0.007 g, lysine 0.041 g and methionine 0.009 g (USDA 2012). Another analysis reported the following proximate composition: energy 296 kJ, moisture 80.6 g, protein 1.1 g, N 0.18 g, fat 0.1 g, ash 0.3 g, dietary fibre 1.3 g, total sugars 16.2 g, fructose 7.6 g, glucose 7.9 g, sucrose 0.7 g, malic acid 0.4 g, Ca 3 mg, Fe 0.5 mg, Mg 7 mg, K 150 mg, Na 1 mg, Zn 0.6 mg, thiamine 0.05 mg, riboflavin 0.07 mg, niacin 0.5 mg and vitamin C 49 mg (Wills et al. 1986).

The ascorbic acid content of Hawaii-grown lychee cultivars was found to range from 21 to 36 mg/100 g with a mean of 27.6 mg/100 g (Wall 2006). Consumption of lychee fruit (100 g) would meet 2–4% of the DRI (Daily Recommended Intake) for six minerals (P, K, Mg, Fe, Zn, Mn), and would provide 22% of the DRI for Cu.

A total of 96 volatiles were detected in lychee fruit, of which 43 were identified (Wu et al. 2009). Seventeen common volatiles in all the samples included linalool, *cis*-rose oxide, α-terpineol, β-citronellol, geraniol, *p*-cymene, ethanol, 3-methyl-3-buten-1-ol, 3-methyl-2-buten-1-ol, 1-hexanol, (E)-2-hexen-1-ol, 2-ethyl-1-hexanol, 1-octen-3-ol, 1-octanol, ethyl acetate, *p*,α-dimethylstyrene and 3-tert-butyl-4-hydroxyanisole. Although the volatile composition and concentration varied between these cultivars, the components with the highest OAVs (odour activity value) in most cultivars were still *cis*-rose oxide, *trans*-rose oxide, 1-octen-3-ol, and geraniol. Another analysis reported 51 odour-active compounds in lychee fruit (Mahattanatawee et al. 2007). Eight sulfur volatiles were identified as follows: hydrogen sulfide, dimethyl sulfide, diethyl disulfide, 2-acetyl-2-thiazoline, 2-methyl thiazole, 2,4-dithiopentane, dimethyl trisulfide, and methional. Cultivar Mauritius contained 25% and Brewster contained

81% as much total sulfur volatiles as Hak Ip. The 24 odour volatiles common to all three cultivars were acetaldehyde, ethanol, ethyl-3-methylbutanoate, diethyl disulfide, 2-methyl thiazole, 1-octen-3-one, *cis*-rose oxide, hexanol, dimethyl trisulfide, α-thujone, methional, 2-ethyl hexanol, citronellal, (E)-2-nonenal, linalool, octanol, (E,Z)-2,6-nonadienal, menthol, 2-acetyl-2-thiazoline, (E,E)-2,4-nonadienal, β-damascenone, 2-phenylethanol, β-ionone, and 4-vinyl-guaiacol.

Twenty-five compounds were identified in the free and glycosidically-bound volatile fractions of lychee juice, including one ester, 14 alcohols, two aldehydes, four acids, two ketones and two terpenes (Chyau et al. 2003). In the free fraction (2,907 mg/kg), the major volatile compounds found were acetoin (30.1%), geraniol (15.6%), 3-methyl-2-buten-1-ol (15.3%), octanoic acid (7.28%), 2-phenylethanol (4.91%), *cis*-ocimene (4.32%), and butyric acid (3.40%). In the bound fraction (1,576 mg/kg), the latent major volatile compounds found were geraniol (73.7%) and geraniol (7.95%). In aroma evaluation, the free volatile fraction showed a fresh-fruity, lychee-like aroma whereas the bound fraction was odourless. The characteristic lychee-like aroma was noted in the bound fraction after enzymatic hydrolysis. On combination of the free and hydrolysed bound fractions, a strongly fruity, lychee-like aroma was perceived.

Fatty acid composition of litchi seed lipids was reported to consist of: palmitic acid (12%), oleic acid (27%), linoleic acid (11%) and cyclopropanoic fatty acid (CPFA) (42%) (Gaydou et al. 1993). The CPFA fraction consisted of dihydrostercularic acid (37%), *cis*-7-8-methylenehexadecanoic acid (4%), *cis*-5,6-methylenetetradecanoic acid (0.4%), and *cis*-3-4-methylenedodecanoic acid (0.1%). CPFA from litchi seeds belong to the n-9 series as observed in the longan. Four polyphenolic compounds: protocatechuic aldehyde (I), protocatechuic acid (II), daucosterol (III) and (–)-epicatechin (IV) were isolated from the 65% ethanol litchi seed extract (Yan and Liu 2009). 3,12-dihydroxy-*cis*-3,4-methylenedodecanoic acid 3-O-β-d-glucopyranoside, trivially named litchioside C, the first cyclopropyl-containing fatty acid glycoside, was isolated along with three

previously uncharacterized galactosylacylglycerols from the seeds of *Litchi chinensis* (Xu et al. 2011b). Huang et al. (2012) isolated stigmaterol, *p*-hydroxy-benzaldehyde protocatechuic acid, daucosterol and kaempferol-3-*O*- β -D-glucopyranoside from litchi seeds.

Various parts of the lychee tree especially the fruit pericarp and seed have various pharmacological attributes.

Antioxidant Activity

Litchi fruit pericarp tissue was found to be an important source of dietary phenolics. Studies using scavenging activities of DPPH radicals, hydroxyl radical and superoxide anion indicated that at 45–60 °C or pH 3–4, the extracted anthocyanins exhibited a relatively high antioxidant activity (Zhong et al. 2007; Ruenroengklin et al. 2008). The main oligomeric procyanidins from litchi pericarp A2 (–)-epicatechin and procyanidin A2 and epicatechin-(4 β → 8, 2 β → O → 7)-epicatechin-(4 β → 8)-epicatechin exhibited free radical-scavenging effect on OH with IC₅₀ values of 2.60 μ g/mL, 1.75 μ g/mL and 1.65 μ g/mL respectively (Liu et al. 2007). Another study reported that the purified product from the aqueous extract of litchi fruit pericarp tissues was a neutral polysaccharide, with a molecular weight of 14 kDa and comprised mainly of 65.6% mannose, 33.0% galactose and 1.4% arabinose (Yang et al. 2006). This purified polysaccharide had the highest antioxidant activity and should be explored as a novel potential antioxidant.

Large amount of polyphenolic compounds with strong antioxidant activity was present in the pericarp of harvested lychee fruits (Zhao et al. 2006). Most of the lychee flavonoids were partitioned into the ethyl acetate fraction. Three major components of the ethyl acetate fraction were identified as proanthocyanidin B4, proanthocyanidin B2 and epicatechin. The ethyl acetate fraction, proanthocyanidin B4, proanthocyanidin B2 and epicatechin exhibited a good antioxidant capability. The hydroxyl radical and superoxide anion scavenging activities of proanthocyanidin

B2 was greater than those of proanthocyanidin B4 and epicatechin, while the epicatechin had the highest DPPH scavenging activity. In another study, anthocyanins from litchi fruit pericarp strongly inhibited linoleic acid oxidation and exhibited a dose-dependent free-radical-scavenging activity against DPPH radical, superoxide anions and hydroxyl radical (Duan et al. 2007). The degradation of deoxyribose by hydroxyl radicals was shown to be inhibited by anthocyanins acting mainly as chelators of iron ions rather than directly scavenging hydroxyl radicals. Anthocyanins were also found to have excellent reducing power. The reducing power of anthocyanins, ascorbic acid and butylated hydroxytoluene all at 100 μ g/mL were 3.70, 0.427 and 0.148, respectively, indicating that anthocyanins from litchi pericarp had a strong electron-donating capacity. Furthermore, application of anthocyanins to harvested litchi fruit significantly prevented pericarp browning and delayed the increase in membrane permeability. It was therefore suggested that anthocyanins could be beneficial in scavenging free radicals and reducing lipid peroxidation of litchi fruit pericarp.

Litchi fruit pericarp was found to contain significant amounts of polyphenolic compounds. The principal characteristic of the litchi skin polyphenolic compounds was their orthodiphenolic structure, which endowed them high oxidability (Sarni-Manchado et al. 2000). Four major pigments were formally identified as cyanidin 3-rutinoside, cyanidin glucoside, quercetin 3-rutinoside (rutin), and quercetin glucoside. The tannin content was characterized after the depolymerization thiolysis reaction. Tannins (polymeric proanthocyanidins) were mainly constituted with epicatechin units linked by A- and B-type bonds. Condensed tannins were the most abundant (4 mg/g of fresh skin), followed by epicatechin and procyanidin A2 (1.7 and 0.7 mg/g) of fresh pericarp, respectively. The amount of anthocyanins was found to be comparable to that of flavonols, with a value of approximately 0.4 mg/g of fresh pericarp.

Oligonol, a phenolic product derived from lychee fruit extract and green tea extract, was found to contain catechin-type monomers and oligomers of proanthocyanidins, produced by a

manufacturing process which converted polyphenol polymers into oligomers (Fujii et al. 2008). Studies reported that levels of reactive oxygen species (ROS) and the expression of adipokine genes decreased in HW mouse white adipocytes upon treatment with oligonol, as compared to control cells (Sakurai et al. 2008). The transcriptional activity of nuclear factor-kappaB (NF-kappaB) and the activation of extracellular signal-regulated kinase (ERK) 1/2 were also down-regulated by oligonol. In addition, when C57BL/6 J mice were fed a high fat diet (HFD) for 5 weeks, the levels of epididymal white adipose tissue (WAT) mass and lipid peroxidation in WAT both increased, but oligonol intake clearly inhibited such HFD-induced increases. Furthermore, dysregulated expression of genes for adipokines in WAT of mice fed solely a HFD was attenuated by oligonol intake. These results suggested that oligonol had antioxidative effects and that it attenuated HFD-induced dysregulated expression of genes for adipokines in adipocytes. The safety of oligonol was assessed in acute and subchronic studies and genotoxicity assays (Fujii et al. 2008). In a single dose acute study of oligonol, male and female rats were administered 2,000 mg/kg body weight (bw) oligonol in water by gavage. Oligonol caused no adverse effects and body weight gain and food consumption were within normal range, thus the LD₅₀ of oligonol was determined to be greater than 2,000 mg/kg. A 90 day subchronic study (100, 300 and 1,000 mg/kgbw/day, oral gavage) in male and female rats reported no significant adverse effects in food consumption, body weight, mortality, clinical chemistry, haematology, gross pathology and histopathology. Similarly, no adverse effects were observed in mice fed diets providing 2, 20 or 200 mg/kg bw oligonol or 200 mg/kg bw lychee polyphenol for 90 days. Oligonol did not show any potential to induce gene mutations in reverse mutation tests using *Salmonella typhimurium* TA98, TA100, TA1535, TA1537 and *Escherichia coli* WP2uvrA strains. Oligonol did not induce chromosomal aberrations in cultured Chinese hamster lung cells, but it showed increased polyploidy. In a micronucleus assay in mice, oligonol did not induce any micronuclei or suppress bone marrow, indicating

it does not cause chromosome aberrations. The results from these safety studies and previous reports supported the safety of oligonol for human consumption.

Litchi fruit pericarp (LFP) tissues was found to comprise approximately 15% by weight of the whole fresh fruit and with significant amount of flavonoids. The major flavonoids in ripe litchi fruit pericarp (LFP) included flavonols and anthocyanins (Li and Jiang 2007). The major flavanols in the LFP were reported to be procyanidin B4, procyanidin B2 and epicatechin, while cyanidin-3-rutinside, cyanidin-3-glucoside, quercetin-3-rutinoside and quercetin-3-glucoside were identified as the important anthocyanins. Litchi flavanols and anthocyanins exhibited good potential antioxidant activity. The hydroxyl radical and superoxide anion scavenging activities of procyanidin B2 were greater than those of procyanidin B4 and epicatechin, while epicatechin had the highest DPPH scavenging activity (Li and Jiang 2007). Litchi fruit pericarp (LFP) extract contained significant amounts of polyphenolic compounds, and exhibited powerful antioxidative activity against fat oxidation in-vitro.

Two A-type trimeric proanthocyanidins with two doubly bonded interflavanoid linkages, litchitannin A1 [epicatechin-(2 β →O→7,4 β →6)-epicatechin-(2 β →O→7,4 β →8)-catechin] (1) and litchitannin A2 [epicatechin-(2 β →O→7,4 β →6)-epicatechin-(2 β →O→7,4 β →6)-epicatechin] (2), were isolated from lychee seeds together with aesculitannin A (3), epicatechin-(2 β →O→7,4 β →8)-epiafzelechin-(4 α →8)-epicatechin (4), proantho-cyanidin A1 (5), proanthocyanidin A2 (6), proanthocyanidin A6 (7), epicatechin-(7,8-bc)-4 β -(4-hydroxyphenyl)-dihydro-2(3 H)-pyranone (8), and epicatechin (9) (Xu et al. 2010). Compounds 1-9 showed more potent antioxidant activity than L-ascorbic acid with ferric reducing antioxidant power (FRAP) values of 3.71–24.18 mmol/g and IC₅₀ values of 5.25–20.07 μ M toward DPPH radicals.

Four polysaccharide-enriched fractions were isolated from litchi pulp tissue exhibited a dose-dependent free radical scavenging activity as shown by their DPPH radical, superoxide anion and hydroxyl radical inhibition, chelating ability

and reducing power (Kong et al. 2010). Among the different fractions, LFP-III showed the strongest scavenging activity against DPPH radical, superoxide and hydroxyl radicals and chelating ability. The findings suggest litchi polysaccharides from pulp tissue have potential as functional foods with enhanced antioxidant activity. A novel polysaccharide (LCP50S-2) of mean molecular weight 2.19×10^5 kDa isolated from *Litchi chinensis* was found to have antioxidant activity (Hu et al. 2011). The backbone of LCP50S-2 was composed of (1 → 3)-linked β -L-rhamnopyranosyl residues, (1 → 4)-linked α -D-xylopyranosyl residues, (1 → 4)-linked β -D-glucopyranosyl residues, and (1 → 4)-linked α -D-glucopyranosyl residues which branched at O-6. The two branches consisted of α -L-arabinopyranosyl residues and (1 → 6)-linked β -D-galactopyranosyl residues terminated with α -L-arabinopyranosyl residues, respectively. In in-vitro antioxidant assay, LCP50S-2 was found to possess DPPH radical-scavenging activity and hydroxyl radical-scavenging activity with IC_{50} values of 220 and 266 μ g/mL, respectively.

Results of studies showed that antioxidant effects of lychee flower extracts as evaluated by three biochemical models: inhibition of Cu^{2+} -induced oxidation of human low-density lipoprotein, scavenging ability of oxygen radicals in human blood, and inhibition of human erythrocyte hemolysis induced by peroxy radicals were in the order: acetone extract > ethanol extract > hot-water extract (Chen et al. 2011). A similar trend was observed for the contents of flavonoids and phenolic acids. Gentistic acid and epicatechin were the major phenolic acid and flavonoid in the extracts, respectively. The acetone extract of litchi flower was found to have notable antioxidant capacities by scavenging DPPH radicals and inhibiting low-density lipoprotein (LDL) oxidation (Yang et al. 2012). The ethyl acetate fraction was found to have the highest phenolic levels and antioxidant capacities and the bioactive compounds in the fraction were identified as (–)-epicatechin and proanthocyanidin A2. Their contents in the litchi flower were 5.52 and 11.12 mg/g of dry weight, respectively.

Anticancer Activity

In addition to the antioxidant activity, litchi fruit pericarp (LFP) extract displayed a dose- and time-dependent inhibitory effect on human breast cancer, which could be attributed, in part, to its inhibition of proliferation and induction of apoptosis in cancer cells through upregulation and down-regulation of multiple genes (Li and Jiang 2007). Further, various anticancer activities were observed for epicatechin, procyanidin B2, procyanidin B4 and the ethyl acetate fraction of LFP tissue extracts. Procyanidin B4 and the ethyl acetate fraction showed a stronger inhibitory effect on HELF (human embryonic lung fibroblast) than human breast cancer MCF-7 proliferation, while epicatechin and procyanidin B2 have lower cytotoxicities towards MCF-7 and HELF than paclitaxel. It was therefore suggested that flavonoids from LFP might be potentially useful components for functional foods and/or anti-breast cancer drugs.

Studies showed the hexane, ethyl acetate and water fractions of litchi pericarp extract had much higher stimulatory effects on splenocyte proliferation than that of the reference, rutin (Zhao et al. 2007). Epicatechin and the ethyl acetate fraction showed a significantly stimulatory effect when the concentration was up to 12.5 μ g/mL. Proanthocyanidin B2 and proanthocyanidin B4 exhibited little lower stimulatory effects than epicatechin and the ethyl acetate fraction. The anti-breast cancer activities of epicatechin, proanthocyanidin B2, proanthocyanidin B4 and the ethyl acetate fraction were also evaluated. Epicatechin and proanthocyanidin B2 had lower cytotoxicities to human breast cancer cell MCF-7 and human embryonic lung fibroblast than paclitaxel.

In another study, litchi fruit pericarp (LFP) extract demonstrated a dose- and time-dependent inhibitory effect on human breast cancer cell growth (IC_{50} = 80 μ g/mL), and it significantly inhibited colony formation and BrdU (bromodeoxyuridine) incorporation of human breast cancer cells (Wang et al. 2006b). Oligonucleotide microarray analysis identified 41(1.22%) up-regulated and

129 (3.84%) down-regulated genes after LFP water-soluble CEE treatment; the predominantly up-regulated genes were involved in various biological functions including cell cycle regulation and cell proliferation, apoptosis, signal transduction and transcriptional regulation, and extracellular matrix/adhesion molecules; and down-regulated genes were mainly associated with adhesion, invasion, and malignancy of cancer cells. A 40.70% tumour mass volume reduction and significant increase of caspase-3 protein expression were observed in vivo experiment. The findings in this study suggested that LFP extract might have potential anticancer activity on both ER (Estrogen Receptor) positive and negative breast cancers, which could be attributed, in part, to its DNA damage effect, proliferating inhibition and apoptosis induction of cancer cells through up-regulation and down-regulation of multiple genes involved in cell cycle regulation and cell proliferation, apoptosis, signal transduction and transcriptional regulation, motility and invasiveness of cancer cells. In another study, litchi fruit pericarp (LFP) extract demonstrated a dose- and time-dependent inhibitory effect on human hepatocellular carcinoma cell growth; IC_{50} was 80 μ g/mL, and significantly inhibited colony formation in-vitro, tumour growth and BrdU incorporation into cancer cells in-vivo (Wang et al. 2006a). The tumour inhibitory rates at doses of 0.15, 0.3, and 0.6 g/kg/day were 17.31%, 30.77%, and 44.23%, respectively. BrdU (Bromodeoxyuridine) labelled tumour cells of treated animals were 11.80, and were significantly lower than that in untreated controls. The findings showed that litchi fruit pericarp extract exhibited potential anticancer activity against hepatocellular carcinoma in vitro and in vivo through proliferating inhibition and apoptosis induction of cancer cells. Semen Litchi containing serum groups was found to inhibit the proliferation of HepG2 cells, probably through cell apoptosis (Xiong et al 2008). Seven flavonoid glycosides were obtained from lychee seeds and identified as litchioside D (1), (–)-pinocembrin 7-O-neohesperidoside (2), (–)-pinocembrin 7-O-rutinoside (3), taxifolin 4'-O- β -D-glucopyranoside (4), kaempferol 7-O-neohesperidoside (5), tamarixetin 3-O-rutinoside (6), and

phlorizin (7) (Xu et al. 2011a). Among them, compounds 1, 4, and 5 showed in-vitro antitumour activity against A549 (lung carcinoma), LAC (lung adenocarcinoma), Hep-G2 (human hepatocellular carcinoma), and HeLa (cervical cancer) cell lines in the 3-(4,5-dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide (MTT) colorimetric assay.

Hepatoprotective Activity

Studies reported that carbon tetrachloride administration in rats elevated the level of serum glutamate pyruvate transaminase (SGPT), serum glutamate oxalate transaminase (SGOT), alkaline phosphatase (ALP) and serum bilirubin. Administration of LIV-52 (a marketed product served as standard), alcoholic and aqueous extract significantly prevented this increase (Souza et al. 2007). Aqueous extract was found to be more effective than the alcoholic extract. Histopathological studies also confirmed the above investigation. Studies in Thailand reported that Gimjeng and Chakapat lychee cultivar extracts exhibited contents of vitamin C (1.2 and 4.3 mg/100 g) and phenolics like *trans*-cinnamic acid and pelargonidin-3-O-glucoside (9.80 and 19.56 mg GAE/g extract, respectively), and trolox equivalent antioxidant capacity (TEAC) values (11.64 and 9.09 g/mg trolox), respectively (Bhoopat et al. 2011). The Gimjeng cv as compared to the Chakapat cv demonstrated a better antioxidant activity as revealed by anti-lipid peroxidation activity with the TEAC values. Administration of CCl₄ in rats elevated the serum GPT, GOT, and ALP level whereas silymarin, Gimjeng and Chakapat extracts prevented these increases significantly. Significant decrease of apoptotic cells together with restoration of morphological changes confirmed the hepatoprotective effect in the CCl₄-induced rats pretreated with the lychee extracts.

Antiplatelet Activity

A 70% ethanol extract from *Litchi chinensis* (LCE) dose-dependently inhibited collagen- and

ADP-induced platelet aggregation in rat platelet-rich plasma and at 4 mg/mL had a maximal inhibitory effect on platelet aggregation (Sung et al. 2012). Litchi extract (4 mg/mL)-treated group showed almost complete inhibition in the collagen-induced platelet aggregation assay. It also significantly prolonged coagulation times, such as the activated partial thromboplastin and prothrombin time, in rat platelet-poor plasma. The extract also increased fibrinolytic activity in a dose-dependent manner. These results demonstrated the antithrombotic effects of LCE and suggest that *Litchi chinensis* may be a new natural source for the development of antiplatelet, anticoagulant and thrombolytic therapeutics for thrombotic and cardiovascular diseases.

Antiviral Activity

Litchitannin A2 an A-type trimeric proanthocyanidin, isolated from lychee seeds, was found to exhibit in-vitro antiviral activity against coxsackie virus B3 (CVB3) and compounds 3 and 6 displayed antiherpes simplex virus 1 (HSV-1) activity (Xu et al. 2010). Oligonol, a lychee fruit-derived low molecular weight polyphenol, was found to inhibit influenza virus proliferation by blocking attachment of the virus to MDCK (Madin Darby canine kidney) cells and by suppression of nuclear export of influenza virus ribonucleoprotein (RNP) (Gangehei et al. 2010). the underlying mechanism for the inhibitory effect of oligonol on influenza virus RNP nuclear export was attributable to blocking of ROS-dependent induction of extracellular-signal-regulated kinases (ERK) phosphorylation

Antidiabetic Activity

Of the extracts and organic fractions of *L. chinensis* tested, a methanol extract and an ethyl acetate fraction were found to be potent inhibitors of rat lens aldose reductase (RLAR) in-vitro, their IC_{50} values being 3.6 and 0.3 $\mu\text{g/mL}$, respectively (Lee et al. 2009). From the active ethyl acetate fraction of extracts of litchi fruits, four minor compounds

with diverse structural moieties were isolated and identified as D-mannitol (1), 2,5-dihydroxybenzoic acid (2), delphinidin 3-O- β -galactopyranoside (3), 39,59-di-O- β -glucopyranoside (3), and delphinidin 3-O- β -galactopyranoside-39-O- β -glucopyranoside (4). Among these, compound 4 was found to be the most potent RLAR inhibitor ($IC_{50}=0.23 \mu\text{g/mL}$), and may be useful in the prevention and/or treatment of diabetic complications. Aldose reductase had been reported to play an important role in sugar-induced cataract. Separate studies showed in type 2 diabetic rats with insulin resistance (T2DR-IR), administration of lychee seed aqueous extract lowered concentrations of fasting glucose, total cholesterol, triacylglycerol, free fatty acid, leptin, tumour necrosis factor- α and fasting insulin (Guo et al. 2004). It increased index of insulin sensitivity, total protein, albumin and the activity of superoxide dismutase and decreased the levels of blood urea nitrogen, creatine, malondialdehyde and activities of alanine aminotransferase and aspartate aminotransferase. The extract modulated the hyperinsulinemia and insulin sensitivity. The results suggested that litchi seed aqueous extract could reduce the levels of TNF- α , hyperleptinemia and hyperinsulinemia, antagonize insulin resistance, fortify insulin sensitivity, reduce lipodystrophy and maladjustment of glycometabolism, enhance antioxidation, and improve functions of liver and kidney in T2DR-IR rats.

Antihyperlipidemic Activity

Studies found that oligonol, a lychee fruit low-molecular polyphenol containing catechin-type monomers and lower oligomers of proanthocyanidin, significantly enhanced lipolysis in primary adipocytes, independent of cAMP production, but its effect is dependent on activation of the ERK1/2 pathway, leading to down-regulation of perilipin protein expression (Ogasawara et al. 2009). Results of further in-vitro studies suggested that oligonol activated the Ras/Raf-1/MEK1/2 signalling pathway, independent of the interleukin IL-6 signalling pathway, leading to activation of ERK1/2 proteins that accompanied

an in-vitro increase in lipolysis in the rat primary adipocytes (Ogasawara et al. 2010). In a more recent study, Ogasawara et al. (2011) reported that adding oligonol, exerted a greater effect on lipolysis in primary adipocytes compared with tea (-)-epigallocatechin-3-gallate (EGCG) alone, accompanied by a significant increase in activation of extracellular signalling-related kinase 1/2 (ERK1/2). Further, the addition of oligonol and EGCG significantly increased the levels of phosphorylated MEK1/2 and heme oxygenase-1 (HO-1) compared with the non-treated control cells. These results suggested that the coordinated direct effect of mixed polyphenol, comprising oligonol, on ERK1/2 played a key role in a greater lipolytic response to oligonol than EGCG alone. Another recent study found that db/db mice administered orally with oligonol, a low-molecular polyphenol derived from lychee fruit showed significant reductions of reactive oxygen species (ROS), lipid peroxidation, and the TAG and total cholesterol concentrations in both the serum and liver (Noh et al. 2011). Additionally, oligonol attenuated oxidative stress through the inhibition of advanced glycation endproduct formation and its receptor expression. Further the enhanced expressions of NF- κ Bp65 and inducible NO synthase were down-regulated to the levels of m/m mice in the group treated with oligonol at 20 mg/kg. Lower hepatic lipid resulted from the down-regulation of sterol regulatory element-binding protein-1 and its target gene of lipogenic enzymes in the liver of db/db mice. The results suggested that oligonol had protective effects against ROS-related inflammation and excess lipid deposition in the type 2 diabetic liver.

Administration of 2.5% and 5% litchi flower-water-extract (LFWE) in the drinking water lowered serum lipids, cardiac index, and hepatic lipids in high-fat/cholesterol-dietary hamsters (Yang et al. 2010). This was attributed to higher LDL receptor and peroxisome proliferator-activated receptor- α (PPAR- α) gene expressions and lower fatty acid synthase (FAS) gene expression, as well as increased faecal lipid and bile acid excretions. Drinking LFWE also lowered serum malondialdehyde (MDA) contents in high-fat/cholesterol-dietary hamsters, and even showed the

same serum MDA contents as the normal chow diet and normal distilled water group's which could be due to increased serum trolox equivalent antioxidant capacity (TEAC). They concluded that LFWE exhibited a protective effect on cardiovascular health in-vivo.

Antiinflammatory Activity

The petroleum ether extract of litchi leaves was found to possess antiinflammatory, analgesic and antipyretic activity (Besra et al. 1996). Acute toxicity studies revealed that the extract, up to a dose of 1 g/kg intraperitoneally, was nontoxic. The extract did not inhibit arachidonic acid-induced paw inflammation thus indicating that it may inhibit the cyclooxygenase pathway of arachidonic acid metabolism. The extract also enhanced peritoneal cell exudate along with macrophage significantly.

Antimutagenic Activity

An unusual amino acid, α -(methylenecyclopropyl) glycine from *Litchi chinensis* seeds was identified as antimutagen against spontaneous mutation of *Salmonella typhimurium* TA100 (Minakata et al. 1985).

Inflammatory Activity

Studies found that water extracts of the 'heating foods', litchi, longan, or dried longan applied to RAW264.7 macrophages in absence of LPS (lipopolysaccharide) had a dose-dependent enhancing effect on PGE(2) prostaglandin E2 (well-known proinflammatory mediator) production, with EC₅₀ values of 8.4, 16, and 11 mg/mL respectively (Huang and Wu 2002). In contrast, LPS-induced PGE(2) production was inhibited in a dose-dependent manner by the water extracts of the 'cooling foods', chrysanthemum flower, bitter melon, and lotus seed plumule. It was concluded that water-soluble extracts of foods traditionally regarded as 'heating' enhanced basal PGE(2)

production, while those from ‘cooling’ foods significantly inhibited LPS-induced PGE(2) production by the macrophage cell line. The ethyl acetate extract of litchi pulp was found to stimulate prostaglandin E2 (PGE2) production in J774 murine macrophage cells (Zhou et al. 2011). Three compound were isolated from the extract: benzyl alcohol, hydrobenzoin and 5-hydroxymethyl-2-furfuraldehyde (5-HMF). Benzyl alcohol caused marked increase in PGE2 and NO production compared with lipopolysaccharide (LPS) as the positive control in a dose-dependent manner. Hydrobenzoin and 5-HMF also stimulated PGE2 and NO production moderately in a dose-dependent manner. Besides regulation of cyclooxygenase-2 (COX-2) and inducible nitric oxide synthase (iNOS), mRNA expression might be involved in the stimulative effects of the three isolated compounds on PGE2 and NO production in J774 macrophage cells. The results supported the premise that *Litchi chinensis* is a ‘heating’ fruit in China, which can cause serious inflammation symptoms in people.

Antiinflammatory Activity

Nishizawa et al. (2011) found that supplementation of young athletes with a flavanol-rich lychee fruit extract (FRLFE) suppressed inflammation or tissue damage caused by high-intensity exercise training. Compared with the placebo group, the change in the serum interleukin-6 level between pre- and mid-training were significantly lower in the FRLFE group, while the change in the transforming growth factor- β level between pre- and post-training was significantly greater in the FRLFE group. Some parameters, including the white blood cell count, were significantly modified by FRLFE supplementation.

Anaphylactic Reaction

Lychee fruit was found to contain a significant amount of profilin (Fäh et al. 1995). Consumption of this exotic fruit could cause severe anaphylactic reactions in patients being sensitized against the plant pan-allergen, profilin.

Traditional Medicinal Uses

Lychee fruit, peel and seed are used in traditional medicine; decoctions of the root, bark and flowers are used as a gargle to alleviate ailments of the throat. Seeds are used as an anodyne in neuralgic disorders and orchitis. Ingested in moderate amounts, the lychee is said to relieve coughing and to have a beneficial effect on gastralgia, tumors and enlargements of the glands. A tea of the fruit peel is taken to overcome small-pox eruptions and diarrhea. In India, the seeds are powdered and, because of their astringency, administered in intestinal troubles, and they have the reputation there, as in China, of relieving neuralgic pains. One stomach-ulcer patient in Florida, has reported that, after eating several fresh lychees he was able to enjoy a large meal that, ordinarily, would have caused great discomfort. Chinese people believe that excessive consumption of raw lychees causes fever and nosebleed.

Other Uses

Lychee seed was found to contain the unusual cyclopropanoic fatty acid, *cis*-9,10-methylene-octadecanoic acid (C(19)CA) at a relative level of 35–48%, cyclopropanoic fatty acids have potential value for industry (as inks, cosmetics, detergents, lubricants, etc.) (Gontier et al. 2000).

The wood is said to be durable, although it is brittle and has few uses. The bark provides tannin or dyestuff. Lychee tree is a popular ornamental tree in gardens and parks.

Comments

Lychee can be successfully propagated by several methods. Seedlings appear suitable for selection of new cultivars and rootstocks, cuttings for rapid multiplication of new cultivars, marcottage and stooling for commercial multiplication of established cultivars and grafting for top-working new cultivars onto mature trees and/or onto improved rootstocks (Menzel 1985).

Selected References

- Alves JA, de Oliveira Lima LC, Nunes CA, Dias DR, Schwan RF (2011) Chemical, physical-chemical, and sensory characteristics of lychee (*Litchi chinensis* Sonn) wines. *J Food Sci* 76(5):S330–S336
- Besra SE, Sharma RM, Gomes A (1996) Antiinflammatory effect of petroleum ether extract of leaves of *Litchi chinensis* Gaertn. (Sapindaceae). *J Ethnopharmacol* 54(1):1–6
- Bhoopat L, Srichairatanakool S, Kanjanapothi D, Taesotikul T, Thananchai H, Bhoopat T (2011) Hepatoprotective effects of lychee (*Litchi chinensis* Sonn.): a combination of antioxidant and anti-apoptotic activities. *J Ethnopharmacol* 136(1):55–66
- Chen YC, Lin JT, Liu SC, Lu PS, Yang DJ (2011) Composition of flavonoids and phenolic acids in lychee (*Litchi Chinensis* Sonn.) flower extracts and their antioxidant capacities estimated with human LDL, erythrocyte, and blood models. *J Food Sci* 76:C724–C728
- Chyau CC, Ko PT, Chang CH, Mau JL (2003) Free and glycosidically bound aroma compounds in lychee (*Litchi chinensis* Sonn.). *Food Chem* 80(3):387–392
- Cull BW, Paxton BF (1982) The litchi, *Litchi chinensis*. *Aust Hortic* 80(12):87–99
- Duan X, Jiang Y, Su X, Zhang Z, Shi J (2007) Antioxidant properties of anthocyanins extracted from litchi (*Litchi chinensis* Sonn.) fruit pericarp tissues in relation to their role in the pericarp browning. *Food Chem* 101(4):1365–1371
- Fäh J, Wüthrich B, Vieths S (1995) Anaphylactic reaction to lychee fruit: evidence for sensitization to profilin. *Clin Exp Allergy* 25(10):1018–1023
- Fujii H, Nishioka H, Wakame K, Magnuson BA, Roberts A (2008) Acute, subchronic and genotoxicity studies conducted with Oligonol, an oligomerized polyphenol formulated from lychee and green tea extracts. *Food Chem Toxicol* 46(12):3553–3562
- Gangehei L, Ali M, Zhang W, Chen Z, Wakame K, Haidari M (2010) Oligonol a low molecular weight polyphenol of lychee fruit extract inhibits proliferation of influenza virus by blocking reactive oxygen species-dependent ERK phosphorylation. *Phytomedicine* 17(13):1047–1056
- Gaydou EM, Ralaimanarivo A, Bianchini JP (1993) Cyclopropanoic fatty acids of litchi (*Litchi chinensis*) seed oil. A reinvestigation. *J Agric Food Chem* 41(6):886–890
- Gontier E, Boussouel N, Terrasse C, Jannoyer M, Ménard M, Thomasset B, Bourgaud F (2000) *Litchi chinensis* fatty acid diversity: occurrence of the unusual cyclopropanoic fatty acids. *Biochem Soc Trans* 28(6):578–580
- Guo J, Li L, Pan J, Qiu G, Li A, Huang G, Xu L (2004) Pharmacological mechanism of Semen Litchi on antagonizing insulin resistance in rats with type 2 diabetes. *Zhong Yao Cai* 27(6):435–438 (In Chinese)
- Hu SY (2005) Food plants of China. The Chinese University Press, Hong Kong, 844 pp
- Hu XQ, Huang YY, Dong QF, Song LY, Yuan F, Yu RM (2011) Structure characterization and antioxidant activity of a novel polysaccharide isolated from pulp tissues of *Litchi chinensis*. *J Agric Food Chem* 59(21):11548–11552
- Huang CJ, Wu MC (2002) Differential effects of foods traditionally regarded as ‘heating’ and ‘cooling’ on prostaglandin E(2) production by a macrophage cell line. *J Biomed Sci* 9(6 Pt 2):596–606
- Huang KW, Guo JW, Chen JM, Lin LJ, Xu F (2012) Study on the chemical constituents in ethyl acetate extraction from semen litchi. *Zhong Yao Cai* 35(1):64–66 (In Chinese)
- Kong F, Zhang M, Liao S, Yu S, Chi J, Wei Z (2010) Antioxidant activity of polysaccharide-enriched fractions extracted from pulp tissue of *Litchi Chinensis* Sonn. *Molecules* 15(4):2152–2165
- Lee S-J, Park W-H, Park S-D, Moon HI (2009) Aldose reductase inhibitors from *Litchi chinensis* Sonn. *J Enzym Inhib Med Chem* 24(4):957–959
- Leenhouts PW (1978) Systematic notes on the Sapindaceae Nephelieae. *Blumea* 24:395–403
- Li J, Jiang Y (2007) Litchi flavonoids: isolation, identification and biological activity. *Molecules* 12(4):745–758
- Liu L, Xie B, Cao S, Yang E, Xu X, Guo S (2007) A-type procyanidins from *Litchi chinensis* pericarp with antioxidant activity. *Food Chem* 105(4):1446–1451
- Mahattanatawee K, Perez-Cacho PR, Davenport T, Rouseff R (2007) Comparison of three lychee cultivar odor profiles using gas chromatography-olfactometry and gas chromatography-sulfur detection. *J Agric Food Chem* 55(5):1939–1944
- Menzel CM (1985) Propagation of lychee: a review. *Sci Hortic* 25(1):31–48
- Menzel CM (1995) Lychee: its origin, distribution and production around the world. *West Aust Nut Tree Crop Assoc Yearbook* 19:41–48
- Menzel CM, McConchie CA (1998) Lychee and longan. In: Hyde KW (ed) *The new rural industries*. Rural Industries Research and Development Corporation, Canberra, pp 288–295
- Menzel CM, Simpson DR (1991) A description of lychee cultivars. *Fruit Varieties J* 45(1):45–56
- Minakata H, Komura H, Tamura SY, Ohfuné Y, Nakanishi K, Kada T (1985) Antimutagenic unusual amino acids from plants. *Experientia* 41(12):1622–1623
- Morton JF (1987) Lychee. In: *Fruits of warm climates*. Julia F. Morton, Miami, pp 249–259
- Nishizawa M, Hara T, Miura T, Fujita S, Yoshigai E, Ue H, Hayashi Y, Kwon AH, Okumura T, Isaka T (2011) Supplementation with a flavanol-rich lychee fruit extract influences the inflammatory status of young athletes. *Phytother Res* 25(10):1486–1493
- Noh JS, Park CH, Yokozawa T (2011) Treatment with oligonol, a low-molecular polyphenol derived from lychee fruit, attenuates diabetes-induced hepatic damage through regulation of oxidative stress and lipid metabolism. *Br J Nutr* 106(7):1013–1022
- Ogasawara J, Kitadate K, Nishioka H, Fujii H, Sakurai T, Kizaki T, Izawa T, Ishida H, Ohno H (2009) Oligonol,

- a new lychee fruit-derived low-molecular form of polyphenol, enhances lipolysis in primary rat adipocytes through activation of the ERK1/2 pathway. *Phytother Res* 23(11):1626–1633
- Ogasawara J, Kitadate K, Nishioka H, Fujii H, Sakurai T, Kizaki T, Izawa T, Ishida H, Tanno M, Ohno H (2010) Oligonol, an oligomerized lychee fruit-derived polyphenol, activates the Ras/Raf-1/MEK1/2 cascade independent of the IL-6 signaling pathway in rat primary adipocytes. *Biochem Biophys Res Commun* 402(3):554–559
- Ogasawara J, Kitadate K, Nishioka H, Fujii H, Sakurai T, Kizaki T, Izawa T, Ishida H, Ohno H (2011) Comparison of the effect of oligonol, a new lychee fruit-derived low molecular form of polyphenol, and epigallocatechin-3-gallate on lipolysis in rat primary adipocytes. *Phytother Res* 25(3):467–471
- Ruenroengklin N, Zhong J, Duan X, Yang B, Li J, Jiang Y (2008) Effects of various temperatures and pH values on the extraction yield of phenolics from litchi fruit pericarp tissue and the antioxidant activity of the extracted anthocyanins. *Int J Mol Sci* 9(7):1333–1341
- Sakurai T, Nishioka H, Fujii H, Nakano N, Kizaki T, Radak Z, Izawa T, Haga S, Ohno H (2008) Antioxidative effects of a new lychee fruit-derived polyphenol mixture, oligonol, converted into a low-molecular form in adipocytes. *Biosci Biotechnol Biochem* 72(2):463–476
- Sarni-Manchado P, Le Roux E, Le Guernevé C, Lozano Y, Cheyner V (2000) Phenolic composition of litchi fruit pericarp. *J Agric Food Chem* 48(12):5995–6002
- Souza MG, Singh R, Reddy PP, Hukkeri V, Byahatti VV (2007) Hepatoprotective activity of fruit pulp extract of *Litchi chinensis* Sonner. on carbon tetrachloride induced hepatotoxicity in albino rats. *Internet J Altern Med* 4(1). doi:10.5580/570
- Subhadrabandhu S (1990) Lychee and longan cultivation in Thailand. Rumphai Publication, Bangkok, Thailand, 40 pp
- Sung YY, Yang WK, Kim HK (2012) Antiplatelet, anticoagulant and fibrinolytic effects of *Litchi chinensis* Sonn. extract. *Mol Med Rep* 5(3):721–724
- U.S. Department of Agriculture, Agricultural Research Service (2012) USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory Home Page, <http://www.ars.usda.gov/ba/bhnrc/ndl>
- Wall M (2006) Ascorbic acid and mineral composition of longan (*Dimocarpus longan*), lychee (*Litchi chinensis*) and rambutan (*Nephelium lappaceum*) cultivars grown in Hawaii. *J Food Comp Anal* 19(6–7):655–663
- Wang X, Wei Y, Yuan S, Liu G, Zhang YL, Wang W (2006a) Potential anticancer activity of litchi fruit pericarp extract against hepatocellular carcinoma in vitro and in vivo. *Cancer Lett* 239(1):144–150
- Wang X, Yuan S, Wang J, Lin P, Liu G, Lu Y, Zhang J, Wang W, Wei Y (2006b) Anticancer activity of litchi fruit pericarp extract against human breast cancer in vitro and in vivo. *Toxicol Appl Pharmacol* 215(2):168–178
- Wills RBH, Lim JSK, Greenfield H (1986) Composition of Australian foods. 31. Tropical and sub-tropical fruit. *Food Technol Aust* 38(3):118–123
- Wong KC, Ketsa S (1992) Litchi. In: Verheij EWM, Coronel RE (eds) Plant resources of South-East Asia, vol 2, Edible fruit and nuts. Prosea Foundation, Bogor, Indonesia, pp 191–195
- Wu Y, Pan Q, Qu W, Duan C (2009) Comparison of volatile profiles of nine litchi (*Litchi chinensis* Sonn.) cultivars from southern China. *J Agric Food Chem* 57(20):9676–9681
- Xia N, Gadek PA (2007) Sapindaceae. In: Wu ZY, Raven PH, Hong DY (eds) Flora of China, vol 12 (Hippocastanaceae through Theaceae). Science Press/Missouri Botanical Garden Press, Beijing/St Louis
- Xiong AH, Shen WJ, Xiao LY, Lv JH (2008) Effect of Semen Litchi containing serum on proliferation and apoptosis of HepG2 cells. *Zhong Yao Cai* 31(10):1533–1536 (In Chinese)
- Xu X, Xie H, Wang Y, Wei X (2010) A-type proanthocyanidins from lychee seeds and their antioxidant and antiviral activities. *J Agric Food Chem* 58(22):11667–11672
- Xu X, Xie H, Hao J, Jiang Y, Wei X (2011a) Flavonoid glycosides from the seeds of *Litchi chinensis*. *J Agric Food Chem* 59(4):1205–1209
- Xu X, Xie H, Xu L, Wei X (2011b) A novel cyclopropyl-containing fatty acid glucoside from the seeds of *Litchi chinensis*. *Fitoterapia* 82(3):485–488
- Yan RL, Liu ZG (2009) Isolation and characterization of polyphenols in seed of *Litchi chinensis*. *Zhong Yao Cai* 32(4):522–523 (In Chinese)
- Yang B, Wang J, Zhao M, Liu Y, Wang W, Jiang Y (2006) Identification of polysaccharides from pericarp tissues of litchi (*Litchi chinensis* Sonn.) fruit in relation to their antioxidant activities. *Carbohydr Res* 341(5):634–638
- Yang DJ, Chang YY, Hsu CL, Liu CW, Wang Y, Chen YC (2010) Protective effect of a litchi (*Litchi chinensis* Sonn.)-flower-water-extract on cardiovascular health in a high-fat/cholesterol-dietary hamsters. *Food Chem* 119(4):1457–1464
- Yang DJ, Chang YZ, Chen YC, Liu SC, Hsu CH, Lin JT (2012) Antioxidant effect and active components of litchi (*Litchi chinensis* Sonn.) flower. *Food Chem Toxicol* 50(9):3056–3061
- Zhao M, Yang B, Wang J, Li B, Jiang Y (2006) Identification of the major flavonoids from pericarp tissues of lychee fruit in relation to their antioxidant activities. *Food Chem* 98(3):539–544
- Zhao M, Yang B, Wang J, Liu Y, Yu L, Jiang Y (2007) Immunomodulatory and anticancer activities of flavonoids extracted from litchi (*Litchi chinensis* Sonn.) pericarp. *Int Immunopharmacol* 7(2):162–166
- Zhong J, Duan XW, Qu HX, Yang B, Chen YL, Ruenroengklin N, Jiang YM (2007) Effects of various extraction conditions on phenolic contents and their antioxidant activities of litchi fruit pericarp. *Acta Horti (ISHS)* 804:327–332
- Zhou Y, Wang H, Yang R, Huang H, Sun YM, Shen YD, Lei HT, Gao H (2011) Effects of *Litchi chinensis* fruit isolates on prostaglandin E2 and nitric oxide production in J774 murine macrophage cells. *Afr J Biotechnol* 10(61):13180–13188

Nephelium cuspidatum var. *robustum*

Scientific Name

Nephelium cuspidatum Blume var. *robustum* (Radlk.) Leenh.

Synonyms

Nephelium robustum Radlk.

Family

Sapindaceae

Common/English Names

Giant rambutan.

Vernacular Names

Indonesia: Ketuma;

Malaysia: Kalambuku ([Murut, Sabah](#)), Rambutan Gergasi;

Philippines: Manti ([Palawan](#)).

Origin/Distribution

The species is indigenous to Borneo – Kalimantan, Sarawak, Sabah, Brunei and Palawan in the Philippines.

Agroecology

In its native range, it occurs as middle storey trees in undisturbed to slightly disturbed (open sites) mixed dipterocarp forests, mostly in the lowlands but can be found up to 700 m elevation. It is usually found along rivers and streams and on hill-sides on fertile sandy to clayey soils, but also on calcareous soils. In secondary forests, it is usually present as a pre-disturbance remnant, or planted.

Edible Plant Parts and Uses

The acid sweet sarcotesta is edible and is usually eaten fresh.

Botany

Tree growing to 40 m high with a trunk with 80 cm dbh, and broad-base, sometimes buttressed. Twigs, tomentellous and 5–15 mm in diameter. Stipules absent. Leaves alternate, compound, 8–9 jugate ([Plates 2 and 3](#)). Leaflets simple, elongate-oblong, up to 35 cm long, 5–10 cm wide, margin entire, distinct mid-rib and pinniveined, almost glabrous to densely hairy, sometimes whitish below and borne on 7–15 mm petiolules. Inflorescences terminal panicle, 28 cm long by 15 cm wide. Flowers on short pedicels, small, 5 mm across, yellowish white, apetalous. Calyx 5-partite, 25–50% connate, lobes deltoid

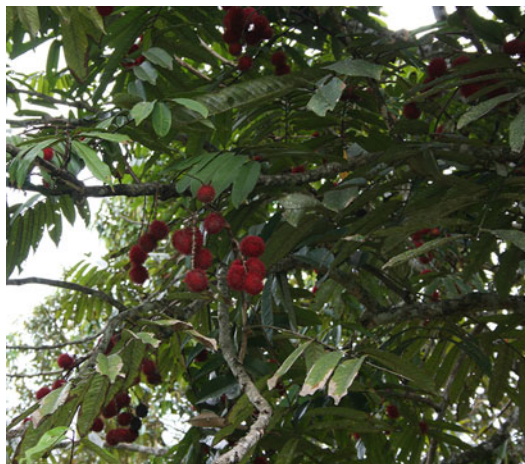


Plate 1 Loose cluster of soft-hairy ripe giant rambutan fruits



Plate 2 Soft hairy ripe fruits and 8–9 jugate leaf with dull green adaxial leaflets

and pubescent, disc hirsute, pistil 2-merous, warty and hairy, stamens short, filiform, anther villous, style short with bifid stigma. Fruit 35–40 mm across, ellipsoid to subglobose drupe,



Plate 3 Dull, glaucous abaxial surface of 8–9 jugate leaf

green ripening red, dense with soft, firm spinterns (Plates 1 and 2). Seed one flattish-ellipsoid, enclosed by the translucent whitish, fleshy, edible sarcotesta.

Nutritive/Medicinal Properties

Information on the nutritive composition of the edible fruit and medicinal properties of the plant have not been published.

Other Uses

The wood is occasionally used for construction but is of inferior quality.

Comments

Nephelium cuspidatum Blume is a complex species and has been divided into 6 varieties, 2 of which is subdivided further into 2 subvarieties (Leenhouts 1986): *Nephelium cuspidatum* Blume var. *bassacense* (Pierre) Leenh., *Nephelium cuspidatum* Blume var. *cuspidatum* subvar. *cuspidatum*, *Nephelium cuspidatum* Blume var. *cuspidatum* subvar. *dasyneurum* (Radlk.) Leenh., *Nephelium cuspidatum* Blume var. *multinerve* (Radlk.) Leenh., *Nephelium cuspidatum* Blume var. *eriopetalum* (Miq.) Leenh., *Nephelium cuspidatum* Blume var. *robustum* (Radlk.) Leenh., *Nephelium cuspidatum* Blume var. *ophiodes* (Radlk.) Leenh. subvar. *beccarianum* (Radlk.)

Leenh., *Nephelium cuspidatum* Blume var. *ophiodes* (Radlk.) Leenh subvar. *Ophiodes* (Radlk.) Leenh..

Two varieties are known to be mainly grown for the fruit: *Nephelium cuspidatum* var. *robustum* and *Nephelium cuspidatum* var. *eripetalum* known locally as deket, rambutan kabung, rang-gung in Indonesia, and sanggul lotong in Malaysia.

Selected References

- Adema F, Leenhouts P W, van Welzen PC (1994) Sapindaceae. Flora Malesiana, ser 1, vol 11, Part 3. Noordhoff-Kolff, Djakarta, pp 419–768
- Adema F, Leenhouts PW, van Welzen PC (1996) Sapindaceae. In: Soepadmo E, Wong KM, Saw LG (eds) Tree flora of Sabah and Sarawak, vol 2. Sabah Forestry Department/Sarawak Forestry Department/Forest Research Institute of Malaysia, Kepong, pp 263–271
- Elmer ADE (1913) *Nephelium robustum* Radlkofer. Leaf Philipp Bot 5:1607
- Leenhouts PW (1986) A taxonomic revision of *Nephelium* (Sapindaceae). Blumea 31:373–436
- Meijer W (1969) Fruit trees in Sabah (North Borneo). Malay Forester 32(3):252–265
- Seibert B (1991) *Nephelium* L. In: Verheij EWM, Coronel RE (eds) Plant resources of South-East Asia No. 2. Edible fruits and nuts. Prosea Foundation, Bogor, pp 233–235
- Slik JWF (2006) Trees of Sungai Wain. Nationaal Herbarium Nederland. <http://www.nationaalherbarium.nl/sungaiwain/>
- van Welzen PC, Lamb A, Wong WWW (1988) Edible Sapindaceae in Sabah. Nat Malay 13(1):10–25

Nephelium lappaceum

Scientific Name

Nephelium lappaceum L.

Common/English Names

Hairy lychee, Rambutan.

Synonyms

Dimocarpus crinita Lour., *Euphoria crinita* Poir. nom.illeg., *Euphoria glabra* Blume nom.illeg., *Euphoria nephelium* DC. nom. illeg., *Euphoria nephelium* Poir. nom. illeg., *Euphoria ramboutan* Labill. nom.illeg., *Litchi ramboutan* Labill. nom. illeg., *Nephelium chryseum* Blume, *Nephelium chryseum* Blume var. *topengii* Wu, *Nephelium echinatum* Noronha nom. nud., *Nephelium glabrum* Cambess., *Nephelium glabrum* Noronha nom. nud., *Nephelium glabrum* Reinw. ex Blume nom. illeg., *Nephelium lappaceum* L. var. *topengii* How & Ho, *Nephelium lappaceum* L. var. *glabrum* Blume, *Nephelium maculatum* Radlk., *Nephelium mutabile* Blume var. *pallens* Hiern, *Nephelium obovatum* Ridley, *Nephelium rambutan* Schnizl., nom. illeg., *Nephelium sufferrugineum* Radlk. nom. inval., *Nephelium topengii* H.S. Lo, *Nephelium xanthioides* Radlk., *Scytalia ramboutan* Roxb. nom. illeg., *Xerospermum topengii* Merr.

Family

Sapindaceae

Vernacular Names

Brazil: Rambutão (Portuguese);
Chinese: Shao-Zi, Shaho-Tzu, Mao-Long-Yan, Mao-Lung Yen, Hong-Mao-Dan, Hung-Mao-Tan;
Costa Rica: Mamón Chino;
Dutch: Ramboetan;
Ecuador: Achotillo;
French: Litchi Chevelu, Ramboutan, Ramboutanier, Ramboitan;
German: Rambutan, Rampostan, Klettenartige Zwillingsspflaume;
Indonesia: Rambot (Acheh, Sumatra), Barangkasa (Alfoersch, Maluku), Buiuwana (Bali), Jailan, Rambutan (Batak), Rambuta (Bima, Timor), Balatung, Bolotu, Wulangas (Boengineesch, Sulawesi), Rambusa (Boeol, Manado, Sulawesi), Banamon, Beliti, Bengayu, Beriti, Kayokan, Maliti, Puson, Rambutan, Sagalong, Sanggalong, Siban (Dayak, Kalimantan), Rambuten (Gajo, Sumatra), Rambuta (Gorontalo, Sulawesi), Rambutan (N. Halmaheira), Rambutan (Java), Buwa Buluwan (Kambang), Puru Bianjak (Koebo, Kalimantan), Hahuyam, Kakapas, Likes, Rabut, Rambuta, Rambutan, Takuyung Alu (Lampong, Sumatra), Bunglon, Rambutan (Madurese),

Balatu, Balatung (Makassar, Sulawesi), Rambutan (Malay, Jambi, Manado, Singkep), Rambutang (Maluku), Lelamu, Lelamun, Toleang (Mandar, Sulawesi), Bairabit (Mentawai), Rambutan (Minangkabau), Folui, Rambuta (Nias, Sumatra), Buluwan (Sasak, Lombok), Rambut, Rambutan (Simaloer, Sumatra), Rambutan, Tundun, Chrogol (Sundanese), Rambuta (Ternate), Walatu, Wayatu, Wilatu (Toraja, Sulawesi);

India: Ramboostan (Hindu);

Italian: Nefelio;

Japanese: Ranbuutan; Khmer: Chle Sao Mao, Saaw Maaw, Ser Mon;

Khmer: Ser Mon, Xhle Sao Mon;

Korean: Ram Bu T'an;

Malaysia: Tanggun, Gerat (In Pangan), Tangguish, Tangui, Tangoi, Tekelakoin (In Semang), Nerat, Gente, Legos (In Sakai), Buan, Ple Baun (In Besisi), Rambutan, Rambustan (Rare);

Nicaragua: Mamón Chino;

Panama: Mamón Chino;

Philippines: Usau (Bisaya), Usare (Sulu), Rambutan (Tagalog);

Russian: Rambutan;

Spanish: Mamón Chino, Rambutan, Ramustan;

Thai: Ngoh, Phruan, Amaw;

Vietnamese: Chômchôm, Vai Thiêu.

Origin/Distribution

Rambutan is indigenous to West Malaysia. Malaysia and Indonesia are the probable centres of origin but the exact location is uncertain. It has been widely cultivated in south east Asia for a long time. It is now grown pantropically in India, Sri Lanka, Zanzibar, and in the lowlands of Central and northern South America, Northern Australia, Papua New Guinea, the Pacific islands and Hawaii.

Agroecology

Rambutan is strictly a tropical species that thrives best in a warm, humid tropical regions with low evaporation rates and well distributed and high rainfall. The optimum temperature

range above 2032°C and humidity should be above 80% and with an annual precipitation of 1,500–3,000 mm evenly distributed throughout the year. Lower temperatures will constrain growth at altitudes above 300 m. In northern Australia, the low night temperatures (<15°C) and the low prevailing diurnal humidity during May to August can inhibit shoot development and cause young leaf, flower and fruit abortion. Controlled environment studies showed that vegetative growth ceases under cool day/night temperatures (22°C/14°C) and is only marginally better at 32°C/14°C. Maximum growth occurs at 32°C/28°C. Windbreaks are necessary because of the strong and dry winds particularly in drier growing areas. A short dry period is important for flower set.

In its natural habitat, rambutan occurs as a lower or middle storey tropical forest tree mainly at low altitudes. Rambutan flourishes from sea-level to 1,600 m elevation. Rambutan can be grown in a wide range of soil types, even ones with poor drainage, but not water-logged. The crop grows best in a well-drained, deep, clay-loam or rich sandy loam rich in organic matter with a pH in the range 5.5–6.5 and does not do well on alkaline soils with high bicarbonate or calcium levels or deep peat. In northern Queensland, rambutan thrives best on the red basaltic soils to the west of Innisfail. Other suitable soils include the metamorphic and alluvial soils in the valleys and foothills. In the Northern Territory, Australia rambutan is grown mainly on the sandy loamy, yellow-brown earths. These soils require regular fertilisation and irrigation for good plant growth and yields.

Edible Plant Parts and Uses

Rambutan is chiefly eaten as a table fruit, the juicy, sweet to acid-sweet, fleshy sarcotesta is eaten fresh or canned in light syrup whole minus the seed or stuffed with cubes of pineapple. The sarcotesta can be canned with other fruits like jackfruit, starfruit in syrup. The fruit can be frozen whole and thawed and served. The sarcotesta can be dehydrated, sweetened in syrup and drained and dehydrated again to make dehydrated

rambutan. The sarcotesta can be processed into jams, jellies, fruit rolls, mix fruit cordials and fruit juices, stews, compote or wine. The seeds can be eaten when roasted. The seed also yield a pleasant scented rambutan tallow, a solid similar to cocoa-butter which turns to oil when heated and the oil can be used for edible purposes.

Botany

A medium-sized, evergreen, much-branched tree, 15–25 m tall with an erect trunk, bole of 40–60 cm diameter, dark brownish-grey bark and a dense spreading crown. Clonal trees developed from grafting are shorter 7–12 m high (Plate 1). Twigs are terete, pubescent when young becoming glabrescent. Leaves are alternate, pinnately compound, 1-foliolate to 6-jugate, petiole 1.5–16 cm long, 1–3.5 mm thick, terete, sometimes grooved; petiolules 1.5–12 mm long, shallowly grooved with a faint median rib. Leaflets are alternate to sub-opposite, soft, pubescent and pale green when young turning dark green, coriaceous and glabrous on the upper surface and pale green and sparsely hairy on the under surface, elliptic, oblong or elliptic-obovate, base cuneate obtuse or rounded, apex shortly acuminate or obtuse, 5–20 cm long by 2.5–11 cm wide, pinnatinerved, mid rib robust, lateral nerves 6–15 pairs and conspicuous on both surfaces. Domatia are present on lower surface of leaflets in the axils of midrib and lateral veins. Inflorescences are axillary or subterminal, erect, widely branched, rusty pubescent, with 15–20 cm long rachis bearing many greenish yellow, faintly sweet-scented, 2.5–4 mm,



Plate 1 A short, grafted prolific-bearing rambutan tree

apetalous flowers that has 4–6 partially connate sepals which are yellowish green and tomentose on the outside and white and pubescent on the inside. There are tree types of functional flowers – staminate flowers, hermaphrodite flowers functioning as male (hfm) and hermaphrodite flowers functioning as female (hff). The staminate flower has 5–8 fertile stamens placed within the disc, with white tomentose filaments and yellowish, bilobed anthers which dehisce to release the sticky barrel-shaped pollens and lacks pistil. Hermaphrodite flowers have stamens and pistil consisting of 2–3 lobed ovary with one anacampylotropous ovule in each locule, with style inserted between the lobes, stigma deeply bifid or trifid which becomes recurved during anthesis. The hfm flowers have fertile stamens but the pistil does not function normally, the bifid stigma splits but remains erect and not reflexed. The hff flowers have well developed pistil which function normally but the stamens remains closely adpressed to the sepals during anthesis and do not release the pollens. Fruit is produced in loose clusters of 10–18 (Plates 2 and 3). The fruit is a drupe with only one of the ovules developing, green when young developing to various shades of red and yellow as per cultivar, round to ovoid (Plates 2, 3, 4), 4.5–6 cm long by 3.4–4.5 cm wide and weighing 20–60 g. The pericarp is fairly thick, 2–4 mm, and is beset with tubercular outgrowths of the ovary wall called spinterns which impart a hairy appearance to the fruit. The spinterns are soft, short to long, 0.5–1.8 cm, green to yellow to red. Inside the pericarp is the seed, elliptic, ovoid or oblong, 15–35 mm by 10–15 mm, brown with 2 unequal cotyledons and a thin testa. The seed is enveloped by the white, fleshy, juicy, sweet to acid-sweet, translucent sarcotesta 4–8 mm in thickness (Plates 4, 5, 6). The seed is recalcitrant losing its viability within 2 weeks.

Nutritive/Medicinal Properties

Analyses carried out in Australia reported fresh yellow-skinned rambutan fruit (minus the skin and seeds) to have the following proximate composition (per 100 g value) (Wills et al. 1986): water 79.2 g, energy 299 kJ, protein 1.1 g, fat



Plate 2 (a and b) Clusters of red-fruited rambutan cultivars cv Rongrein (*left*) and cv R 134 (*right*)



Plate 3 (a and b) Yellow-fruited rambutan cultivars cv R30 (*left*) and cv 165 (*right*)



Plate 4 Kelapa, a Sabah variety showing whole ripe fruits and fruit cross-section

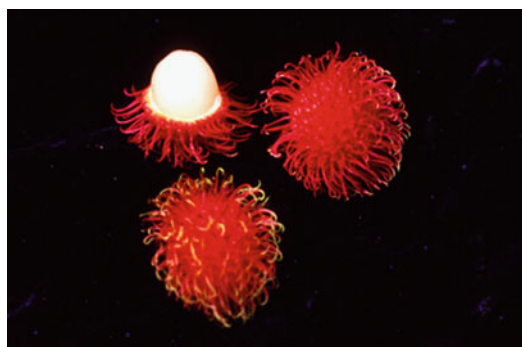


Plate 5 Rambutan fruit with edible white sarcotesta

0.40 g, glucose 2.7 g, fructose 3.0 g, sucrose 9.9 g, dietary fibre 2.9 g, malic acid 0.05 g, citric acid 0.37 g, ash 0.3 g, vitamin C 61 mg, thiamin 0.01 mg, riboflavin 0.07 mg, niacin 0.8 mg, Ca 8 mg, Fe 0.1 mg, Mg 10 mg, K 140 mg, Na 2 mg and Zn 0.6 mg. Tee et al. (1997) reported the fol-

lowing proximate composition for rambutan: energy 59 kcal, water 84.7 g, protein 0.7 g, fat 0.1 g, carbohydrate 13.9 g, fibre 0.3 g, ash 0.3 g, Ca 22 mg, P 6 mg, Fe 2.5 mg, Na 5 mg, K 49 mg, vitamin B-1 0.01 mg, vitamin B-2 0.04 mg, niacin 0.1 mg and vitamin C 38.6 mg. The edible



Plate 6 Rambutan edible sarcotesta with hairy pericarp removed

sarcotesta is rich in vitamin C and sugars and has a unique, faint and agreeable aroma and flavour. The ascorbic acid content of Hawaii-grown rambutan cultivars ranged from 22 to 47 mg/100 g (Wall 2006). Rambutan fruit (100 g) was also found to be a good source of Cu (20% of the DRI (Daily Recommended Intake)) and Mn (8–10% of the DRI). Copper content ranged from 0.16 to 0.20 mg/100 g, and Mn content ranged from 0.07 to 0.38 mg/100 g. Rambutan consumption was also found to meet 2–6% of the DRI for five minerals (P, K, Mg, Fe, Zn).

Of over 100 volatiles detected by GC/MS, twice as many polar volatiles were detected in the ethyl acetate extract of rambutan fruit as in the non-polar Freon extract (Ong et al. 1998). Over 60 compounds in the rambutan fruit extracts had been found to have some odour activity. The concentration of the most potent odorants (20) and contributors to the fruit aroma found in rambutan ($\mu\text{g/l}$ of juice) were: β -damascenone 2.27 μg , (E)-4,5-epoxy-(E)-2-decenal 14.92 μg , vanillin 21.10 μg , (E)-2-nonenal 7.03 μg , phenylacetic acid 131.67 μg , cinnamic acid 1340.15 μg , ethyl 2-methylbutyrate 15.13 μg , δ -decalactone 9.77 μg , 3-phenylpropionic acid 363.09 μg , 2,6-nonadienal 1.22 μg , fura-neol 240.15 μg , 2-phenylethanol 107.78 μg , *m*-cresol 5.65 μg , maltol 53.79 μg , heptanoic acid 30.43 μg , nonanal 51.90 μg , guaiacol 11.99 μg , (Z)-2-nonenal (not determined) and γ -nonalactone 29.43 μg . The exotic aroma character of rambutan

was the interaction of fruity sweet (β -damascenone, ethyl 2-methylbutyrate, fura-neol) and fatty-green (2-nonenal, nonanal, 2,6-nonadienal) notes, with sweaty (phenylacetic acid, heptanoic acid, unknown 1), woody [(E)-4,5-epoxy-(E)-2-decenal, lactones, vanillin], and spicy (cinnamic acid, guaiacol, etc.) notes contributing to the complexity of the flavour. Over 50 volatiles were identified, including alcohols, aldehydes, esters, ketones, terpenes, and other miscellaneous compounds that were not odour active. The non-odour active volatiles included: butyl acetate, δ -octalactone, ethyl crotonate, nonanoic acid, (E)-2-hexenal, 1,2,3-trimethoxybenzene, (E)-2-hexen-1-ol, farnesane, 1-hexanol, ethyl 3-hydroxyoctanoate, γ -butyrolactone, butyl benzoate, amyl acetate, decanoic acid, ethyl 3-hydroxybutyrate, tetradecane, benzaldehyde, *trans*-isoeugenol, ethyl 3-hydroxy-3-methylbutyrate, β -caryophyllene, ethyl hexanoate, methoxybenzene, benzyl alcohol, geranyl acetone, limonene, β -ionone, acetophenone, methyl vanillate, ethyl 2-hydroxycaporate, *o*-phenylphenol, camphor-L, ethyl 4-hydroxybenzoate, 2,3-dihydroxy-3,5-dihydroxy-6-methyl-4(H)-pyran-4-one, vanillic acid, benzyl acetate ethyl vanillate, octyl acetate, lauric acid, ethyl benzoate, lauryl acetate, (Z)-pyran linalool oxide, δ -undecalactone, nonyl alcohol, myristic acid, (E)-pyran linalool oxide, ethyl myristate, benzoic acid, palmitic acid, ethyl phenylacetate, ethyl palmitate and phenylethyl acetate.

Rambutan seed oil was found to contain 83% triglycerides and 17% cyanolipids comprising type III cyanolipids and 1-cyano-2-hydroxymethylprop-1-en-3-ol diesters. (Avato et al. 2006). Oleic and arachidic acids were the two dominant esterified fatty acyl chains in both triglycerides and cyanolipids. Eicosenoic acids (*cis*-vaccenic and paullinic acid) were present in higher amounts in the cyanolipid fraction of the oil.

Studies found that decorticated rambutan seeds comprised 6.1% of the wet weight fruit and contained 1.22% ash, 7.80% protein, 11.6% crude fibre, 46% carbohydrates, and 33.4% fat (dry basis) (Solís-Fuentes et al. 2010). The main fatty acids in the seed fat were 40.3% oleic, 34.5% arachidic, 6.1% palmitic, 7.1% stearic, 6.3% gondoic, and 2.9% behenic; the refraction,

saponification and iodine values were 1.468, 186, and 47.0, respectively. The phase behavior analysis exhibited relatively simple crystallization and melting profiles: crystallization showed three well-differentiated groups of triglycerides around maximum peaks at +30.8, +15.6 and -18.1°C; the fat-melting curve had a range between -14.5 and +51.8°C with a fusion enthalpy of 124.3 J/g. The thermal stability analyzed in an inert atmosphere of N₂ and in a normal oxidizing atmosphere, showed that in the latter, fat decomposition began at 237.3°C and concluded at 529°C, with three stages of decomposition. These results, suggested rambutan seed fat to have physico-chemical and thermal characteristics that may have interesting potential for specific applications in several segments of the food industry.

Antioxidant Activity

The antioxidant activity of the rambutan fruit was determined by free radical 1,1-diphenyl-2-picrylhydrazyl (DPPH) method with IC₅₀ = 21.1 mg/mL and phenolic compound content of 110.2 mg/100 g, compared to that reported for orange (*Citrus sinensis*) IC₅₀ = 18.3 mg/mL and phenolic compound content of 64.2 mg/mL (Franco 2006). The peel and seeds of rambutan were found to contain antioxidants. Higher amounts of phenolic compounds were found in the peel extracts than in the seed extracts and the highest content was in the methanolic fraction (542.2 mg/g dry extract) (Thitilertdech et al. 2008). The peel extracts exhibited higher antioxidant activity than the seed extracts in the methods used - reducing power, β-carotene bleaching, linoleic peroxidation and free radical scavenging activity. The methanolic fraction was found to be the most active antioxidant as shown by their 50% DPPH inhibition concentration of 4.94 µg/mL. The fraction exhibited greater DPPH radical scavenging activity than BHT and ascorbic acid (0.32 g dry extract/g BHT or ascorbic acid). This was also confirmed in another study wherein rambutan pericarp was found to have high phenolic content, low pro-oxidant capacity and strong antioxidant activity (Palanisamy et al. 2008).

Rambutan pericarp had a total phenolic content of 762 mg GAE/g extract, which was comparable to that of a commercial preparation of grape seed extract. Rambutan pericarp had the lowest pro-oxidant capacity compared to that of vitamin C, α-tocopherol, grape seed and green tea. In addition, the extract at 100 µg/mL was seen to limit oxidant-induced cell death (DPPH at 50 µM) by apoptosis to an extent similar to that of grape seed. The extracts were not cytotoxic to normal mouse fibroblast cells or splenocytes while the powdered pericarp was seen to have heavy metals contents far below the permissible levels for nutraceuticals. The results indicated that rambutan pericarp extract either alone or in combination with other active principles, can be used in cosmetic, nutraceutical and pharmaceutical applications. In a separate study, rambutan pericarp tissue was found to be rich in anthocyanins, a good source of natural antioxidants (Sun et al. 2011). The total anthocyanin content in the crude extract was about 181.3 mg/100 g of fresh pericarp tissues. Rambutan pericarp extracts were found to possess antioxidant activity as evaluated by assays of the reducing power, the activity against lipid peroxidation and the ability to scavenge 1,1-diphenyl-2-picrylhydrazyl (DPPH), superoxide anion and hydroxyl radicals. The results showed that rambutan pericarp can be utilized as health-beneficial compounds rather than just be discarded as agricultural waste. In a recent study the ethanol extract of *Nephelium lappaceum* peel, was found to have a lower prooxidant/antioxidant ratio (ProAntidex) than the commercially available Emblica™ extract, an antioxidant agent with very low pro-oxidant activity, indicating rambutan peel to have good free radical scavenging potential (Ling et al. 2010).

The methanolic extract of *N. lappaceum* peels exhibited strong antioxidant properties (Thitilertdech et al. 2010). The active components were identified as ellagic acid (EA) (1), corilagin (2) and geraniin (3). These compounds accounted for 69.3% of methanolic extract, with geraniin (56.8%) as the major component, and exhibited much greater antioxidant activities than BHT in both lipid peroxidation (77–186 fold) and DPPH• (42–87 fold) assays.

The results suggested that the isolated ellagitannins, as the principal components of rambutan peels, could be further utilized as both a medicine and in the food industry. In another study, the soluble phenolic content found in rambutan peels was 213.76 mg GAE/g DW (Sun et al. 2012). The free, soluble conjugate, and insoluble-bound phenolic compounds were fractionated, and the contents of 3 fractions were 185.12, 27.98 and 9.37 mg GAE/g DW, respectively. The contents of syringic acid and *p*-coumaric acid were high in the free fraction, showing 16.86 and 19.44 mg/g DW, and the soluble conjugate and insoluble-bound phenolics were mainly composed of gallic acid and caffeic acid. Antioxidant activities of 3 fractions evaluated in 5 model systems indicated that the free fraction had high antioxidant activities, compared with the soluble conjugate and insoluble-bound fractions.

Antihyperglycemic Activity

Ethanol extract of *N. lappaceum* pericarp was found to have antihyperglycemic activity (Palanisamy et al. 2011a, b). The pericarp apart from being a highly efficient antioxidant was shown to be effective in inhibiting carbohydrate hydrolysing enzymes and enzymes involved in the polypathway. It was shown to be effective in inhibiting the carbohydrate hydrolyzing enzymes, α -glucosidase (EC_{50} = 2.7 μ g/mL) and α -amylase (EC_{50} = 70.8 μ g/mL), at a much more significant level than the drug acarbose (EC_{50} = 3,500 μ g/mL; α -glucosidase; EC_{50} = 12 μ g/m; α -amylase). Geraniin an ellagitannin, was found to be the major active compound. Further to its extremely high antioxidant activity and low pro-oxidant capability, geraniin was found to possess in-vitro hypoglycemic activity (α -glucosidase inhibition, IC_{50} = 0.92 μ g/mL and α -amylase inhibition, IC_{50} = 0.93 μ g/mL), aldol reductase inhibition activity (IC_{50} = 7 μ g/mL) and has the ability to prevent the formation of advanced glycation end products by 43%. Geraniin exerted these activities at more significant levels compared to positive controls acarbose (carbohydrate hydrolysis inhibitor) quercetin (aldol reductase inhibitor)

and green tea (AGE inhibitor). The results indicated geraniin-standardised rmbatuna pericarp to have the potential to be developed into an antihyperglycemic agent.

Antiviral Activity

Among 16 plants screened for anti-HSV-2 (Herpes Simplex Virus-2) activity, 3 plant extracts namely *Barleria lupulina* (leaves), *Clinacanthus siamensis* (leaves) and *Nephelium lappaceum* (pericarp) exhibited the highest anti-HSV-2 activities with 50% inhibitory concentration (IC_{50}) less than 20 μ g/mL and a potent antiviral activity with selectivity index (SI) more than 10 (Wirotasangthong and Rattanakit 2006). Further studies showed that drug-resistant mutants of HSV-1 to either acyclovir (ACV) or foscarnet (FOS), HSV-1 KOS (wild-type) strain were also sensitive to the 3 plant extracts. (IC_{50} < 31.25 μ g/mL for *B. lupulina*, < 62.5 μ g/mL for *C. siamensis* (leaves) and < 31.25 μ g/mL for *N. lappaceum*). The results suggested that all 3 plant extracts would be useful for the alternative therapy of Herpes Simplex Virus infections (Wirotasangthong et al. 2007). Methanol extract of the pericarp of *Nephelium lappaceum* was also reported to significantly prolong the development of skin lesions caused by herpes simplex virus (HSV) type 1 (HSV-1) (Nawawi et al. 1999).

Antimicrobial Activity

Rambutan peel extract displayed antibacterial activity against five pathogenic bacteria (Thitilertdecha et al. 2008). The most sensitive strain, *Staphylococcus epidermidis*, was inhibited by the methanolic extract (MIC 2.0 mg/mL). In another study, dichloromethane extracts of the seeds of *Nephelium lappaceum* afforded two new diastereomeric monoterpene lactones, 1 and 2, and the known butenolide siphonodin (3), as well as kaempferol 3-O- β -D-glucopyranoside-7-O- α -L-rhamnopyranoside. Compounds 1 and 2 exhibited antimicrobial activity (Ragasa et al. 2005).

Anticancer Activity

Ethanol extract of rambutan peel was found to have marked in-vitro activity against human osteosarcoma cancer cells and had no effect on normal cells (Wan Nur Hidayat et al. 2011). The results indicated that the extract induced G2/M arrest via inhibition of cancer cell cycle progression.

Antiobesity Activity

Ten compounds (1-10) comprising mainly flavonoids and olean-type triterpene oligoglycosides, were isolated from rambutan pericarp (Zhao et al. 2011). Compounds 8 and 9 were new hederagenin derivatives and were elucidated as hederagenin 3-O-(2,3-di-O-acetyl- α -l-arabinofuranosyl)-(1 $\rightarrow$ 3)-[α -l-rhamnopyranosyl(1 $\rightarrow$ 2)]- β -l-arabinopyranoside and hederagenin 3-O-(3-O-acetyl- α -l-arabinofuranosyl)-(1 $\rightarrow$ 3)-[α -l-rhamnopyranosyl(1 $\rightarrow$ 2)]- β -l-arabinopyranoside, respectively. All the compounds exhibited inhibitory activity against fatty acid synthase (FAS) with IC₅₀ values ranging from 6.69 to 204.40 μ M, comparable to the known FAS inhibitor EGCG (IC₅₀=51.97 μ M). The study indicated that rambutan pericarp could be considered as potential sources of promising FAS inhibitors and the olean-type triterpene oligoglycosides could be considered as another type of natural FAS inhibitors.

Traditional Medicinal Uses

The edible pulp (sarcotesta) is used as a refrigerant in fevers in folkloric medicine. The fruit (perhaps unripe) is astringent, stomachic; acts as a vermifuge, febrifuge, and is taken to relieve diarrhea and dysentery in traditional medicine. The leaves are poulticed on the temples to alleviate headache. The astringent bark decoction is a remedy for thrush. A decoction of the roots is taken as a febrifuge. In Malaysia, the roots were used in a decoction for treating fever; the leaves for poulticing and the bark for an astringent for tongue diseases. The seeds were said to be bitter and nar-

cotic. In China, the fruit is recommended for severe dysentery and as a warm carminative in "cold" dyspepsia. In Java, the dried fruit rind is sold in drugstores and employed in local medicine.

Other Uses

Young shoots are used to produce a green colour on silk that is first dyed yellow with turmeric. The fruit dye is one of the ingredients used in *air banyar* to dye silk a black colour. The seed kernel yields 37–43% of a solid, white fat or tallow resembling cacao butter at ordinary temperature. When heated, it becomes a yellow oil having a pleasant scent. Its fatty acids are: palmitic, 2.0%; stearic, 13.8%; arachidic, 34.7%; oleic, 45.3%; and ericosenoic, 4.2%. Fully saturated glycerides amount to 1.4%. The oil could be used in making soap and candles. The wood is red, reddish-white, or brownish. It is hard and heavy and suitable for many purposes and general construction though it is susceptible to splitting unless properly dried.

Comments

Three botanical varieties have been recognised by Leenhouts (1986) based on the leaflet characteristics:

var. *lappaceum* Leenh. – leaflets relatively broad, widest above the middles, sides mostly curved, apex usually not acuminate, mid rib beneath sparsely pilose, lower surface not glaucous, nerves widely spreading and strongly curved; commonly cultivated and known commonly as rambutan.

var. *pallens* (Hiern) Leenh. – leaflets narrow, 3–4 cm wide, up to 4.5 times as long as wide, with slightly curved to straight or parallel sides, mid-rib beneath often glabrous, veins and veinlets reticulate to scalariform.

var. *xanthoides* (Radlk.) Leenh. – leaflets up to 10 cm wide, no more than 3.5 times as long as wide, sides curved, midrib beneath densely tomentellous, veins distinctly scalariform.

Rambutan have been traded under numerous named commercial clonal cultivars. Being out-breeders rambutan trees developed from seeds are rather heterogenous and heterozygous and are too variable for commercial purposes. Clonal varieties/cultivars are developed through vegetative propagation methods and are true to type and genetically more uniform. Malaysia way back in 1932 established a systematic program to register all clonal planting materials of various popular fruit trees with the Department of Agriculture and in the case of rambutan, recognised clonal cultivars were given accession numbers preceded by the alphabet R. There are now close to 200 such cultivars/varieties for rambutan registered. Some popular rambutan clonal cultivars recommended in Malaysia include R3 (Gula batu), R9, R 99, R 134, R156 (Muar Gading), R160 (Khaw Tow Bak), R161 (Lee Long), R162 (Daun Hijau), R163, R170 (Deli Cheng), R172 (Taiping 1), R178 (Taiping 7) and R186 (Titi Teras). Indonesian has about 30 recognised commercial varieties and the most popular are 'Binjai', Rapih, 'Simacan', 'Lebak bulus' and 'Sinyonya'. Popular commercial varieties in Thailand include 'Seechompoo', 'Rongrien', 'Bangyeekhan', 'Seetongchoke', 'Namtangruad' and 'Jemong'. Recognised name varieties in the Philippines introduced from Indonesia include 'Seematjan', 'Seenjonja' and 'Maharlika'. Singapore has 'Deli Cheng' and 'Jitlee'.

Selected References

- Adema F, Leenhouts PW, van Welzen PC (1994) Sapindaceae. Flora Malesiana, ser 1, 11, Part 3. Noordhoff-Kolff, Djakarta, pp 419–768
- Almeyda N, Malo SE, Martin FW (1979) Cultivation of neglected tropical fruits with promise, Part 6. The Rambutan. USDA Science and Administration, 14 pp
- Avato P, Rosito I, Papadia P, Fanizzi FP (2006) Characterization of seed oil components from *Nephelium lappaceum* L. Nat Prod Commun 1(9):751–755
- Backer CA, Bakhuizen van den Brink RC Jr (1965) Flora of Java, vol 2. Wolters-Noordhoff, Groningen, 630 pp
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula. Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Corner EJH (1952) Wayside trees of Malaya. GPO, Singapore, Malaya, 772 pp
- Franco EM (2006) Actividad antioxidante in vitro de las bebidas de frutas. Bebidas -Alfa Editores Técnicos, Junio/Julio:20–27 (In Spanish)
- Hu SY (2005) Food plants of China. The Chinese University Press, Hong Kong, 844 pp
- Lam PF, Kosiyachinda S (eds) (1987) Rambutan: fruit development, Postharvest physiology and marketing in ASEAN. ASEAN Food Handling Bureau, Kuala Lumpur, 82 pp
- Leenhouts PW (1986) A taxonomic revision of *Nephelium* (Sapindaceae). Blumea 31:373–436
- Lim TK (1992) The rambutan industry in the Northern Territory – current status, research and development emphasis. Acta Hort 321:62–70
- Lim TK, Diczbalis Y (1998) Rambutan. In: Hyde K (ed) The new rural industries – a handbook for farmers and investors. Rural Industries Research & Development Corporation, Canberra, pp 306–313
- Lim TK, Luders L, Diczbalis Y, Poffley M (1997) Rambutan nutrient requirement and management. Dept Pri Ind Fish Northern Territory Tech. Bull. No. 261
- Ling LT, Palanisamy UD, Cheng HM (2010) Prooxidant/antioxidant ratio (ProAntidex) as a better index of net free radical scavenging potential. Molecules 15(11):7884–7892
- Morton JF (1987) Rambutan. In: Fruits of warm climates. Julia F. Morton, Miami, pp 262–265
- Nawawi A, Nakamura N, Hattori M, Kurokawa M, Shiraki K (1999) Inhibitory effects of Indonesian medicinal plants on the infection of herpes simplex virus type 1. Phytother Res 13(1):37–41
- Ochse JJ, van den Bakhuizen BRC (1931) Fruits and fruit-culture in the Dutch East Indies. G. Kolff & Co, Batavia-C, 180 pp
- Ong PKC, Acree TE, Lavin EH (1998) Characterization of volatiles in rambutan fruit (*Nephelium lappaceum* L.). J Agric Food Chem 46(2):611–615
- Palanisamy U, Cheng HM, Masilamani T, Subramaniam T, Lai TL, Radhakrishnan AK (2008) Rind of the rambutan, *Nephelium lappaceum*, a potential source of natural antioxidants. Food Chem 109(1):54–63
- Palanisamy UD, Ling LT, Manaharan T, Appleton D (2011a) Rapid isolation of geraniin from *Nephelium lappaceum* rind waste and its anti-hyperglycemic activity. Food Chem 127(1):21–27
- Palanisamy UD, Manaharan T, Ling LT, Radhakrishnan AKC, Subramaniam T, Masilamani T (2011b) Rambutan rind in the management of hyperglycemia. Food Res Int 44(7):2278–2282
- Ragasa CY, De Luna RD, Cruz WC, Rideout JA (2005) Monoterpene lactones from the seeds of *Nephelium lappaceum*. J Nat Prod 68(9):1394–1396
- Solís-Fuentes JA, Camey-Ortiz G, Hernández-Medel MDR, Pérez-Mendoza F, Durán-de-Bazúa C (2010) Composition, phase behavior and thermal stability of natural edible fat from rambutan (*Nephelium lappaceum* L.) seed. Biores Technol 101(2):799–803

- Subhadrabanhdu S (2001) Under utilized tropical fruits of Thailand. FAO Rap publication 2001/26, 70 pp
- Sun J, Peng H, Su W, Yao J, Long X, Wang J (2011) Anthocyanins extracted from rambutan (*Nephelium lappaceum* L.) pericarp tissues as potential natural antioxidants. J Food Biochem 35:1461–1467
- Sun L, Zhang H, Zhuang Y (2012) Preparation of free, soluble conjugate, and insoluble-bound phenolic compounds from peels of rambutan (*Nephelium lappaceum*) and evaluation of antioxidant activities in vitro. J Food Sci 77:C198–C204
- Tee ES, Noor MI, Azudin MN, Idris K (1997) Nutrient composition of Malaysian foods, 4th edn. Institute for Medical Research, Kuala Lumpur, 299 pp
- Thitilertdecha N, Teerawutgulrag A, Rakariyatham N (2008) Antioxidant and antibacterial activities of *Nephelium lappaceum* L. extracts. LWT – Food. Part Sci Technol 4(10):2029–2035
- Thitilertdecha N, Teerawutgulrag A, Kilburn JD, Rakariyatham N (2010) Identification of major phenolic compounds from *Nephelium lappaceum* L. and their antioxidant activities. Molecules 15:1453–1465
- Valmayor RV, Valmayor HL, Gonzalez LG (1961) Rambutan varieties and culture. Coll Agric Univ Philipp Technol Bull 7:11–15
- Valmayor RV, Mendoza DB, Aycardo HB, Palencia CO (1968) Growth and flowering habits, floral biology and yield of rambutan (*Nephelium lappaceum* Linn.). Coll Agric Univ Philipp Cent Exp Stat Contrib 3177:359–373
- Van Welzen PC, Verheij EWM (1992) *Nephelium lappaceum* L. In: Verheij EWM, Coronel RE (eds) Plant resources of South-East Asia No. 2. Edible fruits and nuts. Prosea, Bogor, pp 235–240
- Wall M (2006) Ascorbic acid and mineral composition of longan (*Dimocarpus longan*), lychee (*Litchi chinensis*) and rambutan (*Nephelium lappaceum*) cultivars grown in Hawaii. J Food Comp Anal 19(6–7):655–663
- Wan Nur Hidayat WS, Ridhwan AW, Azamn S (2011) Promising effect of *Nephelium lappaceum* rind extract as cancer chemopreventive agent through apoptosis and cell cycle arrest mechanisms on human osteosarcoma cells. In: Proceedings of Universiti Malaysia Terengganu 10th international annual symposium UMTAS 2011: Empowering Science, Technology and Innovation Towards a Better Tomorrow, pp 163–169
- Wills RBH, Lim JSK, Greenfield H (1986) Composition of Australian foods. 31. Tropical and sub-tropical fruit. Food Technol Aust 38(3):118–23
- Wirotasangthong M, Rattanakiat S (2006) Anti-Herpes simplex virus type 2 activities of some Thai medicinal plants. Thai J Pharmaceut Sci 30(1–2):19–27
- Wirotasangthong M, Rattanakiat S, Matsui K, Lipipun V (2007) Characterization of herpes simplex virus type 1 selected in culture for resistance to acyclovir or foscarnet. Thai J Pharmaceut Sci 31(1–2):36–44
- Wong KC, Wong SN, Loi HK, Lim CL (1996) Volatile constituents from the fruits of four edible Sapindaceae: rambutan (*Nephelium lappaceum* L.), pulasan (*N. ramboutan-ake* (Labill.) Leenh.), longan (*Dimocarpus longan* Lour.), and mata kucing (*D. longan* ssp. *male-sianus* Leenh.). Flav Fragr J 11(4):223–229
- Yap SK (1989) Sapindaceae. In: Ng FSP (ed) Tree flora of Malaya, vol 4. Longman, Selangor, pp 434–461
- Zhao YX, Liang WJ, Fan HJ, Ma QY, Tian WX, Dai HF, Jiang HZ, Li N, Ma XF (2011) Fatty acid synthase inhibitors from the hulls of *Nephelium lappaceum* L. Carbohydr Res 346(11):1302–1306

Nephelium maingayi

Scientific Name

Nephelium maingayi Hiern.

Synonyms

Nephelium glabrum auct. non Norona, *Nephelium lappaceum* var. *maingayi* (Hiern) Valet.

Family

Sapindaceae

Common/English Names

Hairless Rambutan, Nude Rambutan.

Vernacular Names

Indonesia: Buah Unjing, Penjaih, Ridan (Sumatra), Duku, Katiau, Puda (Kalimantan); **Malaysia:** Buah Raydun, Kedin, Redan, Redan Tumu, Ronjo (Peninsular), Serait (Malay, Sarawak), Mujau, Serait (Iban, Sarawak), Buah Sungkit (Sabah).

Origin/Distribution

The species is native to Peninsular Malaysia, Sumatra and Borneo (throughout the island).

Agroecology

In its native range, the species occurs in undisturbed mixed dipterocarp, (peat)-swamp and sub-montane forests up to 1,600 m altitude, mainly in alluvial (swamps) sites and alongside rivers and streams. It occurs also in secondary forests usually present as a pre-disturbance remnant.

Edible Plant Parts and Uses

The sarcotesta of ripe fruit is eaten fresh after removing the pericarp.

Botany

A mid-canopy tree, reaching 40 m high with a trunk diameter of 90 cm, sometimes buttress up as high as 1.40 m. Leaves alternate, compound, 3–5 pairs of leaflet, petiole 10 cm. Leaflets elliptic to obovate, 5.75–22 cm long by 3–9 cm wide,



Plate 1 Ripe serait fruits (Kueh, HS)



Plate 2 Ripe seriat fruit with pericarp removed (Kueh, HS)



Plate 3 Ripe seriat fruit with thin pericarp and translucent juicy sarcotesta (Kueh, HS)

penni-veined, glabrous, venation strongly reticulate, petiolule 4–17.5 mm. Inflorescence axillary to terminal panicles, flowers apetalous, greenish-yellow, 2 mm across, stamens 4–6, pistil 1. Fruit ellipsoid 3 cm by 1.6 cm with a persistent style,

pericarp glabrous to slightly warty, thin, red to brown, green turning to yellow, orange and brilliant red when ripe (Plates 1–3). Sarcotesta translucent-white, juicy, acid to sweet (Plate 3), seed flattened ovoid, large.

Nutritive/Medicinal Properties

The nutrient composition of the fruit sarcotesta per 100 g edible portion was reported as: moisture 64.4 %, protein 3.5 g DW, 9.9 g DW, fat 12.8 g, carbohydrate 15.5 g, fibre 1.8 g, ash 0.9 g, P 53 mg, K 283 mg, Ca 104 mg, Mg 46 mg, Fe 22 µg, Mn 7 µg, Cu 3.6 µg, Zn 19.1 µg and vitamin C 2 mg (Voon et al. 1988; Voon and Kueh 1999).

Six saponins designated the trivial names nepheliosides I–VI were isolated from the bark of *Nephelium maingayi* (Ito et al. 2004). Nephelioside I was elucidated as erythrodiol 3-O-[α-L-arabinopyranosyl-(1 → 3)]-β-D-glucopyranosyl-(1 → 2)-β-D-xylopyranoside; nephelioside II as erythrodiol 3-O-[α-L-arabinopyranosyl-(1 → 3)]-β-D-glucopyranosyl-(1 → 2)-β-D-glucopyranoside; nephelioside III as erythrodiol 3-O-(6"-acetyl)-β-D-glucopyranosyl-(3 → 1)-β-D-xylopyranoside; nephelioside IV as 7α-methoxyerythrodiol 3-O-[α-L-arabinopyranosyl-(1 → 3)]-β-D-glucopyranosyl-(1 → 2)-β-D-glucopyranoside; nephelioside V as maniladiol 3-O-[α-L-arabinopyranosyl-(1 → 3)]-β-D-xylopyranoside and nephelioside VI as maniladiol 3-O-[α-L-arabinopyranosyl-(1 → 3)]-β-D-glucopyranosyl-(1 → 2)-β-D-glucopyranoside. Nephelioside 5 exhibited weak cytotoxic effect against Lu1 (human lung cancer) LNCap (hormone-dependent prostate cancer), MCF-7 (breast adenocarcinoma) and HUVEC (human umbilical vein endothelial) cell lines. Nephelioside 1 exhibited weak response against Lu1. All other compounds were inactive.

Other Uses

The wood has no commercial significance and is used for firewood.

Comments

The species is propagated from seeds or by various asexual modes of grafting.

Selected References

- Ito A, Chai HB, Kardono LB, Setowati FM, Afriastini JJ, Riswan S, Farnsworth NR, Cordell GA, Pezzuto JM, Swanson SM, Kinghorn AD (2004) Saponins from the bark of *Nephelium maingayi*. *J Nat Prod* 67(2):201–205
- Leenhouts PW (1986) A taxonomic revision of *Nephelium* (Sapindaceae). *Blumea* 31:373–436
- Saw LG, LaFrankie JV, Kochummen KM, Yap SK (1991) Fruit trees in a Malaysian rain forest. *Econ Bot* 45(1):120–136
- Slik JWF (2006) Trees of Sungai Wain. Nationaal Herbarium Nederland. <http://www.nationaalherbarium.nl/sungaiwain/>
- Uji T (1998) *Nephelium* L. In: Sosef MSM, Hong LT, Prawirohatmodjo S (eds) Plant resources of South-East Asia No 5(3), Timber trees: lesser known timbers. Prosea Foundation, Bogor, pp 404–406
- Voon BH, Kueh HS (1999) The nutritional value of indigenous fruits and vegetables in Sarawak. *Asia Pac J Clin Nutr* 8(1):24–31
- Voon BH, Chin TH, Sim CY, Sabariah P (1988) Wild fruits and vegetables in Sarawak. Sarawak Department of Agriculture, 114 pp

Nephelium ramboutan-ake

Scientific Name

Nephelium ramboutan-ake (Labill.) Leenh.

Synonyms

Euphoria longana Blume, *Euphoria ramboutan-ake* Labill., *Litchi ramboutan-ake* Labill. ex DC., *Nephelium intermedium* Radlk. ex Perkins, *Nephelium mutabile* Blume, *Nephelium mutabile* (Labill.) Leenh., *Nephelium pallens* Radlk., *Nephelium philippense* Monsalud et al.

Family

Sapindaceae

Common/English Names

Meritam, Pulasan.

Vernacular/Local Names

Burmese: Kyetmauk;
Dutch: Kapoelasan;
French: Kapulasan;
Indonesia: Rambutan Ake, Rambutan Babat, Sebatat, (Java), Tenggarang (Kalimantan Tengah), Pulasan, Kapulasan, (Sundanese), Tukou Biawak (Kubu), Molaitomo (Gorontalo), Mulitan (Toli-Toli);

Japanese: Purasan;

Malaysia: Pulasan, Rambutan Paroh, Rambutan Kafri, (Peninsular Malaysia), Longitan (Dusun, Sabah), Meritam (Kedayan, Sabah) Rambutan Hutan (Malay, Sabah), Buah Mua, Buah Ma, Melanjan, Mujan, Pudun (Iban, Sarawak), Meritam (Sarawak);
Philippines: Malapution (Samar-Leyte Bisaya), Karayo, Bulala (Tagalog);

Singapore: Pulasan;

Spanish: Pulasán;

Thai: Amaw, Ngoh Khon San, Ugan.

Origin/Distribution

The species is found in India, Indo-China, Myanmar, Thailand, Peninsular Malaysia, Borneo, Java and Sumatra. The centre of diversity appears to be in Peninsular Malaysia and Borneo. Wild trees of pulasan can be found in the lowland forests of Peninsular Malaysia as well as in Sabah and Sarawak. Pulasan and rambutan or their progenitors were believed to be evolved in the Sunda-shelf at the time when there was one tract of rain-forest connecting Malaya, Borneo, Sumatra and Java (Corner 1952). It is grown throughout southeast Asia and Assam (India).

Agroecology

Pulasan is a tropical species that grows well in areas with high humidity of 80% or more, with high temperatures from 24 to 35°C and with

heavy rainfall about 2,000–5,000 mm annually. However, a short dry period is necessary to stimulate flowering. Temperatures below 20°C can cause retardation in growth and below 15°C can cause defoliation. Pulasan is most commonly grown within 12° from the equator. It can be found from near sea level up to 1,100 m altitude.

In its native environment, pulasan occurs mostly in lowland primary tropical, mixed Dipterocarp forests, sometimes on river banks, usually on alluvial soils and also on sand or clay. Pulasan thrives best in deep, rich, well-drained, sandy loams or clay loam, with high organic matter content but more rarely on shale, basalt or limestone. A pH range of 4.5–6.5 is ideal. Supplementary irrigation from flower set to harvest will result in high yield as water stress during flower and fruit development leads to small fruit size and premature ripening with thin sarcotesta.

Edible Plant Parts and Uses

Pulasan fruits are usually consumed fresh, the juicy, sweet, fleshy sarcotesta (pulp) is eaten. The sarcotesta can also be frozen used in ice cream and puddings or dried. It can also be made into preserves, jams, jellies and sauces. Usually fruits that are sour with sarcotesta adherent to the seeds are usually used into making jams, jellies or pickles. Pulasan can also be used in tropical juice blends. Similar to rambutan, the flesh can also be canned in heavy syrup or in mixed cocktails. Seeds can be eaten raw and tastes like nuts but are usually boiled or roasted. Seeds are used also to prepare a cocoa-like beverage. The dried seed kernels can produce a faintly sweet fragrant oil or cocoa-butter which is suitable for use in food in various ways.

Botany

A medium-sized, evergreen, dioecious tree, growing to 10 m– 16 m – (30)m tall with a trunk diameter of 20 cm and smooth brown bark becoming rough with age. The canopy is dense,



Plate 1 Cluster of juvenile pulasan fruits



Plate 2 Matured Yellow-green fruited pulasan and leaves

sub-spherical to irregular. Leaves are pinnate with 1–5 pairs of leaflets, petiole 3–9 cm long, petiolules 2–4 mm. Leaflets are opposite to sub-opposite, lanceolate, elliptic to obovate, 7.5–13.5 cm by 2.5–4.5 cm, apex acuminate, bases acute to obtuse, upper surface glabrous, waxy and green, lower surface glaucous and paler green (Plates 1 and 2). Inflorescences are axillary or



Plate 3 Ripe yellow-green fruited pulasan variety



Plate 6 Red-fruited pulasan with thick pericarp and white sarcotesta



Plate 4 Young and maturing red fruited pulasan



Plate 5 Ripe red-fruited pulasan



Plate 7 Reddish-black fruited pulasan

pseudoterminal, 17–37 cm long, consisting of hundreds of small, sweet scented flowers. Flowers are apetalous, with yellowish sepals connate at base. Male flowers have 5–8 stamens. Hermaphrodite flowers have 5–8 stamens and 1-2-merous ovary. Female flowers are sweetly

scented and have staminodes and similar ovaries. Fruit is globose, ovoid or ellipsoid, 4.0–8.0 cm by 3.0–6.8 cm; pericarp coriaceous, 4–9 mm thick, coarsely hairy with short, stout bulbous-based spineterns, 3–9 mm long, imparting a warty appearance. Depending on varieties, the pericarp



Plate 8 Reddish- black fruited pulasan with thick pericarp and edible sarcotesta



Plate 9 Black-fruited pulasan with juicy, translucent sarcotesta

varies from yellow-green to yellow, dark red, purplish red, blackish-red to almost black in colour (Plates 2–9). The thickness of the sarcotesta (edible flesh) ranges from 0.3 to 2.2 cm thick, translucent white, either soft, firm or crispy in texture and juicy (Plates 6, 8, 9). The sarcotesta tastes sweet, acidic-sweet or sour. The sarcotesta is cling-stone that is adherent to the seed or free-stone detaches easily from the seed. Seeds are ovoid, ellipsoid or elongated, covered with two layers of testa and consist of two unequal cotyledons.

Nutritive/Medicinal Properties

The nutrient value of the pulasan sarcotesta per 100 g edible portion was reported as: water 84.5–90.8 g, protein 0.82 g, fat 0.55 g, carbohydrate 12.86 g, fibre 0.14 g, Ca 0.01–0.05 mg and Fe

0.02 mg (Pareek et al. 1998). Tee et al. (1997) reported the following nutrient composition per 100 g edible portion: energy 71 kcal, water 81.2 g, protein 0.9 g, fat 0.1 g, carbohydrate 16.6 g, fibre 0.5 g, ash 0.7 g, Ca 54 mg, P 9 mg, Fe 0.1 g, Na 6 mg, K 94 mg, vitamin B-1 0.02 mg, vitamin B-2 0.05 mg, niacin 0.2 mg and vitamin C 10.8 mg. In another analysis, the fruit of pulasan was reported to contain per 100 g edible portion: water 85 g, protein 0.8 g, fat 0.6 g, carbohydrates 13 g, fibre 0.1 g and ash 0.4 g (Subhadrabanhdu 2001).

Pulasan fruit also contains other volatile flavour compounds mainly aliphatic hydrocarbons (70.2%), particularly pentadecane (61.4%), and aliphatic alcohols (19.4%) (Wong et al. 1996).

Aqueous leaf extract of pulasan was found to have a very low prooxidant/antioxidant ratio (ProAntidex) of 0.05 compared to 0.69 for Emblica™, an antioxidant agent indicating pulaskan leaf to have high net free radical scavenging activity potential (Ling et al. 2010).

In traditional medicine, the root decoction is used as an antihelmintic, antipyretic and a vermifuge for fever. The roots may also be boiled with *Gleichenia* fern and used for bathing fever patients. The leaves and roots may be used as a poultice.

Other Uses

The sapwood is lighter in colour and is moderately sharply defined from the heartwood, which is red brown to light purple brown. The wood is harder and heavier than that of rambutan and can be used for various purposes but rarely available. The seed oil is also used as an illuminant.

Comments

There are several natural varieties of meritam with at least four found in Borneo. These include green, yellow, dark red and purple-black types. There is also a variety from Peninsular Malaysia that bears large sized fruit. Some recognized

common clonal varieties of Pulasan in Malaysia include P1 (Klang No 1), P2 (Klang No 2), P8, P54 and P64.

Selected References

- Adema F, Leenhouts PW, van Welzen PC (1994) Sapindaceae. Flora Malesiana, Ser 1 11, Part 3. Noordhoff-Kolff, Djakarta, pp 419–768
- Backer CA., Bakhuizen RC, van den Brink Jr (1965) Flora of Java, vol 2. Wolters-Noordhoff, Groningen, 630 pp
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula, Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Corner EJH (1952) Wayside trees of Malaya. Government Printing Office, Singapore, Malaya, 772 pp
- Leenhouts PW (1986) A taxonomic revision of *Nephelium* (Sapindaceae). Blumea 31:373–436
- Ling LT, Palanisamy UD, Cheng HM (2010) Prooxidant/antioxidant ratio (ProAntidex) as a better index of net free radical scavenging potential. Molecules 15(11):7884–7892
- Pareek OP, Sharma S, Arora RK (1998) Underutilized edible fruits and nuts: an inventory of genetic resources in their regions of diversity. IPGRI Office for South Asia, New Delhi, pp 191–206
- Seibert B (1992) *Nephelium* L. In: Coronel RE, Verheij EWM (eds) Plant resources of South-East Asia. No. 2: edible fruits and nuts. Prosea Foundation, Bogor, pp 233–235
- Slik JWF (2006) Trees of Sungai Wain. Nationaal Herbarium Nederland. <http://www.nationaalherbarium.nl/sungaiwain/>
- Subhadrabanhdu S (2001) Under utilized tropical fruits of Thailand. FAO Rap publication 2001/26, 70 pp
- Tee ES, Noor MI, Azudin MN, Idris K (1997) Nutrient composition of Malaysian foods, 4th edn. Institute for Medical Research, Kuala Lumpur, 299 pp
- Uji T (1998) Prawirohatmodjo, S. In: Sosef MSM (ed) Plant resources of South-East Asia. No. 5(3). Timber trees: lesser-known timbers. Prosea Foundation, Bogor, pp 404–406
- Wong KC, Wong SN, Loi HK, Lim CL (1996) Volatile constituents from the fruits of four edible Sapindaceae: Rambutan (*Nephelium lappaceum* L.), Pulasan (*N. ramboutan-ake* (Labill.) Leenh.), Longan (*Dimocarpus longan* Lour.), and Mata Kucing (*D. longan* ssp. *malesianus* Leenh.). Flavour Fragrance J 11(4):223–229
- Yap SK (1989) Sapindaceae. In: Ng FSP (ed) Tree flora of Malaya, vol 4. Longman, Selangor, pp 434–461

Paullinia cupana

Scientific Name

Paullinia cupana Kunth.

Polish: Guarana;

Spanish: Cupana, Guaraná;

Venezuela: Cupana.

Synonyms

Paulinnia sorbilis Mart.

Family

Sapindaceae

Common/English Names

Brazilian Cocoa, Guarana.

Vernacular Names

Brazil: Guaraná, Guaraná-Sipo, Guaraná-Uva, Urana (**Portuguese**);

Danish: Guarana;

Dutch: Guarana;

Eastonian: Guaraana-Pauliinia;

French: Guarana, Guarane;

German: Guarana, Guaraná-Liane;

Hungarian: Brazil Ajzólán, Guarana, Guaraná(Lián);

Italian: Guaranà;

Peru: Cupana;

Origin/Distribution

The species is indigenous to the Amazon basin. The var. *cupana* is found in the area between the south of the Atures and Maipures torrents of the Orinoco River and in the region of the upper Negro River and tributaries on the frontiers between Brazil, Colombia and Venezuela, where it seems to be relatively common (Lleras 1994). The var. *sorbilis* or true guarana, seems to have been domesticated in the southern strip of the Amazon River between the gorges of the Purús and Madeira Rivers. Guarana plants are commercially cultivated exclusively in Brazil to supply the national carbonated soft-drink industry and natural product stores around the world.

Agroecology

In its native range, the temperature is isothermal, with an annual mean of 28–29°C. The minimum temperature tolerated is 12°C. The mean annual precipitation is approximately 2,000 to 2,200 mm, well-distributed throughout the year. The soils in which it is found in the native state are generally gley soils or dystrophic lateritic soils with low pH (3.5–4.5).

Edible Plant Parts and Uses

In the last two decades or so, guaraná a caffeine rich fruit, has emerged as a key ingredient in various ‘sports’ and energy drinks as well as concoctions that allegedly boost one’s libido (Smith and Atroch 2010). Guaraná has long been used as a tonic and to treat various disorders in Brazil and abroad and became a national soda in Brazil about a century ago. As a dietary supplement, guarana is an effective stimulant it contains about twice the caffeine found in coffee beans. Generally, South America obtains most of its caffeine from guarana. Guarana is marketed as sticks and soluble or insoluble powder, capsules and is used industrially for the production of sweetened or carbonated soft drinks, syrups, energy shots, an ingredient of herbal tea and other herbalists’ products. Brazilian sales of guarana beverages exceed those of cola drinks. In Peru, Guaraná is a Peruvian brand of soft drink containing guarana fruit, owned by Backus and Johnston.

Botany

Guarana is a scandent shrub or woody evergreen liana with arching woody, longitudinally-furrowed stem climbing up tree trunks for support reaching high into the forest canopy but under cultivation growing to 2 m high. Its leaves are alternate, pinnately compound with 5 glabrous, shiny leaflets (Plate 1) and, when tendrils exist, they are axillary. The inflorescences (Plate 2) are on axillary racemes or originate on the tendrils. The flowers are male and female, zygomorphic and have five petals and sepals, eight stamens and a trilocular ovary with a glandular semi-disc at the base. The fruit is a septicidal capsule, green turning orangey-red (Plates 3–5) and partially open when ripe, revealing one to three black or greenish seeds which are covered at the base with a farinaceous white aril.

The var. *cupana* differs from the var. *sorbilis* in that it has no tendrils, its leaflets are more strongly lobed and its flowers and fruit are bigger.



Plate 1 Pinnate compound leaf with five leaflets



Plate 2 Inflorescence with flower buds



Plate 3 Very young fruits

Nutritive/Medicinal Properties

Guarana seeds were reported to contain 2.7–5.8% caffeine as well as theophylline and theobromine (Lleras 1994; Henman 1982; Duke 1992, 1994), tannins, resins, tetramethylxanthine, starch, xanthine and traces of the saponin, timbonine



Plate 4 Cluster of ripening fruits



Plate 5 Close-up of ripening fruits

(Henman 1982; Duke 1992, 1994), adenine, catehutannic acid, choline, D-catechin, fat, ash, guanine, hypoxanthine, mucilage, protein (Duke 1992, 1994). Caffeine was the major xanthine found in guarana seeds while theobromine and theophylline were present in small amounts but the presence of a tetramethylxanthine was not detected (Bempong et al. 1993). Guarana seeds contained 2–4.5% caffeine twice the caffeine found in coffee beans (1–2%). Guarana seeds were found to contain caffeine, catechin, epicatechin, and procyanidins B2, B3 and B4 (Antonelli-Ushirobira et al. 2007). The following compounds: caffeine, catechin, epicatechin, ent-epicatechin, and procyanidins B1, B2, B3, B4, A2, and C1 were isolated from guarana seeds (Yamaguti-Sasaki et al. 2007). Guarana seed kernel (embryo with bulky cotyledons) and the seed coat (testa) were found to accumulate much caffeine, i.e. 4.28 and 1.64%, respectively, whereas the ‘white of the eye’, the aril, was virtually alkaloid-free, but contained

glucose, fructose and sucrose up to almost 70% of aril dry weight (Baumann et al. 1995).

The essential oil extracted from guarana seeds were found to contain: two methylbenzenes, a cyclic monoterpene and two cyclic sesquiterpene hydrocarbons, two methoxyphenylpropenes and two alkylphenol derivatives (Benoni et al. 1996). The alleged psychoactivity of the essential oil was presumably due to the identified constituents estragole and anethole. Guarana seed oil was found to have 3% cyanolipids and 28% acylglycerols (Avato et al. 2003). Type I cyanolipids (1-cyano-2-hydroxymethylprop-2-ene-1-ol diesters) were present in the oil. *Cis*-11-octadecenoic (*cis*-vaccenic acid) (30.4%) and *cis*-11-eicosenoic acids (38.7%) were the main fatty acids. Oleic acid (37.4%) was the dominant fatty acyl chain in the acylglycerols. Paullinic acid (7.0%) was also an abundant component.

The pharmacological activity of guaraná-containing products was found to be primarily due to methylxanthine alkaloids (Carlson and Thompson 1998). For guaraná preparations, methylxanthine: theobromine, theophylline, caffeine levels and, more significantly, the presence of several polyphenol compounds ((+)-catechin and (–)-epicatechin) provide phytochemical markers of authenticity. Twenty-four products including dried seeds, dried paste, seed powders, tablets, and capsule formulations were assayed and conclusions were drawn about their authenticity (Carlson and Thompson 1998). Results and chromatographic profiles for 14 commercial products in solid dosage form indicated that a number of these products may not contain authentic guaraná as an active ingredient or contained less than the declared quantity of guaraná. Using ultra-performance liquid chromatography, commercial dietary guarana supplements were found to contain theophylline, theobromine and caffeine at concentrations of 4.45 mg/tablet, 5.48 mg/tablet, 139 mg/tablet, respectively (Hasegawa et al. 2009). Taking 4 tablets of such product according to the directions on the package could be dangerous to consumers because of possible overdosing of these ingredients.

In the United States, guarana has been regarded as “generally recognized as safe” (GRAS) by the American Food and Drug Administration (FDA).

Some of the pharmacological properties of guarana seeds are elaborated below.

Antioxidant Activity

Guarana showed an antioxidant effect because, even at low concentrations (1.2 µg/mL), it inhibited the process of lipid peroxidation (Mattei et al. 1998). The antioxidant activity of guarana seed extract determined by the malonyldialdehyde (MDA) test, measuring the MDA concentration in 3T3-L1 cells after induced cellular damage using ferric ammonium citrate (Basile et al. 2005). The reduction of lipid peroxidation was 62.5% using a guarana extract with a concentration of 2 µg/mL and was dose-dependent. The total phenolics content in the ethanol guarana seed extract was 8.43 mg/g gallic acid equivalents (GAE) and the concentration of catechol equivalent was 6.06 mg/g. The correlation index between antioxidant activity and catechol content was 0.96. The guarana seed water extract obtained at room temperature contained higher amounts of caffeine and catechins, epicatechin (EC), catechin (C) and epicatechin gallate (ECG) than did alcoholic guarana seed extracts (Majhenic et al. 2007). All tested guarana seed extracts displayed strong antioxidant and radical-scavenging properties as evaluated using the β-carotene–linoleic acid emulsion system and the stable free radical 2,2-diphenyl-1-picrylhydrazyl (DPPH). The semi-purified fraction of guarana seed extract exhibited radical-scavenging activity and protected DPPH from discoloration at 5.23 µg/mL, and for the phosphomolybdenum complex showed a higher Relative Antioxidant Capacity (RAC) at 0.75 (Yamaguti-Sasaki et al. 2007). The semi purified fraction had a total polyphenolics content of 65.80% while the plant drug showed 5.47 and 6.19% for total polyphenolics and methylxanthines, respectively. The following compounds: caffeine, catechin, epicatechin, ent-epicatechin, and procyanidins B1, B2, B3, B4, A2, and C1 were isolated from guarana seeds.

Studies showed that rats fed a novel dietary supplement composed of three well-known

phytochemicals, namely, *Salvia officinalis* (sage) extract, *Camellia sinensis* (oolong tea) extract, and *Paullinia cupana* (guarana) extract, and two prominent vitamins (thiamine and niacin) were more active, and the results suggest that dietary supplement exposure produced normal serum chemistry coupled with elevated antioxidant capacity of hepatorenal and cardiac enzymes in rats fed up to seven times the normal human dose and did not adversely influence any of the vital target organs – kidney, liver and heart (Bulkue et al. 2010). Additionally, the study reiterated the potential benefits of exposure to a pharmacologically relevant combination of phytochemicals compared to a single phytochemical entity.

Anticancer Activity

Studies showed that guaraná (*Paullinia cupana* var. *sorbilis*) had a chemopreventive effect on mouse N-nitrosodiethylamine hepatocarcinogenesis (Fukumasu et al. 2006b) by reducing incidence and multiplicity of preneoplastic lesions; and reduced diethylnitrosamine-induced DNA damage (Fukumasu et al. 2006a). In subsequent studies, guaraná was found to reduce cell proliferation and increased apoptosis of B16/F10 melanoma lung metastases in mice consequently reducing the tumour burden area (Fukumasu et al. 2008). In a recent study, the authors found that guarana exerted an antiproliferative effect on Ehrlich Ascites Carcinoma (EAC)-bearing animals (Fukumasu et al. 2011). Guarana decreased the ascites volume, cell number and hemorrhage that occurred through a G1-phase arrest induced by a decreased gene expression of Cyclin D1 in EAC cells. These results reinforced the cancer therapeutic potential of *Paullinia cupana*.

Antimicrobial Activity

The guarana seed extract, at a concentration between 16 and 128 µg/mL, showed a significant antibacterial effect expressed as minimum inhibitory concentration (MIC) against both Gram-negative and Gram-positive bacteria (Basile et al. 2005).

In particular, *Pseudomonas aeruginosa* (MIC=16 µg/mL), *Proteus mirabilis* (MIC=32 µg/mL), *Proteus vulgaris* (MIC=32 µg/mL) and *Escherichia coli* (MIC=32 µg/mL) were the most inhibited. In a later study, guarana seed extracts and isolated substances exhibited no antibacterial activity against *Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli* and *Pseudomonas aeruginosa* even at concentrations up to 1,000 µg/mL (Antonelli-Ushirobira et al. 2007). The alcoholic guarana seed extracts displayed stronger antimicrobial activity against all tested microorganisms namely three food-borne fungi: *Aspergillus niger*, *Trichoderma viride* and *Penicillium cyclopium*, and three health-damaging bacteria: *Escherichia coli*, *Pseudomonas fluorescens* and *Bacillus cereus* than did water extracts (Majhenic et al. 2007). In-vitro assessment of the antibacterial potential of the *Paullinia cupana* seed extracts against *Streptococcus mutans* showed that these could be used in the prevention of bacterial dental plaque (Yamaguti-Sasaki et al. 2007).

Cognitive Behaviour, Anxiolytic, Anti-fatigue, Antidepressant Activities

In a double blind study, long-term administration of guarana to normal, elderly volunteers did not elicit significant cognitive alterations in these volunteers (Galduróz and Carlini 1996). In a double-blind, counterbalanced, placebo-controlled study of 28 healthy young (18–24) participants, treatments of 75mg of a dried ethanolic extract of guarana (12% caffeine), 200 mg of *Panax ginseng* (G115), and their combination (75 mg/200 mg), resulted in improved task performance throughout the day (Kennedy et al. 2004). In the case of guarana, improvements were observed across ‘attention’ tasks (but with some evidence of reduced accuracy), and on a sentence verification task. While also increasing the speed of attention task performance, both ginseng and the ginseng/guarana combination also enhanced the speed of memory task performance, with little evidence of modulated accuracy. Guarana and the combination, and to a lesser extent ginseng, also led to

significant improvements in serial subtraction task performance. The results suggested that guarana and ginseng had psychoactive effects in humans. In a pilot double-blind, counterbalanced, placebo-controlled study of 26 humans, different doses (37.5 mg, 75 mg, 150 mg and 300 mg) of a standardised guaraná extract were evaluated for acute, dose-related behavioural effects (Haskell et al. 2007). Memory, alertness and mood were enhanced by the two lower doses supporting previous findings of cognitive improvements following 75 mg guaraná. However, the findings suggest that the effects cannot be attributed to caffeine alone. In a double-blind, randomised, placebo-controlled, parallel groups study of 129 healthy young adults (18–24 years), a vitamin/mineral/guaraná drink combination resulted in improved task performance, in comparison to placebo drink, in terms of both increased speed and accuracy of performing the Rapid Visual Information Processing (RVIP) task (Kennedy et al. 2008). The increase in mental fatigue associated with extended task performance was also attenuated by the supplement. The findings further demonstrated guaraná’s cognition enhancing properties and provided evidence that its addition to a multi-vitamin-mineral supplement could improve cognitive performance and reduce the mental fatigue associated with sustained mental effort.

Guaraná had been reported to have a long history of use as a stimulant in South America (Scholey and Haskell 2008). Its purported stimulant effects had often been attributed to the presence of caffeine. However, guaraná’s behavioral profile can be differentiated from that of caffeine. Recent evidence in humans and rodents suggested that other components of the plant (for example flavonoids) may contribute to its modulation of cognitive performance.

Rats administered with the crude lyophilized guarana seed extract (EBPC) (30.0 mg/kg) and semi-purified constituents (EPA) (2.0 mg/kg) but not semi-purified EPB (2.0 or 4.0 mg/kg) showed a smaller escape latency to find the emerged platform in Morris water maze test (MWM), showing nootropic-like effect in normal rats, and in scopolamine induced amnesia rats compared

to their controls (saline+0.2% Tween 80) group (Otobone et al. 2005). These extracts had no significant effect in open field test (OFT). Caffeine did alter escape latency in MWM only in scopolamine induced amnesia rats and increased the crossings number in OFT, showing significant stimulant effect. Chronic treatment showed the same increase in body weight and average lifespan indicating a low toxicity for the extracts. Results of further animal studies by Otobone et al. (2007) suggested that the crude lyophilized extract of *Paullinia cupana* seeds (EBPC) and semi-purified extract (EPA) produced an antidepressant-like effect after long-term administration. Acute or chronic administration of EBPC (3.0, 30.0 or 60.0 mg/kg) did not alter the percentage of entries or the time spent in the open arm in the plus maze test. In the forced swimming test, chronic treatment with 30.0 mg EBPC/kg and 4.0 mg EPA/kg extract decreased the immobility time similarly to the antidepressant reference drug, imipramine (20.0 mg/kg). Locomotor activity in the open field test was not increased by these extracts. Caffeine (10.0 mg/kg) significantly reduced the immobility time in the forced swimming test, but increased locomotor activity in the open field test indicating psychostimulant activity.

Studies showed that mice that ingested a suspension of guarana (0.3 mg/mL) displayed a significant increase in physical capacity when subjected to a stressful situation such as forced swimming after 100 and 200 days of treatment (Espinola et al. 1997). Such an effect, however, was not observed with a dose of 3.0 mg/mL guarana, nor with the ingestion of a suspension of ginseng 5.0 mg/mL, nor of a solution of caffeine 0.1 mg/mL. A single (3.0 and 30 mg/kg) or chronic administrations (0.3 mg/mL) of guarana, was able to partly reverse the amnesic effect of scopolamine as measured through a passive avoidance test in mice and rats, indicating a positive effect on memory acquisition. However, no effect was obtained when an active avoidance task was used in rats, even after 20 days of guarana administration. Rats treated with 0.3 mg/mL of guarana was found to better maintain the memory of a Lashley III maze path. The animals had the same average

lifespan, indicating a low toxicity of guarana, even after 23 months of treatment. Guarana (25 and 50 mg/kg, p.o.) and caffeine (10 and 20 mg/kg, p.o.) each significantly reduced the duration of immobility in the forced swimming test suggesting an antidepressant-like effect in mice but did not affect ambulation in the open field test (Campos et al. 2005). However, a high dose of guarana (100 mg/kg) and caffeine (30 mg/kg) significantly enhanced the locomotor activity in the open field test. Caffeine, but not guarana, could effectively block an adenosine agonist, cyclopentyl adenosine (CPA)-induced increase in swimming immobility suggesting that mechanism(s) other than the adenosinergic mechanism were involved in the antidepressant-like activity of guarana.

Administration of purified guarana seed extract (8 and 16 mg/kg) and the positive control, paroxetine (3 mg/kg) to rats increased one-way escape latencies from the open arm of the elevated T-maze (ETM), indicating a panicolytic effect compared to the control group (Roncon et al. 2011). The panicolytic effect produced by guarana seed extract (8 mg/kg) was blocked by both metergoline (2 mg/kg) and sulpiride (20 mg/kg), whereas the panicolytic effect produced by PAR (3 mg/kg) was blocked only by metergoline (2 mg/kg). The results showed that chronic treatment with purified guarana seed extract produced a panicolytic effect during the ETM test, and that the dopaminergic and the serotonergic neurotransmission systems were involved in this effect.

da Costa Miranda et al. (2009) found in a randomized double-blind crossover trial of 36 patients with breast cancer undergoing radiation therapy that daily consumption of guaraná did not afford any advantage over placebo for both post-radiation fatigue and depressive symptoms. In a more recent study, de Oliveira Campos et al. (2011) found guarana to be an effective, inexpensive, and nontoxic alternative for the short-term treatment of fatigue in breast cancer patients receiving systemic chemotherapy. Guarana significantly improved the Functional Assessment of Chronic Illness Therapy-Fatigue (FACIT-F), Functional Assessment of Chronic

Illness Therapy-Endocrine Symptoms (FACT-ES) and Brief Fatigue Inventory (BFI), global scores compared to placebo on days 21 and 49.

Antiallergic Activity

Guarana seed extract was found to be a candidate for effective therapeutic material for allergic diseases (Jippo et al. 2009). The extract orally administered inhibited the anti-dinitrophenol IgE-induced passive cutaneous anaphylaxis reaction in mice. It also inhibited the degranulation of rat basophilic leukemia RBL-2H3 cells but was not cytotoxic to RBL-2H3 cells.

Antiplatelet Aggregation Activity

Aqueous guaraná extracts were found to have anti-aggregatory and de-aggregatory actions on platelet aggregation induced by ADP or arachidonate but not by collagen (Bydlowski et al. 1988). The active principal was shown to be water soluble and heat resistant and appeared to be different from salicylates, nicotinic acid or known xanthines. Guaraná extracts inhibited platelet aggregation in rabbits following either intravenous or oral administration. The aqueous guaraná extract (100 mg/mL) and fractions were found to decreased rabbit platelet aggregation (37, 27 and 31% of control values, respectively) and platelet thromboxane formation from [¹⁴C]-arachidonic acid (Bydlowski et al. 1991). The decreased thromboxane synthesis could be responsible, at least in part, for the antiaggregatory action of guaraná.

Guarana seed extract was found to possess strong antiplatelet aggregating properties (Subbiah and Yunker 2008). The bioactive fraction was found to contain catechins, epicatechins, and their dimers, with a small amount of caffeine. The authors suggested that complexes containing caffeine and catechins (and their dimers) might be responsible for antiplatelet aggregating activity in guarana seeds and might offer health benefits towards decreasing risk of thrombosis and cardiovascular disease.

Antihypoglycemic Activity

A water extract of guarana (500 mg/kg) increased the blood glucose level and decreased the liver glycogen contents of mice 60 min after oral maltose administration (Miura et al. 1998). The extract also significantly suppressed exercise-induced hypoglycemia. However, the extract did not affect blood glucose in epinephrine-induced glycogenolytic and exercise mice indicating that the suppressive mechanism of hypoglycemia might be due to the promotion of glycogen resolution.

Gastroprotective Activity

Pre-treatment of mice with guarana (50 and 100 mg/kg p.o.) resulted in a significant reduction in the severity of gastric lesions induced by absolute ethanol in a manner similar to caffeine (20 and 30 mg/kg p.o.) (Campos et al. 2003). Against indomethacin-induced gastric ulceration, guarana at a higher dose offered significant protection but caffeine was ineffective at the doses tested. In pylorus-ligated rats, both guarana and caffeine caused significant diminution in the gastric secretory volume as well as the total acidity. Gastrointestinal transit in mice was not significantly affected by either of these agents. The results indicated that guarana had a gastro-protective property.

Metabolic Disorder Protective Activity

In a case-controlled epidemiological study of elderly (≥ 60 years of age) patients comprising 421 who habitually drank guaraná (GI) and 239 who never drank guaraná (NG), a lower prevalence of various metabolic disorders was found associated with guaraná ingestion in Brazil (Costa Krewer et al. 2011). The prevalence of hypertension, obesity and metabolic syndrome in the GI group was lower than the prevalence found in the NG group. The NG group exhibited lower systolic and diastolic blood pressure values. Additionally, a significant association

was found between lower levels of advanced oxidative protein product (AOPP) and habitual guaraná consumption. The results suggested a potentially protective effect of habitual guaraná ingestion against metabolic disorders in elderly subjects.

Neuroprotective Activity

Studies showed that the addition of guaraná extract significantly and dose-dependently increased the cell viability of human dopaminergic neuroblastoma SH-SY5Y cells treated with rotenone (de Oliveira et al. 2011). LDH (lactate dehydrogenase) levels were significantly reduced by addition of 0.312 mg/mL of Guaraná, but unexpectedly, no changes were observed with the higher concentration (0.625 mg/mL). Additionally, chromatin condensation and nuclear fragmentation were significantly reduced by addition of any of both concentrations of guarana extract. The results showed the potential beneficial uses of Guaraná in neurodegenerative disorders, such as in Parkinson's disease.

Cadmium Protective Activity

Studies showed that pretreatment of rats with *P. cupana* was effective in attenuating morphological changes in Leydig cells, as well as reducing inflammatory response induced by cadmium, relative to animals exclusively exposed to the metal (Leite et al. 2011). Animals treated only with *P. cupana* presented a significant increase in plasma testosterone levels and a significant increase in volumetric proportions of seminiferous tubules, which were indicative of spermatogenic stimulation.

Effects on Lipid Metabolism and Obesity

Studies showed an average weight losses of 0.8 kg over 10 days and 5.1 kg over 45 days in a group taking the herbal preparation yerbe Mate (containing leaves of *Ilex paraguayensis*, guarana

seeds and leaves of damiana, *Turnera diffusa* var. *aphrodisiaca*) compared to 0.3 kg with placebo after 10 days and 0.3 kg with placebo after 45 days (Anderson and Foght 2001). The herbal preparation, YGD capsules, significantly delayed gastric emptying, reduced the time to perceived gastric fullness and induced significant weight loss over 45 days in overweight patients.

Muscle oleate incorporation was decreased in rats receiving decaffeinated guarana in relation to two different doses of whole guarana extract (G1-0.130 g/kg; G2-0.325 g/kg); as was carnitine palmitoyltransferase I mRNA expression in the gastrocnemius (Lima et al. 2005). Whole guarana extract supplementation, but not decaffeinated extract induced reduced plasma lactate concentration in trained rats. G1 showed higher muscle glycogen content compared with all other groups. The results showed an effect of guarana on aspects of lipid metabolism associated with the methylxanthine content of guarana that was abolished by decaffeination. In a randomized, placebo-controlled, double-blind, cross-over study of 14 subjects, ingestion of encapsulated green tea and Guarana extracts containing a mixture of epigallocatechin-3-gallate (EGCG) and caffeine significantly increased 24 h energy expenditure by about 750 kJ compared to placebo (Bérubé-Parent et al. 2005). No effect of the EGCG-caffeine mixture was observed for lipid oxidation. Systolic and diastolic blood pressure increased by about 7 and 5 mmHg, respectively, with the EGCG-caffeine mixtures compared with placebo. This increase was significant only for 24 h diastolic blood pressure.

Studies using counter-balanced double-blind design of 10 overweight males showed that ingestion of a widely used commercial formula containing extracts of bitter orange, green tea and guarana did not have any significant effect on total ATP utilisation during 6 h rest or during 60 min treadmill walking (Sale et al. 2006). Changes were observed in the relative contributions of carbohydrate and nonesterified fatty acid (NEFA) oxidation to ATP production in both studies, such that there was an increase in ATP production from carbohydrate and a decrease from NEFA. The increase in carbohydrate oxidation was shown to be as high as 30% at rest.

Toxicological Studies

In high doses of 1,000–2,000 mg/kg (i.p. and p.o.) guarana did not induce significant alterations in parameters for toxicological screening (Mattei et al. 1998). No effects on motor activity were observed, neither did guarana alter the hypnotic effect of pentobarbital. Ginseng (250–1,000 mg/kg i.p.), however, elicited reductions in motor activity, eyelid ptosis and bristling fur. Consumption of liquids containing guarana or ginseng and progress in weight of the animals remained at levels similar to the controls, even after prolonged administration. The percentage mortality was equivalent in control and in treated groups. The absence of toxicity of guarana was also demonstrated by histopathological examination, with no alteration being detected in heart, lungs, stomach, small and large intestine, liver, pancreas, kidneys, bladder and spleen. In-vitro toxicity studies showed that the lowest concentration of guarana tested was not toxic and that the IC_{50} values calculated with the neutral red uptake, total protein content (kenacid blue) and tetrazolium assays were lower than the highest concentration tested (40 mg/mL) (Santa Maria et al. 1998). The results suggested that the concentration of guarana was of critical importance in its cytotoxic activity and high doses could be harmful to human health. A Brazilian study found that chronic administration of 25 ml Catuama containing a mixture of *Paullinia cupana* (guarana), *Trichilia catigua* (catuaba), *Ptychopetalum olacoides* (muirapuama) and *Zingiber officinale* (ginger) twice a day during 28 days by healthy human volunteers of both sexes caused no severe adverse reactions or haematological and biochemical changes (Oliveira et al. 2005). Catuama is used as a body stimulant, energetic, tonic and aphrodisiac.

Studies showed that guarana semi purified fraction, containing caffeine and several flavan-3-ols and proanthocyanidins, caused no toxicity in rats at the smallest dose evaluated (30 mg/kg) (Antonelli-Ushirobira et al. 2010). No rats died during the tests. Males dosed at 150 or 300 mg/kg gained weight more slowly and lost kidney weight (absolute and relative weights, compared to the

control group). Hematological and biochemical tests showed few changes, differing somewhat between males and females; the histopathological evaluation indicated no significant changes.

Adverse Effects

Aqueous extracts of guarana were found to be genotoxic as assessed by lysogenic induction in *Escherichia coli* and they were also able to induce mutagenesis in *Salmonella typhimurium* (da Fonseca et al. 1994). Addition of S9 microsomal fraction, catalase, superoxide dismutase or thiourea counteracted the genotoxic activity of guarana, suggesting that oxygen reactive species played an essential role in the genotoxicity of aqueous guarana extracts. In a randomized, double-blind, 3-arm crossover study of 16 healthy adults, consumption of 2 doses of ephedra and guarana dietary supplement containing 25 mg ephedra alkaloids and 200 mg caffeine, per supplement label recommendations, resulted in persistent increases in heart rate and blood pressure and unfavorable actions on glucose and potassium homeostasis (Haller et al. 2005). Such effects could be detrimental in persons with hypertension, atherosclerosis, or glucose intolerance, conditions that are strongly associated with obesity.

Traditional Medicinal Uses

Roasted guarana seed extracts have been used as medicinal beverages since pre-Colombian times, due to their reputation as stimulants, aphrodisiacs, tonics, as well as protectors of the gastrointestinal tract (Ângelo et al. 2008). The rainforest tribes have used guarana mainly as a stimulant, astringent, analgesic, febrifuge, cardiovascular drug, and tonic to treat chronic diarrhoea, hypertension, migraine, neuralgia, and dysentery (Duke 1992; Lleras 1994). The traditional method of using guarana and one that is still widespread nowadays is as follows after separation of the seed from the fruit and removal of the aril and seed

coats, they are roasted, this is marketed as “guarana en rama”, i.e. raw guarana (Erickson et al. 1984; Lleras 1994). The remaining seeds are immersed in water to form a paste. From this are made sticks which, after being dried over a slow fire and smoked for 1 month, are marketed. The traditional way of preparing the drink consists of scraping part of the stick in water to produce an infusion.

Other Uses

Guarana plays an important role in Tupi, Sateré-Maué and Guaraní Paraguayan cultures in religious, superstitious and magical practices besides having folkloric medicinal uses. Guarana is also employed as fish-poison and as dye.

Comments

There are two varieties of *Paullinia cupana*: var. *guarana* and var. *sorbilis*. Both are fertilized by bees of the genera *Melipona* and *Apis* and are dispersed by birds.

Selected References

- Anderson T, Foght J (2001) Weight loss and delayed gastric emptying following a South American herbal preparation in overweight patients. *J Hum Nutr Diet* 14(3):243–250
- Ângelo PCS, Nunes-Silva CG, Brígido MM, Azevedo JSN, Assunção EN, Sousa ARB, Patrício FJB, Rego MM, Peixoto JCC, Oliveira WP Jr, Frietas DV, Almeida ERP, Viana AMHA, Souza AFPN, Andrade EV, Acosta POA, Batista JS, Walter MEMT, Leomil L, Anjos DAS, Coimbra RCM, Silva ML, Marins M, Holanda FJ, Abrue RMM, Pando SC, Gonçalves JFC, Carvalho ML, Leal-Mesquita ERBP, da Silveira MA, Batista WC, Atrich AL, França SC, Porto JLR, Schneider MPC, Astolfi-Filho S, Brazilian Amazon consortium for genomic research (2008) Guarana (*Paullinia cupana* var. *sorbilis*), an anciently consumed stimulant from the Amazon rain forest: the seeded-fruit transcriptome. *Plant Cell Rep* 27(1):117–124
- Antonelli-Ushirobira TM, Yamaguti E, Uemura LM, Nakamura CV, Dias Filho BP, Palazzo De Mello JC (2007) Chemical and microbiological study of extract from seeds of guaraná (*Paullinia cupana* var. *sorbilis*). *Lat Am J Pharm* 26(1):5–9
- Antonelli-Ushirobira TM, Kaneshima EN, Gabriel M, Audi EA, Marques LC, Mello JC (2010) Acute and subchronic toxicological evaluation of the semipurified extract of seeds of guaraná (*Paullinia cupana*) in rodents. *Food Chem Toxicol* 48(7):1817–1820
- Avato P, Pesante MA, Fanizzi FP, Santos CA (2003) Seed oil composition of *Paullinia cupana* var. *sorbilis* (Mart.) Ducke. *Lipids* 38(7):773–780
- Basile A, Ferrara L, Pezzo MD, Mele G, Sorbo S, Bassi P, Montesano D (2005) Antibacterial and antioxidant activities of ethanol extract from *Paullinia cupana* Mart. *J Ethnopharmacol* 102(1):32–36
- Baumann TW, Schulthess BH, Hanni K (1995) Guarana (*Paullinia cupana*) rewards seed dispersers without intoxicating them by caffeine. *Phytochemistry* 39(5):1063–1070
- Bempong DK, Houghton PJ, Steadman K (1993) The xanthine content of guarana and its preparations. *Pharm Biol* 31(3):175–181
- Benoni H, Dallakian P, Taraz K (1996) Studies on the essential oil from guarana. *Z Lebensm Unters Forsch* 203(1):95–98
- Bérubé-Parent S, Pelletier C, Doré J, Tremblay A (2005) Effects of encapsulated green tea and guarana extracts containing a mixture of epigallocatechin-3-gallate and caffeine on 24 h energy expenditure and fat oxidation in men. *Br J Nutr* 94(3):432–436
- Bulku E, Zinkovsky D, Patel P, Javia V, Lahoti T, Khodos I, Stohs SJ, Ray SD (2010) A novel dietary supplement containing multiple phytochemicals and vitamins elevates hepatorenal and cardiac antioxidant enzymes in the absence of significant serum chemistry and genomic changes. *Oxid Med Cell Longev* 3(2):129–144
- Bydlowski SP, Yunker RL, Subbiah MT (1988) A novel property of an aqueous guaraná extract (*Paullinia cupana*): inhibition of platelet aggregation in vitro and in vivo. *Braz J Med Biol Res* 21(3):535–538
- Bydlowski SP, D’Amico EA, Chamone DA (1991) An aqueous extract of guaraná (*Paullinia cupana*) decreases platelet thromboxane synthesis. *Braz J Med Biol Res* 24(4):421–424
- Campos AR, Barros AI, Santos FA, Rao VS (2003) Guarana (*Paullinia cupana* Mart.) offers protection against gastric lesions induced by ethanol and indomethacin in rats. *Phytother Res* 17(10):1199–1202
- Campos AR, Barros AI, Albuquerque FA, Leal MLK, Rao VS (2005) Acute effects of guarana (*Paullinia cupana* Mart) on mouse behaviour in forced swimming and open field tests. *Phytother Res* 19(5):441–443
- Carlson M, Thompson RD (1998) Liquid chromatographic determination of methylxanthines and catechins in herbal preparations containing guaraná. *J AOAC Int* 81(4):691–701
- da Costa MV, Trufelli DC, Santos J, Campos MP, Nobuo M, da Costa MM, Schlinder F, Riechelmann R, del Giglio A (2009) Effectiveness of guaraná (*Paullinia*

- cupana*) for postradiation fatigue and depression: results of a pilot double-blind randomized study. *J Altern Complement Med* 15(4):431–433
- Da Costa KC, Ribeiro EE, Ribeiro EA, Moresco RN, Marques UdRMI, Santos Montagner GF, Machado MM, Viegas K, Brito E, da Cruz IBM (2011) Habitual intake of guaraná and metabolic morbidities: an epidemiological study of an elderly Amazonian population. *Phytother Res* 25:1367–1374
- da Fonseca CA, Leal J, Costa SS, Leitão AC (1994) Genotoxic and mutagenic effects of guarana (*Paullinia cupana*) in prokaryotic organisms. *Mutat Res* 321(3):165–173
- de Oliveira Campos MP, Riechelmann R, Martins LC, Hassan BJ, Casa FB, Giglio AD (2011) Guarana (*Paullinia cupana*) improves fatigue in breast cancer patients undergoing systemic chemotherapy. *J Altern Complement Med* 17(6):505–512
- de Oliveira DM, Barreto G, Galeano P, Romero JI, Holubiec MI, Badorrey MS, Capani F, Giraldez Alvarez LD (2011) *Paullinia cupana* Mart. var. *sorbilis* protects human dopaminergic neuroblastoma SH-SY5Y cell line against rotenone-induced cytotoxicity. *Hum Exp Toxicol* 30(9):1382–1391
- Duke JA (1992) Handbook of phytochemical constituents of GRAS herbs and other economic plants. CRC Press, Boca Raton, 654 pp
- Duke JA (1994 onwards) Dr. Duke's Phytochemical and Ethnobotanical Databases. <http://www.ars-grin.gov/duke/plants.html>
- Erickson HT, Corrêa MPF, Esco JR (1984) Guaraná (*Paullinia cupana*) as a commercial crop in Brazilian Amazonia. *Econ Bot* 38:273–286
- Espinola EB, Dias RF, Mattei R, Carlini EA (1997) Pharmacological activity of guarana (*Paullinia cupana* Mart.) in laboratory animals. *J Ethnopharmacol* 55(3):223–229
- Fukumasu H, Avanzo JL, Heidor R, Silva TC, Atroch A, Moreno FS, Dagli ML (2006a) Protective effects of guarana (*Paullinia cupana* Mart. var. *sorbilis*) against DEN-induced DNA damage on mouse liver. *Food Chem Toxicol* 44(6):862–867
- Fukumasu H, da Silva TC, Avanzo JL, de Lima CE, Mackowiak II, Atroch A, de Souza SH, Moreno FS, Dagli ML (2006b) Chemopreventive effects of *Paullinia cupana* Mart var. *sorbilis*, the guaraná, on mouse hepatocarcinogenesis. *Cancer Lett* 233(1):158–164
- Fukumasu H, Avanzo JL, Nagamine MK, Barbuto JA, Rao KV, Dagli ML (2008) *Paullinia cupana* Mart var. *sorbilis*, guaraná, reduces cell proliferation and increases apoptosis of B16/F10 melanoma lung metastases in mice. *Braz J Med Biol Res* 41(4):305–310
- Fukumasu H, Latorre AO, Zaidan-Dagli ML (2011) *Paullinia cupana* Mart. var. *sorbilis*, guarana, increases survival of Ehrlich ascites carcinoma (EAC) bearing mice by decreasing cyclin-D1 expression and inducing a G0/G1 cell cycle arrest in EAC cells. *Phytother Res* 25(1):11–16
- Galduróz JC, Carlini EA (1996) The effects of long-term administration of guarana on the cognition of normal, elderly volunteers. *Sao Paulo Med J* 114(1):1073–1078
- Haller CA, Jacob P, Benowitz NL (2005) Short-term metabolic and hemodynamic effects of ephedra and guarana combinations. *Clin Pharmacol Ther* 77(6):560–571
- Hasegawa T, Takahashi K, Saijo M, Ishii T, Nagata T (2009) Rapid determination of theophylline, theobromine and caffeine in dietary supplements containing guarana by ultra-performance liquid chromatography. *Shokuhin Eiseigaku Zasshi* 50(6):304–310 (In Japanese)
- Haskell CF, Kennedy DO, Wesnes KA, Milne AL, Scholey AB (2007) A double-blind, placebo-controlled, multi-dose evaluation of the acute behavioral effects of guaraná in humans. *J Psychopharmacol* 21(1):65–70
- Henman AR (1982) Guaraná (*Paullinia cupana* var. *sorbilis*): ecological and social perspectives on an economic plant of the central Amazon basin (South America). *J Ethnopharmacol* 6(3):311–338
- Jippo T, Kobayashi Y, Sato H, Hattori A, Takeuchi H, Sugimoto K, Shigekawa M (2009) Inhibitory effects of guarana seed extract on passive cutaneous anaphylaxis and mast cell degranulation. *Biosci Biotechnol Biochem* 73(9):2110–2112
- Kennedy DO, Haskell CF, Wesnes KA, Scholey AB (2004) Improved cognitive performance in human volunteers following administration of guarana (*Paullinia cupana*) extract: comparison and interaction with *Panax ginseng*. *Pharmacol Biochem Behav* 79(3):401–411
- Kennedy DO, Haskell CF, Robertson B, Reay J, Brewster-Maund C, Luedemann J, Maggini S, Ruf M, Zangara A, Scholey AB (2008) Improved cognitive performance and mental fatigue following a multi-vitamin and mineral supplement with added guaraná (*Paullinia cupana*). *Appetite* 50(2–3):506–513
- Leite RP, Wada RS, Monteiro JC, Predes FS, Dolder H (2011) Protective effect of guaraná (*Paullinia cupana* var. *sorbilis*) pre-treatment on cadmium-induced damages in adult wistar testis. *Biol Trace Elem Res* 141(1–3):262–274
- Lima WP, Carnevali LC Jr, Eder R, Costa Rosa LF, Bacchi EM, Seelaender MC (2005) Lipid metabolism in trained rats: effect of guarana (*Paullinia cupana* Mart.) supplementation. *Clin Nutr* 24(6):1019–1028
- Lleras E (1994) Species of *Paullinia* with economic potential. In: Hernández Bermejo JE, Lean J (eds) *Neglected crops: 1492 from a different perspective*. Plant production and protection series no. 26. FAO, Rome, pp 223–228
- Majhenic L, Skerget M, Knez Z (2007) Antioxidant and antimicrobial activity of guarana seed extracts. *Food Chem* 104(3):1258–1268
- Mattei R, Dias RF, Espínola EB, Carlini EA, Barros SB (1998) Guarana (*Paullinia cupana*): toxic behavioral effects in laboratory animals and antioxidants activity in vitro. *J Ethnopharmacol* 60(2):111–116
- Miura T, Tatara M, Nakamura K, Suzuki I (1998) Effect of guarana on exercise in normal and epinephrine-

- induced glycogenolytic mice. *Biol Pharm Bull* 21(6):646–648
- Oliveira CH, Moraes ME, Moraes MO, Bezerra FA, Abib E, De Nucci G (2005) Clinical toxicology study of an herbal medicinal extract of *Paullinia cupana*, *Trichilia catigua*, *Ptychopetalum olacoides* and *Zingiber officinale* (Catuama) in healthy volunteers. *Phytother Res* 19(1):54–57
- Otobone FJ, Sanches AC, Nagae RL, Colombo Martins JVC, Obici S, De Mello JCP, Audi EA (2005) Effect of crude extract and its semi purified constituents from guaraná seeds [*Paullinia cupana* var. *sorbilis* (Mart.) Ducke] on cognitive performance in Morris water maze in rats. *Brazilian Arch Biol Technol* 48(5): 723–728
- Otobone FJ, Sanches AC, Nagae R, Martins JV, Sela VR, de Mello JC, Audi EA (2007) Effect of lyophilized extracts from guaraná seeds [*Paullinia cupana* var. *sorbilis* (Mart.) Ducke] on behavioral profiles in rats. *Phytother Res* 21(6):531–535
- Roncon CM, Biesdorf de Almeida C, Klein T, de Mello JC, Audi EA (2011) Anxiolytic effects of a semipurified constituent of guaraná seeds on rats in the elevated T-maze test. *Planta Med* 77(3):236–241
- Sale C, Harris RC, Delves S, Corbett J (2006) Metabolic and physiological effects of ingesting extracts of bitter orange, green tea and guarana at rest and during treadmill walking in overweight males. *Int J Obes (Lond)* 30(5):764–773
- Santa Maria A, Lopez A, Diaz MM, Muñoz-Mingarro D, Pozuelo JM (1998) Evaluation of the toxicity of guarana with in vitro bioassays. *Ecotoxicol Environ Saf* 39(3):164–167
- Scholey A, Haskell C (2008) Neurocognitive effects of guaraná plant extract. *Drugs Fut* 33(10):869–874
- Smith N, Atroch AL (2010) Guaraná's journey from regional tonic to aphrodisiac and global energy drink. *Evid Based Complement Alternat Med* 7(3):279–282
- Subbiah MT, Yunker R (2008) Studies on the nature of anti-platelet aggregatory factors in the seeds of the Amazonian herb guarana (*Paullinia cupana*). *Int J Vitam Nutr Res* 78(2):96–101
- Yamaguti-Sasaki E, Ito LA, Canteli VC, Ushirobira TM, Ueda-Nakamura T, Dias Filho BP, Nakamura CV, de Mello JC (2007) Antioxidant capacity and in vitro prevention of dental plaque formation by extracts and condensed tannins of *Paullinia cupana*. *Molecules* 12(8):1950–1963

Pometia pinnata

Scientific Name

Pometia pinnata J.R. Forst. & G. Forst.

pinnata var. *javanica* Koord. & Valet., *Pometia tomentosa* (Blume) Teijsm. & Binn., *Pometia tomentosa* var. *cuspidata* (Blume) J.Britten.

Synonyms

Aphania neo-ebudica Guillaumin, *Aporetica pinnata* DC., *Dabanus acuminatus* Kuntze, *Dabanus pinnatus* (Forst. & Forst.) Kuntze nom. illeg., *Eccremanthus eximius* Thwaites, *Euphoria pinnata* Poir. nom. illeg., *Euphoria pometia* Poir., *Irina alnifolia* Blume, *Irina diplocardia* Blume, *Irina glabra* Blume, *Irina tomentosa* Blume, *Irina tomentosa* var. *alnifolia* (Blume) Miq., *Irina tomentosa* forma *cuspidata* Blume, *Nephelium acuminatum* Hook. f., *Nephelium diplocardia* F. v. M., *Nephelium eximium* Thw., *Nephelium pinnatum* (Forst. & Forst.) Camb., *Pometia acuminata* (Hook.f.) Radlk., *Pometia alnifolia* (Blume) King, *Pometia annamica* Gagn., *Pometia coriacea* Radlk., *Pometia glabra* Blume, *Pometia glabra* (Blume) Teijsm. & Binn., *Pometia gracilis* King, *Pometia macrocarpa* Kurz., *Pometia pinnata* forma *acuminata* (Hook. f.) Jacobs, *Pometia pinnata* forma *alnifolia* (Blume) Jacobs, *Pometia pinnata* forma *cuspidata* (Blume) Jacobs, *Pometia pinnata* forma *glabra* (Blume) Jacobs, *Pometia pinnata* forma *macrocarpa* (Kurz) Jacobs, *Pometia pinnata* forma *pinnata* Jacobs, *Pometia pinnata* forma *repanda* Jacobs, *Pometia pinnata* forma *tomentosa* (Blume) Jacobs, *Pometia*

Family

Sapindaceae

Common/English Names

Fijian Longan, Dawa, Island Lychee, Oceanic Lychee, Pacific Lychee.

Vernacular Names

Borneo: Dipangah, Kasai, Kayu sapi, Kuang, Lantupak, Matoa, Pangak, Pitanah

Chinese: Fan Long Yan;

Cook Islands: Tava;

Fiji: Dawa, Dawa Moli, Dawa Sere, Dawadawa, Tavisivesi, Tawa Vesi Ni Wai, Vesi Wai, Vesivsei;

French: Bois De Pieu, Le Pomet (Pometier), Lychee Sauvage;

French Polynesia: Kava;

India: Kasai (**Hindu**);

Indonesia: Kalasina, Kablauw, Iwa (Irian Jaya, Sentani Language), Kayu Sapi (Java), Langsir, Leungsir (**Sundanese**), Langsek Anggang (**Sumatra**), Matoa;

Malaysia: Asam Kuang, Kasai, Kasai Daun Besar, Kasai Daun Kecil, Sibu (Peninsular), Enselai, Kasai (Sarawak, Iban);

Niue: Tava;

Papua New Guinea: Koiawo (Buna), Dame (Evara), Okamu (Motu), Taun (Pidgin), Ohabu (Vailala), Bas (Waria), Cuhinh (Yabim), Tze (Yalu);

Philippines: Agupanga, Malugai, Tugau;

Rotuman: Fao, Fava;

Russian: Pometiia;

Samoa: Kava, Tava;

Solomon Islands: Nyia, Tava (Ayiwo), Nodae (Graciosa Bay), Tauna, Igi, Ako, Dawa (Kwara' Ae Language), Tao (Lengu), Gema (Roviana), Mede (Marovo), Taao (Nginia), Awa (Santa Ana), Tava (Vaiakau), Piraka Taba (Varisi);

Spanish: Longán De Fiji;

Thai: Daeng-Náam;

Tonga: Tava, Tava Kula, Tava Moli, Tava Toua;

Vanuatu: Rao (Ambrym), Tava, Dava, Ndava, Netva (Aneityum), Tava (Aniwa), Netowe, Tewen, Tien, Wuten (Banks Group), Nandao (Bislama Language), Burklata (Epi), Dau (Erromango), Ndalawa, N'Dalaoa (Maewo), Dra, Nendo, Nendro (Malekula), Vujarie, Vujaria (Malo), Jaria, Jariea, Ah, Jarie, Ha, Kao, Nsai, N'Seire, Jarie, Ndao (Santonendre), Nandem (Tanna);

Vietnam: Truong, Truong Maat;

Wallis And Futuna: Tava.

Eastern Indonesia Sumbawa, Timor, Wetar (forma *cuspidata*), and Tanimbar Islands (f. *cuspidata* and f. *pinnata*);

India Andaman Islands (probably f. *glabra* and f. *tomentosa*);

Laos

Papua New Guinea (f. *pinnata*, f. *glabra*, and f. *repanda*);

Peninsula Malaysia/Indonesia Simalur and Sumatra (f. *glabra*, f. *alnifolia*, f. *macrocarpa*); Java (f. *glabra* and f. *tomentosa*);

Philippines/Indonesia Sulawesi and Moluccas, Aru Islands, Irian Jaya;

South China Yunnan Province (probably f. *tomentosa*);

South Pacific Solomon Islands, Vanuatu, Fiji, Tonga, Wallis and Futuna, Samoa, and Niue (f. *pinnata*);

Southern Thailand (rare, probably f. *glabra* and f. *alnifolia*);

Sri Lanka (f. *tomentosa*);

Taiwan (f. *tomentosa*);

Vietnam (f. *tomentosa*).

Agroecology

The species is adapted to the warm to hot, humid and wet subtropical to tropical region from 14°N to 20°S with mean annual rainfall ranging from 1,500 to 5,000 mm. In its native range in Malesia, it is found in undisturbed mixed dipterocarp, forests up to 700 m altitude, often on alluvial sites and along or near rivers and streams, but also on hillsides. In secondary forests it is usually present as a pre-disturbance remnant. The species is shade tolerant up to 50% shade but grows well in full to partial sun. It is sensitive to extended dry periods greater than 3–4 months. The species is tolerant of strong, steady winds and moderately resistant to cyclonic winds. It thrives on a wide range of soils but does best on slightly acidic to neutral (pH 5–7), well drained, fertile sandy, loamy and clayey soils, but will tolerate mildly alkaline soils of pH 7–8 and even soils with impeded drainage.

Origin/Distribution

Pometia pinnata is indigenous in Andaman Islands, Sri Lanka, south China, Vietnam, Malaysia, Indonesia, Philippines, Papua New Guinea and the South Pacific islands.

The species is highly polymorphic and Jacobs (1962) has recognized eight distinctive forms and many unclassified paramorphs and their occurrence in the native range in Asia Pacific have been reported as follows:

Borneo (Sarawak, Sabah, Brunei, and Kalimantan) (forma *acuminata*, f. *glabra*, and f. *alnifolia*, plus two other paramorphs);

Edible Plant Parts and Uses

The arilode of ripe fruit is sweet and is eaten fresh. The oily seeds are boiled or roasted and eaten.

Botany

P. pinnata is a small to large, evergreen tree, typically 12–20 m (–50 m) high with a large, spreading crown with a spread of 10–20 m across. The bole is cylindrical, straight up to 7 m high and diameter up to 30 cm with fawnish to reddish bark. Old trees have distinct buttresses. Leaves are paripinnately compound and arranged spirally along grooved branches (Plate 1). Juvenile leaves are pink to reddish-brown and pubescent (Plate 2). Leaves have 4–8 (–13) subopposite



Plate 1 Large erect, terminal inflorescence

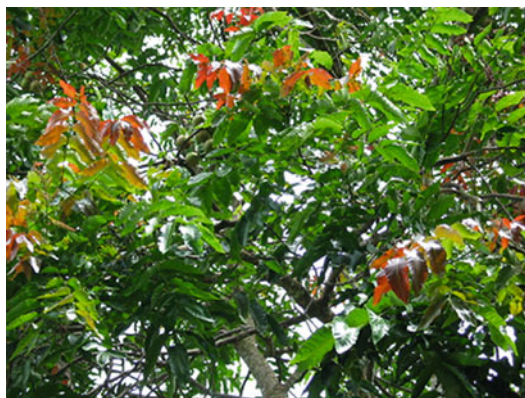


Plate 2 Juvenile reddish brown leaflets and mature green leaflets



Plate 3 A cluster of ripe brownish-black fruits

pairs of subsessile leaflets on a rachis up to 1 m long (Plate 3). Leaflets are coriaceous, oblong to elliptic, 15–34 × 5–12 cm, apex acute or acuminate, margin slightly serrate with 11–25 pairs of secondary veins; vein ending in tooth, lower surface pale green, upper surface glossy, dark green. Inflorescence is an erect panicle with lax branches up to 55 cm long (Plate 1) often with leaf-like stipules at the bases of the branches and small, actinomorphic, 5-parted flowers. The species is monoecious, with unisexual male and female flowers on the same tree and within the same panicle. Female flowers may appear bisexual, but the anthers are reduced and sterile. Calyx is cupulate with five short lobes; petals 5 small, whitish to greenish-white; stamens 5 free with whitish filaments and yellow or red anthers. Ovary in female flowers are deeply 2-lobed (rudimentary in male flowers), densely brown-pubescent with a straight red style. Fruit 3–5 cm long and wide, round to broadly ellipsoid; pericarp thin



Plate 4 Sub-opposite, leathery, dark green leaflets and small cluster of brown fruits



Plate 6 Ripe greenish-yellow fruit with thin rind and translucent arillode

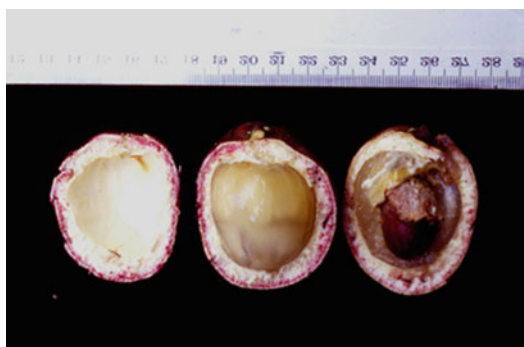


Plate 5 Fruit with thick rind, translucent edible arillode and a large seed

or moderately thick, smooth, greenish-yellow (Plate 6), reddish-brown, purplish, dark red or black (Plate 3–5), enclosing a gelatinous, sweet, juicy, white translucent, pulpy arillode which partially encase a single large seed (Plate 5) with curved embryo.

Nutritive/Medicinal Properties

Nutrient composition of the edible fruit has not been published.

A new triterpenoidal saponin, designated pometin, was isolated from the stem bark of *Pometia pinnata* and elucidated as 3-O-[β -D-glucopyranosyl-(1 $\rightarrow$ 2)- β -D-glucopyranosyl-(1 $\rightarrow$ 3)- β -D-glucopyranosyl]-oleanolic acid (Mohammad et al. 2010).

Malaysian timbers such as *Pometia pinnata* can be a source of antioxidants. *P. pinnata* bark was found to have antioxidant activity expressed as EC_{50} 14.43 μ g/mL when evaluated by 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay, and 28.93% total phenols; heartwood antioxidant activity of EC_{50} >30 μ g/mL and total phenols 39.53%; sapwood antioxidant activity of EC_{50} 28.57 μ g/mL and total phenols 24.51% (Kawamura et al. 2010).

Traditional Medicinal Uses

In Papua New Guinea, the masticated bark is applied to burns. In Fiji, both leaf and bark extracts are used, either individually or in combination with other plants, to treat a wide range of ailments, including stomach complaints, diarrhea, dysentery, pain relief (bones, muscles, joints, chest, headache), colds, flu, diabetes, and mouth ulcers. In the Solomon Islands an oral medicine is prepared from the bark to protect babies from the devil. In Tonga, an infusion of the bark was used to treat diarrhea in children, stomach trouble, serious coughs accompanying fever and constipation, and the leaves were also used medicinally. In parts of Sarawak (Malaysia), it was used as a traditional treatment for chicken pox, with the patient being bathed in an infusion (hot water extract) of the bark. Malays boil leaves and bark and used decoction in a bath for fever. In Java, the bark is used for festering sores.

Other Uses

The trees are occasionally planted as fences, boundary markers, avenue trees, shade trees and as wind-breaks and used in urban greenings. The tree provides a very good general purpose hardwood timber that is particularly well suited to light construction, moldings, interior joinery and framing, non-impact tool handles, furniture, for canoes, boats and ship construction, agricultural and sports implements, paddles, flooring, plywood and veneers. The wood is also used to produce excellent charcoal. A canoe putty is extracted from the inner bark. In Fiji, an extract of the leaves was formerly used to dye hair black. The leaves are used against rice-pests.

Comments

Jacobs (1962) recognised eight distinct forms based on inflorescence and leaf characters: *P. pinnata* forma *acuminata* (Hook. f.) Jacobs, forma *alnifolia* (Blume) Jacobs, forma *cuspidata* (Blume) Jacobs, forma *glabra* (Blume) Jacobs, forma *macrocarpa* (Kurz) Jacobs, forma *pinnata*, forma *repanda* Jacobs, and forma *tomentosa* (Blume) Jacobs. In Papua New Guinea, three distinctive forms have been found: f. *pinnata*, f. *glabra*, and f. *repanda* (Jacobs 1962).

Selected References

- Adema F, Leenhouts PW, van Welzen PC (1996) Sapindaceae. In: Soepadmo E, Wong KM, Saw LG (eds) Tree flora of Sabah and Sarawak, vol 2. Sabah Forestry Department/Sarawak Forestry Department/Forest Research Institute of Malaysia, Kepong
- Anonymous (1996) A guide to some indigenous Fijian trees. Department of Forestry, Ministry of Agriculture, Fisheries and Forestry and the Fiji German Forestry Project, Suva, Fiji, 238 pp
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula. Revised reprint. 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Cambie RC, Ash J (1994) Fijian medicinal plants. Commonwealth Scientific and Industrial Research Organisation, Canberra, 350 pp
- Chai PPK (2006) Medicinal plants of Sarawak. Lee Ming Press, Kuching, 212 pp
- Chand VS, Croft KD (1980) Bark constituents of *Pometia pinnata*. Fiji J Agric 42(1):51–52
- Conn BJ, Damas KQ (2006) Guide to trees of Papua New Guinea. (<http://www.pngplants.org/PNGtrees>)
- Corner EJH (1952) Wayside trees of Malaya. GPO, Singapore, 772 pp
- Croft KD, Tu'ipulotu P (1980) A survey of Tongan medicinal plants. South Pacific J Nat Sci 1:45–57
- de Graaf NR, Hildebrand JW, Laming PB, Fundter JM (1994) *Pometia* J.R. Forster & J.G. Forster. In: Lemmens RHMJ, Soerianegara I, Wong WC (eds) Plant resources of South-East Asia 5(1) Timber trees: minor commercial timbers. Backhuys Publishers, Leiden
- Holdsworth D, Gideon O, Pilokos B (1989) Traditional medicine of New Ireland, Papua new guinea part III konos, Central New Ireland. Pharm Biol 27(1):55–61
- Jacobs M (1962) *Pometia* (Sapindaceae), a study in variability. Reinwardtia 6:109–144
- Kawamura F, Shaharuddin NA, Sulaiman O, Hashim R, Ohara S (2010) Evaluation on antioxidant activity, antifungal activity and total phenols of 11 selected commercial Malaysian timber species. JARQ 44(3):319–324
- Mohammad FV, Ahmad VU, Noorwala M, Lajis NH (2010) A new triterpenoid saponin from the stem bark of *Pometia pinnata*. Nat Prod Commun 5(2):191–195
- Powell JM (1976) Ethnobotany. In: Pajmans K (ed) New guinea vegetation. ANU Press, Canberra
- Slik JWF (2006) Trees of Sungai Wain. Nationaal Herbarium Nederland. <http://www.nationaalherbarium.nl/sungaiwain/>
- Thomson LAJ, Thaman RR (2006) *Pometia pinnata* (tava), ver 2.1. In: Elevitch CR (ed) Species profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai'i. <http://www.traditionaltree.org>
- Van Royen P (1964) Manual of the forest trees of New Guinea. Part 2 – Sapindaceae. Division of Botany, Department of Forests, Lae, Papua New Guinea
- Walter A, Sam C (2002) Fruits of Oceania. ACIAR Monograph No. 85. Australian Centre for International Agricultural Research, Canberra, 329 pp
- Weiner MA (1971) Ethnomedicine in Tonga. Econ Bot 25:423–450
- World Health Organisation (WHO) (1998) Medicinal plants in the South Pacific. WHO Regional Publications Western Pacific Series No 19, 151 pp
- Xia N, Gadek PA (2007) Sapindaceae. In: Wu ZY, Raven PH, Hong DY (eds) Flora of China, vol 12 (Hippocastanaceae through Theaceae). Science Press/Missouri Botanical Garden Press, Beijing/St Louis

Chrysophyllum cainito

Scientific Name

Chrysophyllum cainito L.

Synonyms

Cainito pomiferum Tussac, *Chrysophyllum bicolor* Poir., *Chrysophyllum bonplandii* Klotzsch ex Miq. pro syn., *Chrysophyllum caeruleum* Jacq., *Chrysophyllum cainito* var. *caeruleum* Jacq., *Chrysophyllum cainito* var. *jamaicense* (Jacq.) Bois, *Chrysophyllum cainito* var. *pomiferum* (Tussac) Pierre, *Chrysophyllum cainito* var. *portoricense* A.DC., *Chrysophyllum cainito* var. *typicum* Stehlé nom. inval., *Chrysophyllum jamaicense* Jacq., *Chrysophyllum maliforme* L., *Chrysophyllum cainito* var. *martinicense* Pierre ex Duss, *Chrysophyllum monopyrenum* Spreng., *Chrysophyllum ottonis* Klotzsch ex Miq. pro syn., *Chrysophyllum sericeum* Salisb. nom. superfl., *Cynodendron bicolor* (Poir.) Baehni.

Family

Sapotaceae

Common/English Names

Caimito, Golden Leaf Tree, Milk Fruit, Satin Leaf, Starapple, Star Plum, West Indian Star Apple.

Vernacular Names

Argentina: Aguay, Olivoa;
Barbados: Star Plum;
Belize: Damsel;
Bolivia: Caimitero, Murucuja;
Brazil: Caimito;
Burmese: Hnin-Thagya;
Chinese: Hsing-P'ing-Kuo, Xing-Ping-Guo;
Columbia: Caimo, Caimo Morado (Purple Variety), Caimito Maduraverde (Green Variety);
Cook Islands: Urua'Eke ([Maori](#));
Creole: Bon Kaymit, Gran Kaymit, Kaymit Fèy Dò, Kaymit Fran, Kaymit Jaden; **Cuba:** Caimito Blanco, Caimito Morado ([Spanish](#));
Czech: Zlatolist Obecný;
Danish: Stjerneæble;
Dutch: Sterappel;
Eastonian: Harilik Kuldlehtik;
El Salvador: Guayabillo;
French: Bon Caïmite, Caimite, Caïmite Des Jardins, Caïmite Franche, Caïmitier, Caïmitier À Feuilles D'or, Grand Caïmite;
French Guiana: Caimite, Jaune D'oeuf, Pai-Caillemit ([Creole](#)), Macoucou;
French West Indies: Buis, Pomme Surette;
German: Sternapfel;
Haiti: Caimitier, Caimitier A Feuilles D'or, Pied Caimite;
India: Tarsiphala ([Marathi](#));
Indonesia: Sawo Kadu ([Bantam](#)), Sawo Doeren ([Malay](#)), Sao Ijo ([Java](#)), Sao Doeren, Sao Hejo ([Sundanese](#));

Laotian: Namz Nom;

Malaysia: Pepulut, Sawu Duren;

Palauan: Kaimito;

Peru: Camito;

Philippines: Caymito (*Bisaya*), Cauje, Caimitoro Estrella (*Spanish*), Kaymito (*Tagalog*);

Portuguese: Ajara, Cainito;

Samoa: Pipi O'Eva;

Spanish: Caimito, Caimitoro, Estrella, Mamey;

Singapore: Chicle Durian;

Sri Lanka: Maduraverde (*Sinhalese*);

Surinam: Apra, Goudblad Boom, Sterappel;

Thai: Sataa Appoen, Numnom;

Trinidad: Caimite, Kaimit;

Tobago: Caimite, Kaimit;

Vietnam: Vu-Sua;

Virgin Islands: Cainit.

Origin/Distribution

Starapple is probably native to the Greater Antilles in the Caribbean. It is widely cultivated in tropical Central, South America and the Caribbean – Cayman Islands, Cuba, Dominican Republic, Haiti, Jamaica and Puerto Rico. Now it is also cultivated throughout the tropics and subtropics in Florida, Taiwan, India, Thailand, the Philippines, Vietnam, Malaysia, Indonesia and Northern Australia.

Agroecology

Starapple is tropical in its requirements and prefers a warm, humid atmosphere with relatively high temperatures throughout the year. Mature trees are damaged by frosts while young trees are killed by frosts. It grows on almost all types of soil from clayey loam, sand, or limestone and in a range of tropical and subtropical areas but does best in fertile, well-drained and slightly acid soils. Throughout its native range and in southeast Asia, it thrives in the lowlands (up to 400 m elevation) and in areas with a distinct dry season but can grow up to an altitude of 1,000 m.

Edible Plant Parts and Uses

Sweet fleshy ripe fruit mesocarp is edible and delicious. The ripe fruit is eaten fresh or preferably chilled, is cut in half and the flesh spooned out and eaten. It is also used as an ingredient of ice cream and sherbet. In Jamaica it is sometimes made into preserves. The skin and rind are not edible and has a bitter latex. An emulsion of the slightly bitter seed kernels is used to make an imitation of milk-of-almonds.

Botany

An evergreen erect tree, 8–20 m tall, with a trunk of 60 cm diameter and dense, broad crown. Its trunk is usually straight, cylindrical, but often fluted or spurred at the base; buttresses are small or absent; bark surface is rough, irregularly fissured, brown and exude a white gummy latex. Young twigs are reddish-brown and pubescent. The leaves are alternate, elliptic or oblong-elliptic, 5–15 cm long, slightly leathery, rich green and glossy on the upper surface, and coated with persistent reddish-brown silky indumentum on the underside when mature imparting a golden-bronze colour to the underside (Plates 1 and 2), although they are silvery when young. Petioles are 0.6–1.7 cm long. Inflorescences are axillary, ramiflorous or cauliflorous. Flowers are bisexual, fasciculate with 5–35 clustered, small and inconspicuous, yellowish-white flowers. Calyx is 5-lobed, lobes are ovate with obtuse to rounded apex and hairy within. Corolla is 5-lobed with ovate and glabrous lobes. Stamens 5 with deltoid filaments and ovoid anthers. Ovary is ferruginous-villous, 7–10-locular; style glabrous with 7-10-lobed stigma. Fruit is an obovoid-globose or oblate berry, 5–10 cm in diameter, green (Plates 1 and 2) turning yellowish-green (Plate 3) or purplish-green or purple (Plate 4). Rind is thick, leathery, smooth surfaced, somewhat glossy, dull purple in some varieties, light green in others with white and soft, jellylike flesh and a gummy latex. On slicing the fruit transversely,



Plate 1 Immature, green starapple fruit and leaves



Plate 2 Globose fruit and leaves glossy green above and golden-bronze underside



Plate 3 Ripe, glossy, yellowish-pale green starapple variety

the mesocarp is differentiated into 2 sections: directly under the tenacious skin is a layer of soft, somewhat granular flesh, concolorous with the skin, and not very juicy; internal to this section are 8 translucent, whitish segments in which the seeds are embedded giving a star-like pattern (Plate 5).



Plate 4 Ripe, glossy purple starapple variety



Plate 5 Ripe starapple fruit whole and sliced to show the star-shaped transverse section of the flesh

Normally there is 1 seed in each segment, but frequently several are aborted, leaving 3–5 in the fruit. Seeds 3–10, flattened obovoid, about 2 cm × 1 cm × 0.5 cm, purplish-black, with a chartaceous testa and an adaxial scar.

Nutritive/Medicinal Properties

Starapple fruit is very nutritious and contains antioxidants. The nutritional values per 100 g edible portion were reported as : water 80.5–82.6 g, protein 0.7–1.3 g, fat 0.6–1.1 g, carbohydrates 15.3–17.4 g, fibre trace-0.7 g, ash 0.2–0.3 g, calcium 14–17 mg, phosphorous 9–13 mg, iron 0.2–0.4 mg vitamin A trace-10 IU, thiamine 0.01–0.02 mg, riboflavin 0.01–0.02 mg, niacin 0.8–0.9 mg, vitamin C 6–7 mg and energy value 280–300 kJ per 100 g (Galang 1955).

Caimito fruit was reported to have 53–63% edible portion, the tough rind being inedible, and to contain per 100 g edible portion: water 80.5–82.6 g, protein 0.7–1.3 g, fat 0.6–1.1 g, carbohydrates 15.3–17.4 g, fibre trace–0.7 g, ash 0.2–0.3 g, calcium 14–17 mg, phosphorus 9–13 mg, iron 0.2–0.4 mg, vitamin A trace – 10 IU, thiamine 0.01–0.02 mg, riboflavin 0.01–0.02 mg, niacin 0.8–0.9 mg, vitamin C 6–7 mg and energy value 280–300 kJ per 100 g. (dela Cruz 1991). Analyses in Central America showed appreciably higher maximum values for all constituents except water, fat and carbohydrates.

Ripe, raw green and purple cultivar caimito fruit was reported to have the following food composition per 100 g edible portion respectively (Santos-Acuin et al. 1997): protein 0.7 g, 0.3 g; Fat 1.1 g, 0.6 g; carbohydrate 14.6 g, 17.4 g; calcium 17 mg, 14 mg; iron 0.4 mg, 0.2 mg; β -carotene 5 μ g, traces; vitamin A (Retinol Equivalent) 1 μ g, traces; riboflavin 0.02 mg, 0.01 mg; niacin 0.8 mg, 0.9 mg; and ascorbic acid 7 mg, 8 mg.

Green and ripe starapple were found to contain the following phenolic acids (mg/g): gallic acid 10.65 mg, 2.36 mg; protocatechuic acid 7.18 mg, 5.68 mg; *p*-hydroxy benzoic acid 2.89, nd (not detected), vallinic acid nd, nd; chorogenic acid 1.99 mg, 40.68 mg; caffeic acid nd, nd; syringic acid 22.69 mg, nd; *p*-coumaric acid 2.35 mg, nd; ferulic acid 64.28 mg, 14.59 mg; sinapic acid 3.98 mg, nd and total phenolic acid content 116.01 mg, 63.60 mg respectively. Green and ripe starapple fruit were found to contain the following flavonoid content (mg/g dry sample): rutin 12.65 mg, 50.36 mg; myricetin 53, 68.41 mg; luteolin 13.86 mg, 11.37 mg; quercetin 17.88 mg, 20.07 mg; apigenin 0.85 mg, 0.91 mg; kaempferol 0.76 mg, 0.83 mg and total flavonoid content 99.00 mg and 151.95 mg respectively. Green and ripe starapple also contained the following sugar composition (mg/g dw): D(+)sucrose 40.64 mg, nd; D(+)maltose nd; 113.64 mg; D(+)glucose 52.30 mg, 99.08 mg; D(+)galactose 2.80 mg, nd; D(+)fructose 83.69 mg, 117.43 mg; and total sugars 182.56 mg, 330.15 mg respectively. Ripe starapple contained 0.16 mgg vitamin C and 3.47 g/100 g crude fibre.

One hundred and four compounds were identified in the aroma concentrate of the volatile

constituents of the star apple, of which (E)-2-hexenal, 1-hexanol, limonene, linalool, α -copaene and hexadecanoic acid were found to be the major constituents (Pino et al. 2002). The presence of many terpenic compounds was thought to contribute to the unique flavour of the star apple fruit.

Fruit extract of *C. cainito* was found to have potent lectin of >100,00 units/g weight and belonged to the blood type A haemagglutinating group (Wongkham et al. 1995). Lectins are glycoprotein with the ability to interact with carbohydrates, to agglutinate cells or precipitate glycoconjugates and find application for blood typing, mitogenic stimulation of lymphocytes, diagnosing microorganisms, differentiating between normal and malignant cells, purification of glycoconjugates, and study of cell surface of carbohydrates.

The seeds were found to contain 1.2% lucumin, a bitter, cyanogenic glycoside, traces of pouterin 0.0037%, 6.6% of a fixed oil; 0.19% saponin, 2.4% dextrose and 3.75% ash. The leaves possess an alkaloid, resin, resinic acid, and a bitter substance (Morton 1987).

Antioxidant Activity

Unripe, green starapple and ripe starapple was found to have a total phenol content of 17.88 mg and 28.54 mg GAE/g; total flavonoid content of 11.17 mg and 12.92 mg RE/g; FRAP (ferric reducing antioxidant power) value of 36.98 and 44.92 mmol FeSO₄/g; DPPH value of 94.40 and 95.32% inhibition and AEAC (ascorbic acid antioxidant capacity) of 0.88 mg and 0.82 mg ascorbic acid/g respectively (Kubola et al. 2011).

The ethyl acetate soluble fraction of the fruit displayed high antioxidant activity in the 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay (IC₅₀=22 μ g/mL) (Luo et al. 2002). Nine known polyphenolic antioxidants, (+)-catechin, (–)-epicatechin, (+)-gallocatechin, (–)-epigallocatechin, quercetin, quercitrin, isoquercitrin, myricitrin and gallic acid were identified. Of these nine antioxidants, (–)-epicatechin was present in the highest concentration in star apple fruit (7.3 mg/kg fresh weight), and quercetin showed the highest antioxidant activity (IC₅₀=40 μ M) in the

DPPH assay. Cyanidin-3-O- β -glucopyranoside, an anthocyanin antioxidant, was also identified from semi-purified aqueous fractions of starapple fruit (Einbond et al. 2004).

Antispasmodic Activity

Studies showed that the methanol extract of the bark and its fractions caused concentration-dependent relaxation of the vascular smooth muscle in isolated thoracic aortic rings with intact endothelium from male Sprague-Dawley rats (Quentela et al. 2001). Methanol extract and water fraction exhibited the most profound effects.

Traditional Medicinal Uses

In traditional folkloric medicine in tropical America and the Caribbean, the ripe fruit is eaten to treat inflammation in laryngitis, pneumonia and hemorrhage or is cooked and used as anti-pyretic. It is taken as a remedy for diabetes mellitus, and a decoction is gargled to relieve angina. A decoction of the fruit rind, or of the leaves, is taken as a pectoral. The undersides of leaves are grated and applied as a poultice to a wound and a leaf decoction is taken orally for hypoglycaemia. The bark, latex and seeds also have medicinal uses. A decoction of the tannin-rich, astringent bark is taken as a tonic and stimulant, and is drunk to stop diarrhea, dysentery and hemorrhage, and also employed as a treatment for gonorrhea and “catarrh of the bladder”. The bitter, pulverized seed is mixed in water and consumed as a tonic, diuretic and febrifuge. The latex of the tree is applied on abscesses and, when dried and powdered, it is utilized as a potent vermifuge. It is also taken as a diuretic, febrifuge and remedy for dysentery.

Other Uses

The reddish-brown wood is suitable for general indoor construction purposes, such as planking, light framing, flooring, interior trim, cladding,

paneling lining, shelving, balustrades and partitioning. It is also suitable for inlaying, carving, joinery, moldings, light tool handles, furniture and cabinet making. Good-quality veneer and plywood can be obtained from the tree. The mature branches are used as a medium to grow orchids. The tree is widely appreciated as an ornamental. The bark also yields tannin. The latex from the bark has been used as an adulterant of *gutta percha*.

Comments

Starapple can be propagated by seed, air layering, or grafting.

Selected References

- Backer CA, van den Brink Bakhuizen RC, Jr RC (1965) Flora of Java (Spermatophytes only), vol 2. Wolters-Noordhoff, Groningen, 641 pp
- Bailey LH (1949) Manual of cultivated plants most commonly grown in the Continental United States and Canada (Revised edition). The Macmillan Co., New York, 1116 pp
- Brown WH (1951–1957) Useful plants of the Philippines. Reprint of the 1941–1943 edition. 3 volumes. Technical Bulletin 10. Department of Agriculture and Natural Resources. Bureau of Printing, Manila, The Philippines, vol 1 (1951), 590 pp, vol 2 (1954), 513 pp, vol 3 (1957), 507 pp
- dela Cruz FS Jr (1991) *Chrysophyllum cainito* L. In: Verheij EWM, Coronel RE (eds) Plant resources of South-East Asia. No. 2. Edible fruits and nuts. Prosea Foundation, Bogor, pp 115–117
- Einbond LS, Reynertson KA, Luo X-D, Basile MJ, Kennelly EJ (2004) Anthocyanin antioxidants from edible fruits. Food Chem 84(1):23–28
- Galang FG (1955) Fruit and nut growing in the Philippines. AIA Printing Press, Malabon, Rizal
- Govaerts R, Harvey Y, Jessup L, Pennington TD, Vink W (2012) World Checklist of Sapotaceae. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; <http://apps.kew.org/wcsp/>. Retrieved 22 July 2012
- Hu SY (2005) Food plants of China. The Chinese University Press, Hong Kong, 844 pp
- Kennard WC, Winters HF (1960) Some fruits and nuts for the tropics. USDA Agric Res Serv Misc Publ 801:1–135
- Kubola J, Siriamornpun S, Meeso N (2011) Phytochemicals, vitamin C and sugar content of Thai wild fruits. Food Chem 126:972–981
- Luo X-D, Basile MJ, Kennelly EJ (2002) Polyphenolic antioxidants from the fruits of *Chrysophyllum cainito* L. (Star Apple). J Agric Food Chem 50(6):1379–1382

- Morton JF (1987) Starapple. In: Fruits of warm climates. J. F Morton, Miami, pp 408–410
- Ochse JJ (1927) Indische Vruchten. Volkslectuur, Weltevreden, 330 pp
- Pacific Island Ecosystems at Risk (PIER) (2004) *Chrysophyllum cainito* L., Sapotaceae. http://www.hear.org/pier/species/chrysophyllum_cainito.htm
- Pennington TD (1990) Flora Neotropica: Monograph. 52. New York Bot. Garden, New York, 770 pp
- Pennington TD (1991) The genera of the Sapotaceae. Kew Publishing, London, 307 pp
- Pino J, Marbot R, Rosado A (2002) Volatile constituents of star apple (*Chrysophyllum cainito* L.) from Cuba. Flavour Fragrance J 17(5):401–403
- Quentela A, Apostol J, Ysrael MC, Wadsworth RM (2001) A preliminary study on the relaxant effect of the crude extract and fractions of the bark of *Chrysophyllum cainito* L. in isolated rat thoracic aorta. Acta Manilana 49:49–54
- Santos-Acuin C, Gepte AT IV, Dedace MJ (1997) Asian Case Study – Aetas of Morong. The Aetas of Morong. Bataan, Philippines. Community Food System Databases. The Research Institute of Tropical Medicine, Manila
- Standley PC, Williams LO (1967) Sapotaceae. In: Standley PC, Williams LO (eds) Flora of Guatemala – Part VIII, Number 3. Fieldiana, Bot 24(8/3):211–244
- Tropicos Org. Missouri Botanical Garden. Jan 2011. <http://www.tropicos.org>
- Wongkham S, Boonsiri P, Trisonth C, Simasathainsophon S, Wongkham C, Atisoor K (1995) Studies on lectins from Thai plants. J Sci Soc Thailand 21:27–36

Chrysophyllum oliviforme

Scientific Name

Chrysophyllum oliviforme L.

Synonyms

Chrysophyllum mirapoanum Urb., *Chrysophyllum monopyrenum* Swartz, *Chrysophyllum oliviforme* var. *typicum* Cronquist, *Cynodendron oliviforme* (L.) Baehni, *Dactimala oliviformis* (L.) Raf., *Guersentia oliviformis* (L.) Raf., *Sideroxylon derryanum* King & Gamble.

Family

Sapotaceae

Common/English Names

Damson Plum, Date Plum, Olive Plum, Satin Leaf, Satin Leaf Fruit, Satin-leaf Tree, Tuko, Wild Star Apple.

Vernacular Names

Cuba: Caimitillo, Caimitillo De Perro, Caimito, Caimito Cimarron, Caimito Cimarrón, Canela, Macanabo, Palo De Canela, Xaimito ([Spanish](#));

Dominican Republic: Caimitillo, Caimito De Perro ([Spanish](#));

French: Cahimitier, Feuille D'or, Pomme Étoile;

Haiti: Kaymit Mawon ([Creole](#)), Caïmitier Marron, Caïmite Marron ([French](#));

Malaysia: Buah Susu;

Philippines: Caimitillo;

Spanish: Caimitillo, Caimito, Eslo, Pipa.

Origin/Distribution

Its native range includes United States (Florida), West Indies (Greater Antilles, Bahamas) and also Central America. It is also cultivated as a fruit tree in tropical America, southeast Asia, Australia, Sri Lanka and Hawaii.

Agroecology

It occurs in the low-elevation, moist tropical forests in its native range. It grows in full sun on a wide range of soil types but prefers moist, well-drained, loamy soils.

Edible Plant Parts and Uses

The soft and sweetish flesh of the fruit is edible, quite insipid but has an agreeable taste.



Plate 1 Leaf showing the green, upper surface and immature, green Satin Leaf fruit



Plate 2 Ripe, glossy, purplish black and leaves (dark green upper and gold-bronze lower surfaces)

Botany

Small, evergreen tree 5–15 m tall; young twigs, lower leaf surface, and flower buds densely golden-brown or rusty-brown with silky sericeous pubescence. Leaves simple, alternate, apex abruptly short acuminate, entire margin, with pinnate venation, upper surface dark green and glabrous, lower leaf surface densely brown or rusty tomentose imparting a satin golden-bronze appearance (Plates 1 and 2). Flowers are bisexual, pentamerous, in axillary, 5–10 flowered fascicles. Fruits are ellipsoid (olive-shaped) berry, 2–2.5×1 cm, 1-seeded, fleshy, with persistent style, green ripening purple or purple-black (Plates 1 and 2). Seed 1, ovoid to ellipsoid, about 1.5 cm long.

Nutritive/Medicinal Properties

No published data is available on its nutritive and medicinal values.

Other Uses

It is also cultivated as an ornamental because of its decorative satin-like leaves. It can be used for avenue planting. Its timber is dark and heavy.

Comments

The plant can be propagated by seeds or semi-hardwood cuttings under mist.

Selected References

- Brown WH (1951–1957) Useful plants of the Philippines. Reprint of the 1941–1943 edition. 3 volumes. Technical Bulletin 10. Dept Agric Natl Res. Bureau of Printing, Manila. vol 1 (1951), 590 pp, vol 2 (1954), 513 pp, vol 3 (1957), 507 pp
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula, Revised reprint, 2 vol. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Govaerts R, Harvey Y, Jessup L, Pennington TD, Vink W (2012) World checklist of Sapotaceae. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; <http://apps.kew.org/wcsp/>. Retrieved 22 July 2012
- Huxley AJ, Griffiths M, Levy M (eds) (1992) The new RHS dictionary of gardening (4 vols). MacMillan, London
- Jansen PCM, Jukema J, Oyen LPA, van Lingem RG (1992) Minor edible fruits and nuts. In: Verheij EWM, Coronel RE (eds) Plant resources of South-East Asia no. 2. Edible fruits and nuts. Prosea Foundation, Bogor, pp 313–370
- Kennard WC, Winters HF (1960) Some fruits and nuts for the tropics. USDA Agric Res Serv Misc Publ 801:1–135
- Pennington TD (1990) Sapotaceae flora neotropica: Monograph. 52. New York Bot. Garden, New York, 770 pp
- Pennington TD (1991) The genera of the Sapotaceae. Kew Publishing, New York, 307 pp
- Standley PC, Williams LO (1967) Sapotaceae. In: Standley PC, Williams LO (eds) Flora of Guatemala – Part VIII, Number 3. Fieldiana, Bot 24(8/3):211–244

Manilkara jaimiqui

Scientific Name

Manilkara jaimiqui (C. Wright) Dubard.

Synonyms

Manilkara emarginata subsp. *jaimiqui* (C. Wright ex Griseb.) Cronquist, *Mimusops jaimiqui* C. Wright ex Griseb.

Family

Sapotaceae

Common/English Names

Wild Dilly, Wild Sapodilla.

Vernacular Names

Cuba: Jamiqui;
Puerto Rico: Jamiqui.

Origin/Distribution

The species is native to Florida keys and Bahamas in the Caribbean.

Agroecology

Wild dilly is adaptable to tropical or subtropical conditions in its natural range. It will survive brief periods of light frost, short periods of drought and is tolerant of brackish waters. It is found in hammocks, mangroves and other coastal thickets. It does best on moist, well-drained loamy soils rich in organic matter. It thrives under full sun.

Edible Plant Parts and Uses

The fruits are edible, somewhat similar to the sapodilla, but much smaller. The fruit possesses little edible flesh.

Botany

A small, lactiferous, evergreen tree, 5–10 m high with a dense rounded crown, grey to reddish-brown deeply fissured bark and short, gnarled trunk with a bole diameter of <45 cm. Leaves are alternate, simple, coriaceous, glabrous, petiolate (1.2–2.5 cm long), oblong to oblong-elliptic, 5–10 cm by 3.5 cm, base obtuse or broadly cuneate, apex emarginate, margin entire, mid-rib prominent below, glossy green (Plate 1). Flowers are yellow, formed in 2–5 flowered inflorescences, sometimes solitary in upper leaf axils. Sepals are elliptic-lanceolate, 4–8 mm,



Plate 1 Fruits and leaves of wild dilly

apex acute to obtuse, tomentose to subglabrate; corolla campanulate, tube 1–2 mm (shorter than lobes) with yellow petals y divided to base into larger median and 2 lateral segments, lobes 6–7 mm, median segment boat-shaped, clawed, lateral segments lanceolate to falcate, staminodes triangular-lanceolate; ovary appressed-puberulous staminodes triangular-lanceolate; ovary appressed-puberulous. Fruit is a pendulous berry, depressed-globose 3 cm diameter, brown, covered with sandy brown scurf (Plate 1). Seeds 3–5, small, 1.5–2 cm, black and laterally compressed.

Nutritive/Medicinal Properties

No information has been published on the nutritive value of its edible fruit. Tea prepared from the leaves is used to relieve flu and fever.

In Cuba, the plant is used as an astringent and antiseptic.

Other Uses

Its wood is hard, strong, and durable. It is used for roof support, braces and naval construction.

Comments

The plant is propagated from seeds.

Selected References

- Austin DF (2004) Florida ethnobotany. CRC Press, Boca Raton, 952 pp
- Govaerts R, Harvey Y, Jessup L, Pennington TD, Vink W (2012) World checklist of Sapotaceae. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; <http://apps.kew.org/wcsp/>. Retrieved 22 July 2012
- Pennington TD (1990) Sapotaceae. Flora Neotropica: Monograph. 52. New York Bot. Garden, New York, 770 pp
- Tropicos.org. Missouri Botanical Garden (2012) <http://www.tropicos.org/Name/29600642>
- Wunderlin RP, Whetstone RD (1993+) *Manilkara jaimiqui* (C. Wright ex Grisebach) Dubard subsp. *emarginata* (Linnaeus) Cronquist. In: Flora of North America Editorial Committee (eds) Flora of North America North of Mexico, 14+ vols. New York/Oxford, vol 8, p 235

Manilkara kauki

Scientific Name

Manilkara kauki (L.) Dubard.

Synonyms

Achras mammosa Sieber ex A. DC. nom. inval., *Achras octodecemfida* Stokes, *Imbricaria malabarica* Poir., *Kaukenia kauki* (L.) Kuntze, *Mimusops browniana* Benth., *Mimusops elengi* Bojer nom. inval., *Mimusops hookeri* A. DC., *Mimusops kauki* L., *Mimusops kauki* var. *browniana* A. DC., *Mimusops manilkara* G. Don.

Family

Sapotaceae

Common/English Names

Australia – Queensland: Caqui, East Coast Wongi, Torres Straits Wongi, Wongai, Wongai Plum Tree, Wongi Plum.

Vernacular Names

Burmese: Khayah Rgn;
Indonesia: Sawo Kecil, Kayu Sawo (Java); Sawo (sundanese), Sawo Kecil Sabo (Bali), Sabo, Sawo Kecil (Nusa Tenggara);

Malaysia: Sawa, Sauh;
Papua New Guinea: Sner;
Philippines: Duyok-Duyok;
Thailand: Lamut-Sida (Central), Lamut-Thai;
Vietnamese: Viest.

Origin/Distribution

The species is indigenous to the old world tropics. The area of distribution stretches from Sri Lanka, through southeast Asia: Myanmar through Thailand, Indochina, Peninsular Malaysia, and Indonesia (except Kalimantan) to Papua New Guinea and northern Australia.

Agroecology

The species is tropical and grows mostly in coastal lowlands (including non-inundated land close to mangroves) up to 500 m altitude and in relatively dry areas with good drainage, mostly sand, sandy loams or sandy clay regosol. It can be found on coastal sand dunes, coral beaches, on rocky headlands and at banks of small seasonal streams.

Edible Plant Parts and Uses

The fruit is eaten in its native range. In the Torres Strait Islands and Cape York Peninsula in north east Australia both aboriginal children and adults



Plate 1 A cluster of orangey-brown wongai fruit at the apex of shoots

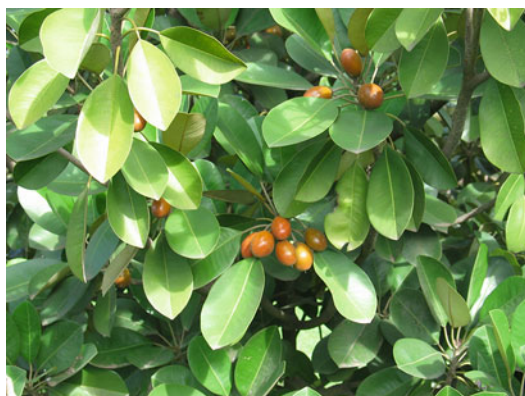


Plate 2 The simple, large leaves clustered towards the apex of shoots

look forward to the fruiting season to eat the ripe fruit from trees near their communities. The fruit is popular to eat fresh after it is soft ripe or left to dry increasing its sweetness and flavour. Ripe wongai have a flavour and texture similar to dates. The pulp is usually eaten fresh but can be added to fruit cake mixes and breakfast cereal. One popular recipe is *Wongai Sabbi Domboy* in the “Torres Strait Cookbook” which consists of wongai fruit cut in half after removal of seeds, plain flour, coconut milk, baking powder and salt. The dough is kneaded and rolled into sausage-shaped Domboys which are then cooked in a boiling mixture of wongai fruit and coconut milk. The



Plate 3 Tree habit of wongai with low branched bole

Domboys are like dumplings that sponge up the coconut cream and wongai.

Botany

A medium-sized, evergreen perennial tree, up to 25 m tall, often with gnarled sometimes columnar and low-branched bole (Plate 3), up to 100 cm in diameter with a dense, large, round crown. Bark is grey-brown and deeply fissured. Leaves are clustered at apex of twigs on 2.5–3 cm petioles, pale green and glabrous above, silky white and velvety beneath (Plate 2). Lamina is broadly ovate to broadly elliptic, 6–15 cm by 3–8 cm, apex rounded to shallowly notched, based acute and margin entire. Flower buds are solid and ovoid. Flowers are yellowish-white, usually bisexual, small, 1 cm across in small axillary clusters on 1.5–2.5 cm pedicel, sepals ovate or triangular, 7 mm; corolla 18 lobed, ovary 6-loculed with distinct glabrous disk. Fruits are obovoid 3.5 cm long by 2 cm, ripening orangey brown to red with 1–6 seeds (Plates 1 and 2).

Seeds glossy, tan, hard and elliptic, 2 cm long by 1 cm wide and 0.75 cm thick.

India and the Philippines, this species is utilised as a rootstock for sapodilla (*Manilkara zapota*).

Nutritive/Medicinal Properties

Analyses carried out in Australia (Brand Miller et al. 1993) reported fresh wongai fruit to have the following food composition (per 100 g edible portion): water 58.9 g, energy 91 kJ, protein 1.2 g, fat 1.9 g, ash 0.9 g, available carbohydrates 0 g, Ca 119 mg, Fe 1.4 mg, Mg 60 mg, P 35 mg, K 472 mg, Na 113 mg, Zn 0.2 mg, Cu 4.8 mg, vitamin C 5 mg, thiamin 0.03 mg, riboflavin 0.19 mg, and niacin equivalent 0.2 mg.

In India, flowers, seeds, roots, bark and leaves have been reported to be used in folk medicine.

Other Uses

The species is mainly grown commercially for its valuable and durable timber. The heartwood is brown, dark brown or reddish brown, sometimes with reddish lines. Sapwood is light brown. The wood is used for heavy construction (house poles, bridge, railway pedestal, telephone poles), charcoal, flooring, furniture, coffins and carving; it is also used for turnery and mills. The wood has a good reputation in Indonesia for use in furniture and fine carving, particularly in Bali.

The species is planted as fruit trees and ornamentals, often near palaces and temples. In Java,

Comments

The plant is propagated from seeds which are soaked in water for 3 days to hasten germination.

Selected References

- Backer CA, van den Bakhuizen BJRC (1965) Flora of Java, vol 2. Wolters-Noordhoff, Groningen, 630 pp
- Brand Miller J, James KW, Maggiore P (1993) Tables of composition of Australian aboriginal foods. Aboriginal Studies Press, Canberra
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula, Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Goebel R (1990) Wongai an Australian fruit. Rare Fruit Council Aust Inc Newsl 63:1–2
- Govaerts R, Harvey Y, Jessup L, Pennington TD, Vink W (2012) World checklist of Sapotaceae. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; <http://apps.kew.org/wcsp/>. Retrieved 22 July 2012
- Ng FSP (1972) Sapotaceae. In: Whitmore TC (ed) Tree flora of Malaya, vol 1, Malaya. Longman Malaya, Kuala Lumpur, pp 388–439
- Tantra IGM, Tonanon N, Lemmens RHMJ, Klaasen R (1994) *Manilkara* Adans. In: Lemmens RHMJ, Soerianegara I (eds) Plant resources of South-East Asia no 5(1). Timber trees: major commercial timbers. Prosea Foundation, Bogor, pp 294–299

Manilkara zapota

Scientific Name

Manilkara zapota (L.) P. Van Royen.

Synonyms

Achradelpha mammosa (L.) O.F. Cook, *Achras breviloba* (Gilly) Lundell, *Achras calderonii* (Gilly) Lundell, *Achras coriacea* Lundell, *Achras konzattii* (Gilly) Lundell, *Achras dactylina* Lundell, *Achras gaumeri* (Gilly) Lundell, *Achras latiloba* Lundell, *Achras lobulata* (Lundell) Lundell, *Achras lucuma* Blanco, *Achras meridionalis* (Gilly) Lundell, *Achras mammosa* L. nom. illeg., *Achras occidentalis* Cels ex Ten. *Achras paludosa* Lundell, *Achras petenensis* (Lundell) Lundell, *Achras rojasii* (Gilly) Lundell, *Achras sapatilla* J. Paul & W. Arnold, *Achras sapota* L. orth. var., *Achras sapota* f. *asperma* M. Gómez, *Achras sapota* var. *candollei* Pierre, *Achras sapota* var. *globosa* Stokes, *Achras sapota* var. *lobata* (A.DC.) Pierre, *Achras sapota* var. *ovalis* Stokes, *Achras sapota* var. *pedicellaris* Pierre, *Achras sapota* var. *sphaerica* (A.DC.) Pierre, *Achras sapota* var. *typica* Stehlé nom. inval., *Achras striata* (Gilly) Lundell, *Achras tabogaensis* (Gilly) Lundell, *Achras tainteriana* Lundell, *Achras tchicomame* Perr., *Achras verrucosa* Stokes, *Achras zapota* L., *Achras zapota* var.

major Jacq., *Achras zapotilla* (Jacq.) Nutt., *Achras zapota* var. *zapotilla* Jacq., *Calocarpum mammosum* (L.) Pierre, *Calospermum mammosum* (L.) Pierre, *Gambeya mammosa* (L.) Pierre, *Lucuma mammosa* (L.) C.F. Gaertn., *Lucuma zapota* (L.) Urb., *Lucuma zapota* var. *anguai* Rojas Acosta, *Manilkara achras* (Mill.) Fosberg, *Manilkara breviloba* Gilly, *Manilkara calderonii* Gilly, *Manilkara konzattii* Gilly, *Manilkara grisebachii* (Pierre) Dubard, *Manilkara gaumeri* Gilly, *Manilkara meridionalis* Gilly, *Manilkara meridionalis* var. *caribbensis* Gilly, *Manilkara rojasii* Gilly, *Manilkara striata* Gilly, *Manilkara tabogaensis* Gilly, *Manilkara zapotilla* (Jacq.) Gilly, *Manilkariopsis lobulata* Lundell, *Manilkariopsis meridionalis* (Gilly) Lundell, *Manilkariopsis petenensis* Lundell, *Manilkariopsis rojasii* (Gilly) Lundell, *Manilkariopsis striata* (Gilly) Lundell, *Manilkariopsis tabogaensis* (Gilly) Lundell, *Mimusops grisebachii* Pierre, *Nispero achras* (Mill.) Aubrév., *Pouteria mammosa* (L.) Cronquist, *Sapota achras* Mill., *Sapota achras* var. *lobata* A.DC., *Sapota achras* var. *sphaerica* A.DC., *Sapota zapotilla* (Jacq.) Coville ex Safford, *Vitellaria mammosa* (L.) Radlk.

Family

Sapotaceae

Common/English Names

Bully Tree, Chicle, Chico Sapote, Chiku, Marmalade Plum, Naseberry, Sapodilla, Sapodilla Plum, Sapote.

Vernacular Names

Aztec: Xicozapoti;
Bahamas: Dilly;
Bangladesh: Sofeda;
Belize: Zapote Morado;
Brazil: Sapoti;
British West Indies: Dilly, Neeseberry, Naseberry;
Chinese: Ren Xin Guo, Ien Xian Guo;
Columbia: Nispero, Zapote;
Costa Rica: Korob, Nispero;
Cuba: Nipero, Zapote;
Czech: Mamej Sapota;
Danish: Tyggegummitræ;
Dominican Republic: Nispero, Nipero, Zapote;
Dutch: Sapodilleboom, Pruimboom, Sapodilla, Westindische mispleboom;
Ecuador: Nispero Quitense;
El Salvador: Nispero, Muyozaot, Zapote;
French: Nèfle D'amérique, Sapote, Sapotier, Sapotillier, Arbre A La Chewing Um;
French Guiana: Sapotille;
French West Indies: Sapotille;
German: Breiapfel, Breiapfelbaum, Kaugum-mibaum, Sapote, Sapotille, Sapotillbaum;
Guatemala: Chicozapote, Zapote Chico, Mui, Ya;
Guyana: Sapadillo, Sapodilla;
Haiti: Sapoti;
Hawaii: Chico Sapote;
India: Baramasi, Sapeta (Bengali), Baramasi (Bihar), Chikoo (Hindu), Chiku, Chikku (Marathi), Chapotta, Chimaibiluppai (Tamil), Sima Ippacettu (Telugu), Chikoo (Urdu);
Indonesia: Sabo Jawa (Bali), Sao Manila, Sau Manila, Sawu Manila (Batak), Sao Mila (Boegineesch, Sulawesi), Sawo Manila, Sawo Londo (Java), Sauh Manila, Sawo Manila, Sawuh

Manila (Lampung, Sumatra), Sau Manila (Manado, Sulawesi), Sauh Manila (Singkep, Riau), Sawo Manila (Jambi, Manado), Jiku (Lingga, Sumatra), Sawo, Sawo Manila (Sundanese), Sabu Manila (Madurese), Sawo Manila (Malay);

Jamaica: Naseberry;

Japanese: Sabojira, Sapojira;

Khmer: Lamut;

Korean: Kkom Na Mu;

Laotian: Lamud;

Malaysia: Ciku, Sawo Manila, Sawo Nilo;

Maldives: Sabudheli;

Mexico: Chico, Chico Sapote, Zapote Chico, Chicozapote, Zapotillo;

Netherlands Antilles: Mispel, Mispu;

Nepalese: Gudalu, Saapotaa;

Nicaragua: Nispero;

Pakistan: Cheeku;

Philippines: Chico (Tagalog);

Portuguese: Sapoti, Sapota, Sapotilha;

Puerto Rico: Nispero;

Spanish: Nispero, Sapote (Latin America), Zapote, Zapotillo;

Sri Lanka: Rata-Mi, Sapathilla;

Surinam: Mispel, Mispu, Sapatia, Sapotilie;

Swedish: Sapotillplommon;

Thai: Lámút Farang (Lamut Farang);

Trinidad & Tobago: Sapodilla;

Venezuela: Nispero, Chicozapote;

Vietnamese: Hồng Xiêm, Hong Xuan Dinh, Tam Lu'c, Xabôchê;

Virgin Islands: Mespil;

Yucatan: Ya.

Origin/Distribution

Sapodilla is indigenous to Yucatan and other adjacent areas of southern Mexico, as well as northern Belize and North-eastern Guatemala in Central America. Now widely distributed pan-tropically and frequently naturalized, especially in Central and South America. It is grown extensively in Mexico and India. It was introduced to southeast Asia where it is cultivated commercially especially in the Philippines, Indonesia, Vietnam, Malaysia and Thailand for its fruit.

Agroecology

Sapodilla is an adaptable species, growing from near sea level up to 2,500 m altitude in the tropics and subtropics. However, it does best at lower altitudes on rich, well-drained, sandy loams. It tolerates most soils including calcareous, organic, lateritic gravel, clayey, volcanic and very saline soils. Sapodilla yields poorly in low, wet or water-logged sites. It thrives in full sunny locations. It survives brief, light frost (-2.2°C), strong winds and salt spray and is highly drought resistant.

Edible Plant Parts and Uses

Ripe sapodilla fruit is eaten fresh or used in fruit cups, fruit salads, sherbets, ice cream, butter, jam, syrup or made into preserves. The fruit is excellent when chilled before eating. The fruit pulp can be blended into an egg custard mix before baking. A dessert sauce can be prepared by adding orange juice to the filtrate of the pulp and topping with whipped cream. The fruits can be preserved in syrup. In the Bahamas the ripe fruit is strained, boiled and the juice preserved as syrup. The Bahamians also add mashed sapodilla pulp to pancake batter and to ordinary bread mix before baking. In Malaysia, Philippines and Indonesia, the fruit can be stewed with lime juice or ginger. In Java, the fruit is sometimes fried as *pisang goreng* (fried bananas). In preparing a conserve, adding a little sour orange juice and sugar and cooking the pulp changes the brown colour of the flesh to a pleasant red colour. Ripe sapodilla can also be used in pies or canned as is done in India. In Trinidad, ripe fruits are processed into wine. In Indonesia, young leafy shoots are eaten raw as or steamed, mixed with other vegetables as *lalab* with rice after washing to eliminate the sticky sap. The milky latex is used as raw material for chewing gum.

Botany

An evergreen, erect, lactiferous tree, growing to 20 m high with a dense symmetrical, pyramidal or round crown with a low branched trunk with rough dark brown bark. Grafted or budded trees are much shorter (Plate 1). Leaves are alternate, ovate-elliptic to oblong-lanceolate, 3.5–15 cm long and 1.5–7 cm wide, cuneate or obtusely pointed at both ends or emarginate, entire, tomentose when young becoming glabrous, subcoriaceous, glossy dark green with prominent midrib below and numerous parallel, lateral nerves and borne on 1–3.5 cm long petioles (Plates 2 and 4). Flowers white, 1–1.5 cm across, long pedicelled, 6-merous, solitary in upper leaf axils. Sepals



Plate 1 A grafted prolific bearing sapodilla tree



Plate 2 Close-up of sapodilla fruit and leaves (adaxial and abaxial surfaces)



Plate 3 (a and b) Variegated sapodilla variety



Plate 4 Immature (*left*) and mature, ripe (*right*) sapodilla fruit

unequal, 3 larger than the others, densely brown tomentose outer surface. Petals 6, gamopetalous, campanulate. Stamens 6, opposite the petals with yellowish-brown ovoid-oblong anthers on short filaments; staminodes as many as the petals, petaloid, style exserted and subulate. The fruit is

a globose, ovoid or ellipsoid berry, 3–10×3–8 cm with yellow-brown thin skin, covered with sandy brown scurf (Plates 2–4). Flesh juicy, soft, yellow-brown to red-brown, sweet, gritty textured with 0–12 obovate, 2 cm long, laterally compressed, glossy, black seeds inside.

Nutritive/Medicinal Properties

Food value of raw, sapodilla (*Manilkara zapota*) per 100 g edible portion exclude 20% seeds and skin was reported as follows (USDA 2012): water 78.00 g, energy 83 kcal (347 kJ), protein 0.44 g, total lipid (fat) 1.10 g, ash 0.50 g, carbohydrate 19.96 g; fibre, total dietary 5.3 g, minerals – calcium 21 mg, iron, 0.80 mg, magnesium 12 mg, phosphorus 12 mg, potassium 193 mg, sodium 12 mg, zinc 0.10 mg, copper 0.086 mg Se 0.6 µg; vitamins – vitamin C (total ascorbic acid) 14.7 mg, thiamin 0.00 mg, riboflavin 0.020 mg, niacin 0.200 mg, pantothenic acid 0.2528 mg, vitamin B-6 0.037 mg, folate (total) 14 µg, vitamin A 60 IU, lipids – fatty acids (total saturated) 0.194 g, 16:0 (palmitic acid) 0.1 g, 18:0 (stearic acid) 0.094 g; fatty acids (total monounsaturated) 0.521 g, 18:1 undifferentiated (oleic acid) 0.521 g; fatty acids (total polyunsaturated) 0.011 g, 18:2 undifferentiated (linoleic acid) 0.011 g; amino acids – tryptophan 0.005 g, threonine 0.012 g, isoleucine 0.015 g, leucine 0.024 g, lysine 0.039 g, methionine 0.003 g, phenylalanine 0.013 g, tyrosine 0.014 g, valine 0.016 g, arginine 0.017 g, histidine 0.016 g, alanine 0.014 g, aspartic acid 0.032 g, glutamic acid 0.038 g, glycine 0.017 g, proline 0.036 g and serine 0.018 g.

Chemical composition of sapota fruit juice was reported as pH 5.36, titrable acidity 0.16% (% citric acid), total soluble solids 20.68%, reducing sugar 9.86%, totals sugars 11.06%, protein 312.5 mg/100 g, ascorbic acid 10.52 mg/100 g, carotenoids 0.92 mg/100 g, total phenolics 134.6 mg/100 g, Fe 0.11 mg/l, Cu 0.09 mg/l, Zn 0.5 mg/l, Ca 20.67 mg/l, and K 6.15 mg/l (Kulkarni et al. 2007).

Sapodilla fruit was found to contain large amounts of leucanthocyanidins (Lakshminarayana and Mathew 1967). Polyphenols found in immature sapota fruit were identified as 3'-caffeoylquinic acid and *cis* and *trans* isomer of 5'-caffeoylquinic (Mathew and Lakshminarayana 1969). Simple polyphenols were shown to decrease while polymeric leucoanthocyanidins increased with sapota fruit maturation (Lakshminarayana et al. 1969). The reduction in astringency as the fruit developed had been found

to be due to polymeric changes, the influence of other constituents such as sugar, and 'dilution' of polyphenols by increase in fruit size. The major compounds were leucodelphinidin and leucocyanidin and minor component, leucopelargonidin.

Hemicellulose, rhamnose, galactose, arbinose (monosaccharides characteristics of pectin) and uronic acid concentrations of sapodilla fruit cell wall decreased markedly during postharvest storage (Morais et al. 2008). The neutral sugar rhamnose, galactose, arabinose released from solubilisation of pectic polymers of the cell wall and mannose, glucose and xylose released from hemicellulosic polymers also declined greatly in accord with decline in pectin and hemicellulose concentration during storage. Postharvest treatment with 1-methylcyclopropene (1-MCP) delayed softening of sapodilla for 11 days by hindering cell-wall polysaccharide metabolism. The treatment reduced depolymerisation of pectin and hemicelluloses, slowing down degradation of cell wall by inhibition of hydrolytic enzymes.

Antioxidant Activity

Manilkara zapota was found to be an excellent source of antioxidants, with over 3,000 mg/l ascorbic acid equivalent antioxidant capacity (AEAC) per 100 g of fresh sample (Shui et al. 2004). The antioxidant capacity of chiku fruits was mainly attributed to polyphenolics with basic blocks of galocatechin or catechin or both. The changes of total antioxidant capacity (TAC) and total phenolics content (TPC) of chiku fruits was found to vary. It was found that the TAC and TPC decreased significantly as the fruits gradually changed from the unripe to the overripe stage. The best time to consume chiku fruits at a flavourful stage with high amounts of antioxidants with AEAC values ranging from 600 to 1,200 mg per 100 g fresh sample was suggested. The change of the content of major antioxidant peaks was also consistent with changes of antioxidant levels during storage. Of five plants used in Saurashtra folk medicine, the methanol of *M. zapota* showed the best 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity and highest total

phenol content (Kanerla et al 2009). The extract contained more cardiac glycosides and triterpenes compared to other phytoconstituents.

Sapota fruit juice was found to show potential antioxidant activity against DPPH free radicals and superoxide radicals (Kulkarni et al. 2007).

Sapota juice potentially inhibited the free radical-mediated lipid peroxidation in a liposome model system. Total reducing-power assay revealed the potential reducing power of sapota juice. The multiple radical-scavenging potential of sapota juice was attributed to its nutraceutical components, viz., phenolics, carotenoids and ascorbic acid.

Studies reported that the methanol extract from the fruit of *Manilkara zapota* cv. Tikal resulted in the isolation of two new antioxidants, methyl 4-O-galloylchlorogenate (1) and 4-O-galloylchlorogenic acid (2), along with eight known polyphenolic antioxidants, namely, methyl chlorogenate (3), dihydromyricetin (4), quercitrin (5), myricitrin (6), (+)-catechin (7), (–)-epicatechin (8), (+)-gallocatechin (9), and gallic acid (10) (Ma et al. 2003). Of the 10 polyphenols, compound 1 showed the highest antioxidant activity ($IC_{50} = 12.9 \mu M$) in the DPPH free-radical assay while compound 2 showed high antioxidant activity ($IC_{50} = 23.5 \mu M$) in the DPPH free-radical assay.

Anticancer Activity

The phenolic antioxidant isolated from *M. zapota* fruit, methyl 4-O-galloylchlorogenate displayed cytotoxicity in the HCT-116 and SW-480 human colon cancer cell lines with IC_{50} values of 190 and 160 μM , respectively (Ma et al. 2003). While another 4-O-galloylchlorogenic acid displayed cytotoxicity in the HCT-116 and SW-480 human colon cancer cell lines with IC_{50} values of 154 and 134 μM , respectively. Intraperitoneal administration the ethyl acetate extract of stem bark of *M. zapota* to Swiss albino mice infected with Ehrlich ascites carcinoma (EAC) reduced viable EAC cells, increased the survival time, and restored altered haematological parameters (Abu Osman et al. 2011b). Significant antitumour

efficacy was observed for the stem bark extract at 100 mg/kg dose.

Antimicrobial Activity

Methanol leaf extract of *M. zapota* showed higher antimicrobial activity than the aqueous leaf extract (Nair and Chanda 2008). The acetone extract of *M. zapota* seeds were found to be bactericidal against both Gram-positive and Gram-negative organisms (Kothari and seshadri 2010). *M. zapota* aqueous extract was found to have quorum-sensing (QS) inhibitory activity (Musthafa et al. 2010). It showed significant reduction in against N-acyl-homoserine lactone (AHL)-mediated violacein production in *Chromobacterium violaceum* and pyocyanin pigment, staphylolytic protease, elastase production and biofilm formation in *Pseudomonas aeruginosa*. However, the extract was not inhibitory to bacterial growth, revealing that the QS inhibition by the extract was not related to static or killing effects on the bacteria.

The ethyl acetate extract of stem bark of *M. zapota* exhibited antimicrobial activity against all the pathogenic bacteria used in the study and also showed activity against *Aspergillus flavus*, *Vasianfactum* sp. and *Fusarium* sp. (Abu Osman et al. 2011a). The ethyl acetate extract of leaves exhibited mild activity against *Bacillus subtilis*, *Bacillus megaterium*, *Sarcina lutea*, *Escherichia coli* and *Salmonella typhi*. The minimum inhibitory concentrations (MICs) of the extracts were found to be in the range of 256–512 $\mu g/mL$. The cytotoxicity (LC_{50}) against brine shrimp nauplii (*Artemia salina*) were also evaluated and found to be 16.17 $\mu g/mL$ for ethyl acetate extract of leaves, 50.26 $\mu g/mL$ for ethyl acetate extract of stem bark and 12.38 $\mu g/mL$ for ampicillin trihydrate. The extracts were found to contain terpenoids, glycosides and flavonoids type compounds.

Analgesic Activity

The petroleum ether and ethanolic extracts of *Manilkara zapota* leaves at doses of 200 mg/kg were found to possess analgesic effect in

laboratory animals, using the hot plate method (Jain et al. 2011).

Potential in Drug Formulation

M. zapota fruit pulp was reported to contain saponin, saponin, fixed oils and bitter alkaloids (Madhav and Khurana 2011). A novel potent bio-emulsifier extracted from the fruit pulp was found to have potential in formulating microemulsions of the anti-depressant drug, escitalopram.

Traditional Medicinal Uses

The fruits, seeds, flowers, leaves and bark have been used in traditional folk medicine. Unripe fruits is high in tannins and is astringent. It is boiled and the decoction taken to halt diarrhoea. An infusion of the young fruits and the flowers is drunk to relieve pulmonary complaints. In Java the flowers together with other ingredients are pounded to make a powder or param that is rubbed over the body of a woman after childbirth. The seed contains saponins and quercetin and are aperient, diuretic, tonic and febrifuge. The crushed seeds have a diuretic action and are claimed to expel bladder and kidney stones. An aqueous extract of the crushed seeds is employed in Yucatan as a sedative and soporific. A paste of the seeds is applied on stings and bites

from venomous animals. A decoction of old, yellowed leaves is drunk as a remedy for coughs, colds and diarrhoea. A combined decoction of sapodilla and *Sechium edule* leaves is sweetened and taken daily to lower blood pressure. The latex is used in the tropics as a crude filling for tooth cavities. The bark is antibiotic, astringent and febrifuge. It is used as tonic and a bark decoction is given in diarrhoea, dysentery and paludism.

Other Uses

A major product of the tree is the gummy latex called chicle. Chicle has been used as the chief ingredient for chewing gum but to a large extent has been replaced by latex from other species and by synthetic gums. Among the miscellaneous industrial applications the latex is utilised as bird-lime, as an adhesive in mending small articles in India; it has been utilized in dental surgery, and as a substitute for gutta percha. The Aztecs used it for modelling figurines. In the Philippines, the tannin-rich bark is used by fishermen to tint their sails and fishing lines.

The timber is hard, strong and durable. Sapodilla timbers which were used for lintels and supporting beams in Mayan temples have been found intact in the ruins. It has also been employed for railway crossties, flooring, native carts, tool handles, shuttles and rulers. The red heartwood is used to make archer's bows, banisters, cabinet-work and furniture.



Plate 5 (a and b) Sapodilla fruit scrubbed to remove the sandy, brown scurf on its surface to make it more appealing to consumers

Synthesized silver nanoparticles (Ag NPs) and aqueous leaf extract of *M. zapota* was found to have acaricidal activity against *Rhipicephalus (Boophilus) microplus* (Rajakumar and Abdul Rahuman 2011). The leaf extract had an LC₅₀ value of 16.75 mg/L. Separate studies showed that synthesized silver nanoparticles (Ag NPs) and leaf aqueous extract of *Manilkara zapota* exhibited feeding deterrent activity of adult house fly, *Musca domestica* (Kamaraj et al. 2011).

Comments

There is also a variegated sapodilla variety (Plate 3). Sapodilla fruits are usually scrubbed to remove the sandy brown scurf on its surface to make it more appealing to consumers (Plate 5) in several countries in southeast Asia.

Selected References

- Abu Osman M, Abdul Aziz MA, Habib MR, Karim MR (2011a) Antimicrobial investigation on *Manilkara zapota* (L.) P. Royen. *Int J Drug Dev Res* 3(1):185–190
- Abu Osman M, Rashid MM, Abdul Aziz MA, Habib MR, Karim MR (2011b) Inhibition of Ehrlich ascites carcinoma by *Manilkara zapota* L. stem bark in Swiss albino mice. *Asian Pac J Trop Biomed* 1(6):448–451
- Brown WH (1951–1957) Useful plants of the Philippines. Reprint of the 1941–1943 edition, 3 vols. Technical Bulletin 10. Department of Agriculture and Natural Resources. Bureau of Printing, Manila, vol 1 (1951), 590 pp, vol 2 (1954), 513 pp, vol 3 (1957), 507 pp
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula, Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Coronel RE (1992) *Manilkara zapota* (L.) P. van Royen. In: Verheij EWM, Coronel RE (eds) Plant resources of South-East Asia. No. 2: edible fruits and nuts. Prosea Foundation, Bogor, pp 220–223
- Council of Scientific and Industrial Research (1962) The wealth of India. A dictionary of Indian raw materials and industrial products (Raw Materials 6). Publications and Information Directorate, New Delhi
- Govaerts R, Harvey Y, Jessup L, Pennington TD, Vink W (2012) World checklist of Sapotaceae. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; <http://apps.kew.org/wcsp/>. Retrieved 22 July 2012
- Jain PK, Soni P, Upmanyu N, Shivhare Y (2011) Evaluation of analgesic activity of *Manilkara zapota* (Leaves). *Eur J Exp Biol* 1(1):14–17
- Kamaraj C, Rajakumar G, Rahuman AA, Velayutham K, Bagavan A, Zahir AA, Elango G (2011) Feeding deterrent activity of synthesized silver nanoparticles using *Manilkara zapota* leaf extract against the house fly, *Musca domestica* (Diptera: Muscidae). *Parasitol Res* 2011:1–10
- Kaneria M, Baravalia Y, Vaghasiya Y, Chanda S (2009) Determination of antibacterial and antioxidant potential of some medicinal plants from saurashtra region, India. *Indian J Pharm Sci* 71(4):406–412
- Kothari V, Seshadri S (2010) In vitro antibacterial activity in seed extracts of *Manilkara zapota*, *Annona squamosa*, and *Tamarindus indica*. *Biol Res* 43(2):165–168
- Kulkarni AP, Policegoudra RS, Aradhya SM (2007) Chemical composition and antioxidant activity of sapota (*Achras zapota* Linn.) fruit. *J Food Biochem* 31:399–414
- Lakshminarayana S, Mathew AG (1967) Leucoanthocyanidins of sapota fruit. *J Food Sci* 32:451–452
- Lakshminarayana S, Mathew AG, Parpia HAB (1969) Changes in polyphenols of sapota fruit (*Achras zapota* L.) during maturation. *J Sci Food Agric* 20:651–653
- Ma J, Luo XD, Protiva P, Yang H, Ma C, Basile MJ, Weinstein IB, Kennelly EJ (2003) Bioactive novel polyphenols from the fruit of *Manilkara zapota* (Sapodilla). *J Nat Prod* 66(7):983–986
- Madhav NVS, Khurana S (2011) A novel, potent, bioemulsifier from the fruit of *Manilkara zapota* for formulating Escitalopram microemulsions. *Int J Pharmtech Res* 3(2):929–933
- Mathew AG, Lakshminarayana S (1969) Polyphenols of immature sapota fruit. *Phytochemistry* 8:507–509
- Morais PLD, Miranda MRA, Lima LCO, Alves JD, Alves RE, Silva JD (2008) Cell wall biochemistry of sapodilla (*Manilkara zapota*) submitted to 1-methylcyclopropene. *Braz J Plant Physiol* 20:85–94
- Morton JF (1987) Fruits of warm climates. Julia F. Morton, Miami, pp 393–398
- Musthafa KS, Ravi AV, Annapoorani A, Packiavathy IS, Pandian SK (2010) Evaluation of anti-quorum-sensing activity of edible plants and fruits through inhibition of the N-acyl-homoserine lactone system in *Chromobacterium violaceum* and *Pseudomonas aeruginosa*. *Chemotherapy* 56(4):333–339
- Nair R, Chanda S (2008) Antimicrobial activity of *Terminalia catappa*, *Manilkara zapota* and *Piper betel* leaf extract. *Indian J Pharm Sci* 70(3):390–393
- Ochse JJ, van den Brink Bakhuizen RC (1931) Fruits and fruitculture in the Dutch East Indies. G. Kolff & Co, Batavia-C, 180 pp

- Ochse JJ, van den Brink Bakhuizen RC (1980) Vegetables of the Dutch Indies, 3rd edition. Ascher & Co., Amsterdam, 1016 pp
- Pennington TD (1990) Sapotaceae. Flora Neotropica: Monograph. 52. New York Bot. Garden, New York, 770 pp
- Pennington TD (1991) The genera of the Sapotaceae. Kew Publishing, New York, 307 pp
- Rajakumar G, Abdul Rahuman A (2011) Acaricidal activity of aqueous extract and synthesized silver nanoparticles from *Manilkara zapota* against *Rhipicephalus (Boophilus) microplus*. Res Vet Sci 93(1):303–309
- Shui G, Wong SP, Leong LP (2004) Characterization of antioxidants and change of antioxidant levels during storage of *Manilkara zapota* L. J Agric Food Chem 52(26):7834–7841
- Standley PC, Williams LO (1967) Sapotaceae. In: Standley PC, Williams LO (eds) Flora of Guatemala – Part VIII, Number 3. Fieldiana, Bot 24(8/3):211–244
- U.S. Department of Agriculture, Agricultural Research Service (USDA) (2012) USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory Home Page, <http://www.ars.usda.gov/ba/bhnrc/ndl>

Mimusops elengi

Scientific Name

Mimusops elengi L.

Synonyms

Imbricaria perroudii Montrouz., *Kaukenia elengi* (L.) Kuntze, *Kaukenia javensis* (Burck) Kuntze, *Kaukenia timorensis* (Burck) Kuntze, *Magnolia xerophila* P. Parm., *Manilkara parvifolia* (R.Br.) Dubard, *Mimusops elengi* var. *parvifolia* (R.Br.) H.J. Lam, *Mimusops erythroxylon* Llanos ex Fern.-Vill. nom. illeg., *Mimusops javensis* Burck, *Mimusops latericia* Elmer, *Mimusops lucida* Poir., *Mimusops parvifolia* R.Br., *Mimusops timorensis* Burck.

Family

Sapotaceae

Common/English Names

Asian Bulletwood, Bullet Wood Tree, Indian Medlar, Red Coondoo Spanish Cherry.

Vernacular Names

Burmese: Kaya;

French: Coing de chine, élendi Marouc, Ravalli;

India: Boal, Bokul, Gokul (Assamese), Bakal, Bakul, Bohl, Bokul, Bukal (Bengali), Bakul, Bolsari, Maulsarau, Maulser, Maulsari, Maulsiri, Molsari, Molsiri, Morsali Mulsari, Tendu, (Hindu), Baagala Mara, Backhul, Bagada, Bagala, Bakkula, Bakul, Bakula, Bhagal, Bogada, Bokal, Boklu, Buckhul, Bukul, Halmadhu, Kaalaale, Kaesara, Kalhaale, Kalhale, Kallaala, Kanja, Kesara, Minjulu, Mugali, Mugula, Mugule, Mulasari, Najalu Mara, Nanja Okula, Pagade, Pagade-Mara, Pagade Mara, Pagademara, Pokkalthu, Pogade, Ranjal, Ranje, Renjil, Pokkalathu, Ranja, Ranjalu, Renje, Renge, Renji, Renjyamboro, Vakula, (Kannada), Bakulam, Elangi, Elani, Elanni, Elengi, Elengii, Elenjee, Erini, Ilanni, Iranni, Makira, Makura Makuram, Mukura (Malayalam), Bokul (Manipuri), Bakhor, Bakul, Bakula, Barsoli, Bkhor, Omval, Ovalli, Owli, Raini, Ranjanasal, Vavoli, Woval, Wowli (Marathi), Simshakesara (Oriya), Anangaka, Bakul, Bakula, Bakulah, Chirapushpa, Cirapuspa, Dhanvi, Dohala, Gudhapushpaka, Kantha, Karuka, Kesara, Kesarapa, Keshara, Madhugandha, Madhupanjara, Madhupushpa, Mukula,

Padyamoda, Sharadika, Sidhugandha, Simhakesara, Sindhugandha, Sinhakesara, Sthirakusuma, Strimukhagandha, Strimukhamadhu, Surabhi, Tailanga, Vakula, Varalahdha, Visharada (*Sanskrit*), Alagu, Ilanci, Ilanji, Kecaram, Kesaram, Kosaram, Magil, Magilam, Magish, Magizham, Mahila, Makilam, Makilam Maram, Makilam Vittu, Makilampu, Makizampu, Mogadam, Makulampu, Magadam, Magizh, Maghizham, Mogidam, Vagulam, Vakulam, Vakulampu (*Tamil*), Bogada, Kaesara, Kasara, Kesara, Nemmi, Nunni, Paarijaatham, Pagada, Pagade Chettu, Pal, Parijatamu, Pogada, Pogada-Manu, Pogada Manu, Pogadoo, Poghada, Vakula, Vakulamu (*Telugu*), Maulsari, Mulsari (*Urdu*);

Indonesia: Tanjung, Karikis, Tanjung Laut;

Laotian: 'Sa Koun, Phi Koun;

Malaysia: Bitis, Bunga Tanjong, Elengi, Mansari, Mengkulu, Nyatoh Batu, Pokok Tanjung;

Pakistan: Bakul, Molsari;

Philippines: Bansalagin, Bansalagon (*Bikol*), Kabibi, Talipopo (*Bisaya*), Pagagan, Papagan, Pappagin, Pappaian (*Ibanag*), Pagapagan, Palpogan, Pamalitien (*Iloko*), Talipopo (*Kuyonon*), Anosep (*Pangasinan*), Bansalagin, Bansalagon, Ligayan (*Sulu*), Bansalagin, Barsik Basal, Pasek, Kabibi Tagatoi Tugatoi (*Tagalog*);

Portuguese: Vonvoleiro;

Sri Lanka: Munamal (*Sinhalese*);

Thailand: Kun, Kaeo, Phikun;

Tibetan: Ba Gu La, Ba Ku La;

Vietnamese: Cat, Cay, Se, Viet.

Origin/Distribution

The species is native to India, Sri Lanka, the Andaman Islands, Myanmar, Indo-China, Peninsular Malaysia to Vanuatu; introduced and cultivated elsewhere.

Agroecology

Mimusops elengi is tropical and subtropical in climatic requirement. It occurs in maritime habitats along the coast, in coastal vine thickets, lowland inland rainforest, and in rocky localities from sea

level to 600 m elevation. It thrives in areas with high humidity and seasonal rainfall and seasonal dry periods. It tolerates brief periods of water logging but requires fertile soil. It is fairly tolerant of brief light frost.

Edible Plant Parts and Uses

The ripe fruit is eaten; it is sometimes used for making preserves and pickles. The seed yields an oil which can be used for cooking.

Botany

Evergreen, small to medium-sized, much-branched tree up to 30 m tall with cylindrical trunk 100 cm in diameter. The bark is dark grey, fissured sometimes peeling off in flaky scales. Leaves are arranged spirally, more or less in clusters at the ends of branches, on grooved, 1–3.5 cm long petiole with minute and caducous stipules. The lamina is entire, simple, ovate to elliptical or oblong-elliptical, 3.5–4.5 × 7–10.5 cm, base cuneate, apex acuminate, with slightly wavy margins and 10–20 pairs of lateral veins (Plates 2 and 3). Flowers are axillary, solitary (Plate 1) or in fascicles of up to 6, creamy white, fragrant, 15 mm in diameter, bisexual or functionally unisexual, and borne on 2 cm long, hairy pedicel. Sepals are in 2 whorls of 4; corolla is creamy-white, with a short tube and 8 lobes each deeply divided into 3, approximately 1 cm long; stamens 8, alternating with 8 staminodes; ovary superior,

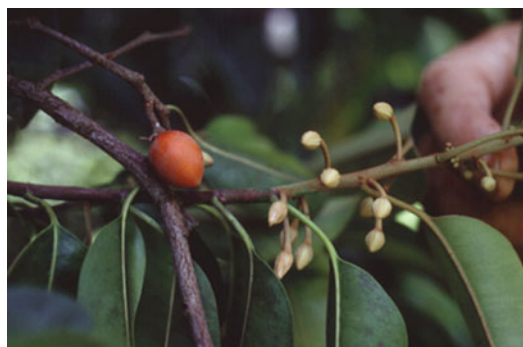


Plate 1 Ripe fruit and flower buds of *Mimusops elengi*



Plate 2 Ripe and unripe fruits and leaves



Plate 3 Ripe fruits

pubescent and (6–) 8-celled. Fruit an ovoid to ellipsoid, fleshy berry, 2–4 cm long, orange-red when ripe (Plates 1–3), 1–2-seeded and with a persistent calyx. Seeds up to 2 cm long, laterally compressed, with a small circular basal scar, endospermic and dicotyledonous.

Nutritive/Medicinal Properties

The fruit is rich in calcium, potassium and sodium and is fairly rich in vitamin C and niacin. The nutrient composition of the raw fruit per 100 g edible portion was reported as follows: energy 48 kJ, moisture 46.6 g, protein 2.9 g, nitrogen 0.46, calcium 139 mg, potassium 499 mg, sodium

172 mg, niacin (derived from tryptophan or protein) 0.5 mg, niacin equivalents 0.5 mg and vitamin C 233 mg (Brand Miller et al. 1993).

The seed kernel was found to contain about 22% oil. The fatty acid composition of the refined oil is: oleic acid 64%, linoleic acid 14.5%, palmitic acid 11%, stearic acid 10% and behenic acid 0.5% (Mandal and Maity 1991). The nutritional quality of the refined oil was comparable with that of groundnut oil in feeding tests with rats. Solubility of the protein concentrate from the seeds was minimum at pH 4.0. Water and oil holding capacities of the seed protein concentrate were 1.70 g/g and 3.23 g/g respectively. Minimum foaming capacity, minimum emulsifying activity, minimum emulsion stability and maximum foam stability were found at pH 4.0. The emulsion stability of the protein concentrate was high (above 88.3%) over the pH range of 2–10.

Other Phytochemicals

Chemical constituents reported from *Mimusops elengi* extracts included 3 β -hydroxy-lup-20(29)-ene-23,28-dioic acid, triterpenes, β -amyrin, lupeol, α -taraxerol and ursolic acid (Jahan et al. 1995); taraxerol, taraxerone, ursolic acid, betulinic acid, α -spinosterol, β -sitosterol glycoside, quercitol from fruit and seed (Misra and Mitra 1967); triterpenoid saponins, such as mimusopsides A and B, mimusopin, mimusopsin, mimusin, mi-saponin A and 16 α -hydroxy mi-saponin from fruits (Chaisuksant et al. 2008); triterpenoid saponins, mimusopin and mimusopsin were isolated from the seeds (Sahu et al. 1995); taxifolin, α -spinasterol glucoside, mi-glycoside 1, triterpenoid saponins mimusopside A and B, pentacyclic triterpenes, such as mimusopgenone and mimugenone from seeds (Sahu 1996); saponins such as mimusin, misaponin A and 16 α -hydroxy mi-saponin A from seeds (Sahu et al. 1997); pentacyclic triterpenes, such as mimusopgenone and mimugenone in the seeds (Sen et al. 1995). Two pentacyclic triterpene acids, mimusopic and mimusopsic acids, possessing the novel migrated oleanane skeleton, mimusopane were isolated from the seeds of

Mimusops elengi and elucidated as 2 β , 3 β , 23-trihydroxy-5, 10-friedooleana-9, 12-dien-28-oic acid and 2 β , 3 β -dihydroxy (23 $\rightarrow$ 10)-oxido-5, 10-friedooleana-9(11), 12-dien-28-oic acid (Sen et al. 1993). Six saponins were isolated from the seed kernel of *Mimusops elengi*, *M. hexandra* and *M. manilkara* (Lavaud et al. 1996). Three of them were new compounds: 3-O-(β -D-glucuronopyranosyl) 28-O-(α -L-rhamnopyranosyl(1 $\rightarrow$ 3) β -D-xylopyranosyl(1 $\rightarrow$ 4) [α -L-rhamnopyranosyl(1 $\rightarrow$ 3)] α -L-rhamnopyranosyl(1 $\rightarrow$ 2) α -L-arabinopyranosyl) protobassic acid; 3-O-(β -D-glucuronopyranosyl) 28-O-(α -L-rhamnopyranosyl(1 $\rightarrow$ 3) β -D-xylopyranosyl(1 $\rightarrow$ 4) α -L-rhamnopyranosyl(1 $\rightarrow$ 2) α -L-arabinopyranosyl) 16- α -hydroxyprotobassic acid; and 3-O-(β -D-glucopyranosyl(1 $\rightarrow$ 3) β -D-glucopyranosyl) 28-O-(α -L-rhamnopyranosyl(1 $\rightarrow$ 3) β -D-xylopyranosyl(1 $\rightarrow$ 4) α -L-rhamnopyranosyl(1 $\rightarrow$ 2) α -L-arabinopyranosyl) protobassic acid.

From the bark, two pentacyclic triterpenes 3 β ,6 β ,19 α ,23-tetrahydroxy-urs-12-ene (1) and 1 β -hydroxy-3 β -hexanoyllup-20 (29)-ene-23, 28-dioic acid (2) were isolated (Jahan et al. 2001) and lupeol from heartwood and root (Misra and Mitra 1968). A new farnane-type pentacyclic triterpene, farnan-2-one-3 β -ol (mimusopfarnanol), was isolated from the stem bark along with the known triterpenoids, farnan-3-one, olean-18-en-2-one-3-ol and lup-20 (29)-en-3 β -ol (Akhtar et al. 2009). Gallic acid esters, characterised as phenyl propanoxyl gallate (1), β -D-glucopyranosyl(6' $\rightarrow$ 1'')- β -D-glucopyranosyl-4''-(4'-ethylphenyl) gallate (2), 2'-(1'''-geranyloxy)- β -D-glucopyranosyl(6' $\rightarrow$ 1'')- β -D-glucopyranosyl-4''-phenoxy gallate (3), β -D-glucopyranosyl(6' $\rightarrow$ 1'')- β -D-glucopyranosyl 3,4,5-trihydroxy benzoate (4), β -D-glucopyranosyl-(6' $\rightarrow$ 1'')- β -D-glucopyranosyl-4''-(4''-n-butylphenyl) 3,4,5-trihydroxy benzoate (5), β -D-glucopyranosyl(6' $\rightarrow$ 1'')- β -D-rhamnosyl 3,4,5-trihydroxy benzoate (6) and β -D-(2'-phenyl glucopyranosyl)-(6' $\rightarrow$ 1'')-(2'',4''-diphenylrhamnopyranosyl)-3,4,5-trihydroxybenzoate (7), along with the known compounds: farnon-3-one, stigmasta-5-en-3- β -ol, olean-18-en-2-one-3-ol, lup-20(29)-en-3- β -ol and stigmasta-5-en-3 β -D-glucopyranoside were isolated from the stem bark (Akhtar et al. 2010)

Leaves were found to contain quercetin, 19.191 mg/g, in powdered leaf sample (Sehgal et al. 2011). A secondary metabolite, dibutyl phthalate, was isolated from *M. elengi* plant (Ruikar et al. 2011).

As seen from the above, various parts of the tree contains medicinally-important bioactive chemicals, particularly the triterpenes and alkaloids. Preclinical studies in the past 5 years have shown that the extracts prepared from Bakul possess antibacterial, antifungal, anticariogenic, free radical scavenging, antihyperglycemic, antineoplastic, gastroprotective, antinociceptive and diuretic effects, thus lending pharmacological support to the tree's ethnomedicinal uses in Ayurveda (Baliga et al. 2011). Some pharmacological properties of *M. elengi* are elaborated below.

Antioxidant Activity

Mimusops elengi fruit is a good source of natural antioxidant. The antioxidant capacity values of the various fractions free phenolic acids (F1), soluble phenolic esters (F2) and insoluble phenolic acid esters (F3), expressed as gallic acid equivalents (GAE) by ABTS assay for immature and mature fruits were determined in the range of 13.5–441.7 mg/g extract with relative capacities being F2>F3>F1 (Boonyuen et al. 2009). The GAE values for ripe fruits were in the range of 192.3–212.5 mg/g extract with relative values of F2=F3>F1. The antioxidant capacity of the crude extract from immature fruit (GAE=318.5 mg/g extract) was higher than that of either the mature (GAE=234.1 mg/g extract) or the ripe fruit (GAE=111.9 mg/g extract). High performance liquid chromatographic analysis confirmed that all phenolic fractions contained gallic acid as a constituent. The total phenolic contents determined by the Folin-Denis assay were consistent with the antioxidant capacity.

The leaf extract showed significant activities in all antioxidant assay namely 1, 1-diphenyl-2-picrylhydrazyl (DPPH) scavenging assay, reducing power and total antioxidant capacity assays compared to the reference antioxidant ascorbic acid in a dose dependent manner (Saha et al.

2008). In DPPH scavenging assay the IC_{50} value of the extract was found to be 43.26 $\mu\text{g/mL}$ while the IC_{50} value of the reference standard ascorbic acid was 58.92 $\mu\text{g/mL}$. Total antioxidant activity was also found to increase in a dose dependent manner. Further, *M. elengi* leaf extract showed strong reducing power. In another study, the methanol leaf extract showed significant antioxidant activity in DPPH free radical and nitric oxide scavenging assays (Karmakar et al. 2011).

Methanol bark extract of *Mimusops elengi* exhibited antioxidant activity (Rao et al. 2011). The IC_{50} values of methanol extract in DPPH radical, nitric oxide, ABTS radical and hydroxyl radical were determined to be 2.2 $\mu\text{g/mL}$, 158.49 $\mu\text{g/mL}$, 7.69 $\mu\text{g/mL}$ and 3 $\mu\text{g/mL}$ respectively. In comparison the IC_{50} values for the standard ascorbic acid were 0.66 $\mu\text{g/mL}$, 200 $\mu\text{g/mL}$, 0.7 $\mu\text{g/mL}$ and 1 $\mu\text{g/mL}$ respectively. Total phenolic content measured by Folin–Ciocalteu reagent was 698.7 mg/g which was found significantly higher when compared to reference standard gallic acid

Antimicrobial/Antiviral Activities

Two pentahydroxy flavones 2,3-dihydro-3,3',4',5,7-pentahydroxyflavone and 3,3',4',5,7-pentahydroxyflavone from the seeds showed strong inhibitory activity against Gram positive and Gram negative bacteria (Hazra et al. 2007). The triterpene, mimusopic acid, from seed possessing the novel migrated oleanane skeleton, mimusopane, exhibited anti-HIV reverse transcriptase activity and modification of this novel compound may lead to more potent bioactive substances (Sahu et al. 2001). Moreover, the saponins present also exhibited antifungal activity against some human pathogens. *M. elengi* fruit extracts were less potent against most of the tested bacterial and fungal organisms compared to those obtained from bark and leaves and were inactive against the fungus *Trichoderma viride* (Ali et al. 2008). Leaves extracts displayed good activity against *Bacillus subtilis* and *Trichoderma viride* but were inactive against *Helminthosporium sativum*. The stem bark extracts showed antibacterial activity against Gram positive and Gram negative

strains viz. *Nocardia asteroides*, *Micrococcus luteus*, *Bacillus subtilis*, *Bacillus licheniformis*, *Proteus mirabilis* and *Salmonella typhimurium* (Shahwar and Raza 2009). The fruit and seed extracts were inactive. The ethyl acetate extract exhibited the highest inhibition (84.5% age, $MIC=0.6$ mg/mL) against *B. subtilis*. The aqueous methanol (2:8) extract also showed significant results with 74.9% inhibition ($MIC=0.9$ mg/mL) against *N. asteroides*. The acetone bark extract was found to be more effective of the various extracts in antimicrobial activity in-vitro against the oral microflora (Deshpande et al. 2010).

Antineoplastic Activity

Mimusops elengi plant extract exhibited promising activity against the human cholangiocarcinoma CL-6 cell line with survival of less than 50% at the concentration of 50 $\mu\text{g/mL}$ (Mahavorasirikul et al. 2010). The methanol leaf extract exhibited an LC_{50} of 80 $\mu\text{g/mL}$ and LC_{90} of 320 $\mu\text{g/mL}$ in the brine shrimp lethality bioassay as an indicator of cytotoxicity (Karmakar et al. 2011)

Antihyperglycemic Activity

Two new triterpenes, $3\beta,19\alpha,23$ -trihydroxy-urs-12-ene (1) and 3β -(*p*-hydroxy-*cis*-cinnamoyloxy) urs-12-en-28-oic acid (2) were isolated from the methanolic extract of *Mimusops elengi* along with 3β -(*p*-hydroxy-*trans*-cinnamoyloxy)urs-12-en-28-oic acid (3), and ursolic acid (4) (Jahan et al. 2000). Compounds (3) and (4) were found to exhibit potent inhibitory activity against α -glucosidase enzyme. The enzyme α -glucosidase catalyzes the final step in the digestive process of carbohydrates, and hence α -glucosidase inhibitors could retard the absorption of glucose. The aqueous extract of *M. elengi* exhibited reducing power as well as DPPH and OH radical scavenging activity in-vitro and antihyperglycemic activity (Ganu and Jadhav 2010). In in alloxan-induced diabetes. The extract may act by increasing peripheral utilization of glucose.

The methanol bark extract of *M. elengi* exerted significant in-vitro reducing power capacity and

radical scavenging activity (Ganu et al. 2011b). The extract exhibited significant antihyperglycemic effect activity in alloxan-induced diabetic as well as non diabetic glucose loaded mice producing significant reduction in elevated glucose levels.

Hypotensive Activity

Recent studies also reported that methanolic extract of *Mimusops elengi* caused hypotensive activity in anaesthetized rats (Dar et al. 1999). On intravenous administration at 2–16 mg/kg, it produced a 7–38% fall in mean arterial blood pressure, in a dose-dependent manner. The effect was independent of adrenergic, muscarinic and histaminergic receptors. The data indicated that *M. elengi* may possess calcium-blocking activity which would explain its hypotensive effect.

Gastroprotective Activity

A pentacyclic triterpene 3 β , 6 β , 19 α , 23-tetrahydro-urs-12-ene reported from bark recorded moderate inhibiting activity against β -glucuronidase enzyme associated with gastric ulcers (Jahan et al. 2001). Studies reported that ethyl acetate fraction of 50% alcoholic extract of *Mimusops elengi* possessed anti-ulcer activity against experimental gastric ulcers (Shah et al. 2003). The extract at the doses of 10, 50 and 100 mg/kg showed dose-dependent inhibition of gastric lesions against ethanol-induced gastric damage. Significant reduction was also observed in total acidity, volume of gastric acid secretion, total acid output and pepsin activity when compared with the control group. The extract also showed protection against water-immersion plus stress-induced gastric lesions that was evident from dose-dependent decrease in ulcer index, score for intensity and total lesion area when compared with the control group. The study concluded that the mechanism of anti-ulcer activity could be attributed to decrease in gastric acid secretory activity along with strengthening of mucosal defensive mechanisms.

Antiinflammatory Activity

The ethanol bark extract of *Mimusops elengi* (200 mg/kg, p.o) significantly inhibited the carrageenan-induced paw oedema at 3rd and 4th hour and in cotton pellet model it reduced the transudative weight and little extent of granuloma weight (Purnima et al. 2010).

Antihyperlipidemic Activity

Rats on high fat diet treated with the combined extracts of *Mimusops elengi* and *Moringa oleifera* had a significant decrease in total cholesterol, LDL (low density lipoprotein), triglyceride and increase in high density lipoprotein levels (Satishchandra and Sumithra 2011). The combined extract treated animals showed significant reduction in lipid peroxidation and increased levels of superoxidase dismutase and catalase activities. *M. elengi* showed better antihyperlipidemic effect than *Moringa* but when combined had a significant synergistic effect. Another earlier study also showed that *M. elengi* extract exhibited antihyperlipidemic activity in Triton WR-1339 induced hyperlipidaemia in rats (Ghaisas et al. 2008).

Anxiolytic Activity

Using the elevated maize test with Swiss albino mice, the methanol bark extract of *M. elengi* was found to have significantly more anxiolytic activity than the aqueous and n-butanol extracts (Ganu et al. 2011a). The activity of methanol extract at 200 mg/kg was comparable to diazepam.

Antiuro lithiatic Activity

Studies found that alcohol extracts of *Mimusops elengi* bark possessed potent antiuro lithiatic activity (Ashok et al. 2010). The increased deposition of stone forming constituents in the kidneys of calculogenic rats were significantly lowered by curative and preventive treatment

with the extract. The extract also produced significant decrease in malondialdehyde, and increased glutathione (GSH), superoxide dismutase (SOD), and catalase (CAT). The extract was safe orally and exhibited no gross behavioral changes in the rats.

Antinociceptive Activity

In the acetic acid-induced writhing and Eddy's hot plate models the ethanol extract of *Mimusops elengi* decreased the acetic acid-induced writhing and it also reduced the rat rectal temperature in Brewer's yeast induced pyrexia (Purnima et al. 2010). The methanol leaf extract at doses of 250 mg/kg and 500 mg/kg body weight produced 45.6% and 63.85% writhing inhibition in the acetic acid induced writhing of white albino mice, respectively which was comparable to the standard reference diclonfenac sodium (76.69% at 250 mg/kg body weight) (Karmakar et al. 2011). In the hot plate test, the extract exerted significant prolongation in the response of latency time to heat stimulus.

Diuretic Activity

Animal studies showed that the alcoholic bark extract of *M. elengi* produced the highest diuretic activity (Koti and Ashok 2010). No such activity was observed with the chloroform and petroleum ether extract. A potent diuretic and electrolyte excretion activity was observed with the alcoholic extract.

Anthelmintic Activity

The crude alcoholic extract and its ethyl acetate and n-butanol fractions of the stem bark significantly demonstrated paralysis, and also caused death of *Pheretima posthuma* and *Ascaridia galli* worms especially at higher concentration of 100 mg/mL, as compared to standard reference piperazine citrate (Mali et al. 2007). The results confirmed the traditional use of bark of *M. elengi* as an anthelmintic.

Traditional Medicinal Uses

The bark, flowers, fruits and seeds of *Mimusops elengi* are considered astringent, cooling, anthelmintic, tonic, and febrifuge in traditional medicine. In Ayurvedic medicine, it is commonly used for treating dental disorders like bleeding gum's, pyorrhea, dental caries and loose teeth. In India, the fruits are used in chronic dysentery, constipations and to relieve burning urination. Pulverised ripe fruit mixed with water is administered to promote delivery in childbirth. Flowers are used against heart diseases, leucorrhoea, menorrhagia and act as antidiuretic in polyuria and antitoxin. Flowers are also used as snuff to relieve cephalalgia and as lotion for wounds and ulcers. Powdered flowers are used in a disease called *Ahwa* in which strong fever, headache and pain in the neck, shoulders and other parts of the body occurs and as brain tonic. The bark is used as a gargle for odontopathy, ulitis and ulemorrhagia. Barks are used to increase fertility in women and known to have antiulcer activity. The tender stems are used as tooth brushes, and in cystorrhea, diarrhoea and dysentery.

In Asia, the leaves are used medicinally to treat headache, toothache, wounds and sore eyes, and are smoked to cure infections of the nose and mouth. A decoction of the bark, sometimes mixed with the flowers, has been used against fever, diarrhoea, inflammation of the gums, toothache, gonorrhoea, wounds and, mixed with tamarind bark, as a lotion for skin complaints. The flowers have been used against diarrhoea. The young fruits have been employed in a gargle for treating gum disorders. The pounded seeds are used to cure obstinate constipation. In the Philippines, the bark, as well as the ripe fruit, yields a powerful astringent remedy. Both are used as a gargle to strengthen the gums. They are further employed in lotions for ulcers, and in urethral injections for gonorrhoea. The bark is astringent and tonic and is used in diarrhoea and dysentery.

In Sarawak, the Malays prepare a paste of the leaves with the dry skin of shallot and rub on the nose and forehead to alleviate painful and itchy nose. The Melanau boil the leaves

with spices that include ketumbar (*Coriander sativum*), cinnamon bark, cloves, fennel and gadung (*Dioscorea hispida*) and drink the concoction to treat leprosy and grey hair in young people.

Other Uses

Mimusops elengi is usually planted for its timber and as an ornamental and shade tree in gardens and along roads, also in coastal sites in Asia. Its wood is luxurious, heavy, hard, strong and durable wood and is well known in Asia. The wood is used for heavy general construction, bridge building, boat and shipbuilding, marine construction, flooring, bearings, doors, framing agricultural implements and oil mills. It has also been used for poles and piles, furniture, foundation sills, railway sleepers, paving blocks, mine timber, and cabinet work, vehicle bodies and wheels, turnery, tool handles, walking sticks, weaving shuttles, toys, sporting goods and musical instruments. The wood is useful in the Philippines and is a favourite for ships' wheels, marine-spikes, fine tool-handles, etc. In Africa the wood is considered good for mortars. A good-quality veneer and plywood can be manufactured from the wood. The tree also provides good fuel-wood. In India the bark has been used for tanning, but the tannin content is low. In Ghana the bark is used for toughening and colouring tackle.

The fresh flowers are used for making fragrant garlands, as necklaces for decoration or placed in linen-cupboards. The flowers yield an oil which is used as perfume. The seeds are also used for necklaces. The seeds yield an oil on pressing, which has been used for cooking and illumination.

Comments

M. elengi can be readily propagated from seeds or cuttings.

Selected References

- Akhtar N, Ali M, Alam MS (2009) Pentacyclic triterpenes from the stem bark of *Mimusops elengi* L. *Acta Poloniae Pharm* 66(5):549–552
- Akhtar N, Ali M, Alam MS (2010) Gallic acid esters from the stem bark of *Mimusops elengi* L. *Nat Prod Res* 24(10):962–972
- Ali MA, Mozid MA, Yeasmin MS, Khan AM, Sayeed MA (2008) An evaluation of antimicrobial activities of *Mimusops elengi* Linn. *Res J Agric Biol Sci* 4(6):871–874
- Ashek P, Koti BC, Vishwanathswamy AHM (2010) Antiuro lithiatic and antioxidant activity of *Mimusops elengi* on ethylene glycol-induced urolithiasis in rats. *Indian J Pharm* 42(6):380–383
- Baliga MS, Pai RJ, Bhat HP, Palatty PL, Boloor R (2011) Chemistry and medicinal properties of the Bakul (*Mimusops elengi* Linn): a review. *Food Res Int* 44(7):1823–1829
- Boonyuen C, Wangkarn S, Suntornwat O, Chaisuksan R (2009) Antioxidant capacity and phenolic content of *Mimusops elengi* fruit extract. *Kasetsart J Nat Sci* 43(1):21–27
- Brand Miller J, James KW, Maggiore P (1993) Tables of composition of Australian aboriginal foods. Aboriginal Studies Press, Canberra
- Brock J (1988) Top end native plants. John Brock, Winnellie, Darwin, Northern Territory, p 354 pp
- Brown WH (1951–1957) Useful plants of the Philippines. Reprint of the 1941–1943 edition. 3 volumes. Technical Bulletin 10. Department of Agriculture and Natural Resources. Bureau of Printing, Manila, the Philippines, vol 1 (1951), 590 pp, vol 2 (1954), 513 pp, vol 3 (1957), 507 pp
- Chai PPK (2006) Medicinal plants of Sarawak. Lee Ming Press, Kuching, Sarawak, p 212
- Chaisuksant R, Boonyuen C, Sunthornwat O (2008) Radical scavenging tests of phenolic fractions from *Mimusops elengi* fruits. *Acta Hort (ISHS)* 787:313–318
- Dar A, Behbahanian S, Malik A, Jahan N (1999) Hypotensive effect of the methanolic extract of *Mimusops elengi* in normotensive rats. *Phytomedicine* 6:373–378
- Deshpande RR, Ruikar AD, Panvalkar PS, Kulkarni AA, Kale AA, Puranik VG, Deshpande NR (2010) Comparative evaluation of antimicrobial properties of different extract of *Mimusops elengi* against oral microflora. *J Pharm Res* 3(10):2354–2355
- Foundation for Revitalisation of Local Health Traditions (2012) FRLHT Database. <http://envis.frlht.org>
- Ganu G, Jadhav S (2010) In vitro antioxidant and in vivo antihyperglycemic potential of *Mimusops elengi* L. in alloxan-induced diabetes in mice. *J Complement Integr Med* 7(1):Article 4
- Ganu G, Garud A, Agrawal V, Suralkar U, Jadhav S, Hshirsagar A (2011a) Anti-anxiety activity of

- Mimusops elengi* bark extracts in experimental animals. *Res J Pharma Biol Chem Sci* 2(3):405–410
- Ganu GP, Jadhav SS, Deshpande AD (2011b) Antioxidant and antihyperglycemic potential of methanolic extract of bark of *Mimusops elengi* L. in mice. *Int J Phytomed* 2(2):116–123
- Ghaisas MM, Kadam AH, Kashirsagar BD, Dhote VV, Dashpande AD (2008) Evaluation of antihyperlipidemic activity of *Mimusops elengi* L. in Triton WR-1339 induced hyperlipidaemia in rats. *J Nat Rem* 8:132–137
- Govaerts R, Harvey Y, Jessup L, Pennington TD, Vink W (2012) World checklist of Sapotaceae. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; <http://apps.kew.org/wcsp/>. Retrieved 22 July 2012
- Haron NW (1998) *Mimusops* L. In: Sosef MSM, Hong LT, Prawirohatmodjo S (eds) Plant resources of South-East Asia No 5(3). Timber trees: lesser-known timbers. Backhuys Publishers, Leiden, pp 382–385
- Hazra KM, Roy RN, Sen SK, Laskar S (2007) Isolation of antibacterial pentahydroxy flavones from the seeds of *Mimusops elengi* Linn. *Afr J Biotechnol* 6(12):1446–1449
- Jahan N, Ahmed W, Malik A (1995) A lupene-type triterpene from *Mimusops elengi*. *Phytochemistry* 39(1):255–257
- Jahan N, Malik A, Afza N, Choudhary MI, Shahzad-ul-Hassan S (2000) Triterpenes from *Mimusops elengi*. *Z Naturforsch* 55b:1206–1210
- Jahan N, Malik A, Mustafa G, Ahmad Z, Ahmad S, Anis E, Malik S, Shujaat S, Afza N, Atta-Ur-Rahman (2001) Triterpenes from *Mimusops elengi*. *Nat Prod Lett* 15(3):177–185
- Karmakar UK, Sultana R, Biswas NN (2011) Antioxidant, analgesic and cytotoxic activities of *Mimusops elengi* Linn. leaves. *Int J Pharmaceut Sci Res* 2(11):2791–2797
- Koti BC, Ashok P (2010) Diuretic activity of extracts of *Mimusops elengi* Linn. bark. *Int J Green Pharm* 4:90–92
- Lavaud C, Massiot G, Becchi M, Misra G, Nigam SK (1996) Saponins from three species of *Mimusops*. *Phytochemistry* 41:887–893
- Lemmens RHMJ (2005) *Mimusops elengi* L. [Internet] Record from Protabase. Louppe D, Oteng-Amoako AA, Brink M (eds) PROTA (Plant Resources of Tropical Africa/Ressources végétales de l'Afrique tropicale), Wageningen. <http://database.prota.org/search.htm>
- Mahavorasirikul W, Viyanant V, Chaijaroenkul W, Itharat A, Na-Bangchang K (2010) Cytotoxic activity of Thai medicinal plants against human cholangiocarcinoma, laryngeal and hepatocarcinoma cells in vitro. *BMC Complement Altern Med* 10:Article 55
- Mali RG, Mahajan SG, Mehta AA (2007) In-vitro antheimintic activity of stem bark of *Mimusops elengi* Linn. *Phcog Mag* 3(10):73–76
- Mandal B, Maity CR (1991) Studies of the oil of *Mimusops elengi* seed. *Acta Aliment Budapest* 20(2):103–107
- Misra G, Mitra CR (1967) Constituents of fruit and seed of *Mimusops elengi*. *Phytochemistry* 6:453
- Misra G, Mitra CR (1968) Constituents of leaves, heartwood and root of *Mimusops elengi*. *Phytochemistry* 7:501–502
- Molesworth AB (1967) Malayan fruits. An introduction to the cultivated species. Moore, Singapore, 245 pp
- Ng FSP (1972) Sapotaceae. In: Whitmore TC (ed) Tree flora of Malaya, vol 1. Longman Malaya, Kuala Lumpur, pp 388–439
- Pennington TD (1990) Sapotaceae. Flora Neotropica: Monograph. 52. New York Bot. Garden, New York, 770 pp
- Purnima A, Koti BC, Thippeswamy AHM, Jaji MS, Vishwantha Swamy AHM, Kurhe YV, Sadiq AJ (2010) Antiinflammatory, analgesic and antipyretic activities of *Mimusops elengi* Linn. *Indian J Pharm Sci* 72(4):480–485
- Rao S, Rani P, Kumar R, Keshar N (2011) Evaluation of in vitro antioxidant activity and total phenolic content of methanol bark extract of *Mimusops elengi*. *Free Rad Antioxid* 1(2):62–71
- Ruikar AD, Gadkari TV, Phalgune UD, Puranik VG, Deshpande NR (2011) Dibutyl phthalate, a secondary metabolite from *Mimusops elengi*. *Chem Natl Comp* 46(6):955–6
- Saha MR, Hasan SMR, Akter R, Hossain MM, Alam MS, Alam MA, Mazumder MEH (2008) In vitro free radical scavenging activity of methanol extract of the leaves of *Mimusops elengi* Linn. *Bangl J Vet Med* 6(2):197–202
- Sahu NP (1996) Triterpenoid saponins of *Mimusops elengi*. *Phytochemistry* 41:883–886
- Sahu NP, Koike K, Jia Z, Nikaido T (1995) Novel Triterpenoid saponins from *Mimusops elengi*. *Tetrahedron* 51:13435–13436
- Sahu NP, Koike K, Jia Z, Nikaido T (1997) Triterpenoid saponins from *Mimusops elengi*. *Phytochemistry* 44:1145–1149
- Sahu NP, Mandal NB, Banerjee S, Siddiqui KAI (2001) Chemistry and biology of the triterpenes and saponins from seeds of *Mimusops elengi*. *J Herb Spice Med Plants* 8:29–38
- Satishchandra A, Sumithra M (2011) Synergistic effect of *Mimusops elengi* and *Moringa oleifera* on high fat induced atheroma in rats. *Int J Adv Pharm Res* 2(6):293–300
- Sehgal S, Gupta N, Gupta R, Saraf SA (2011) Quantitative estimation of quercetin in *Mimusops elengi* L. leaves by HPTLC. *Der Pharm Lett* 3(5):12–19
- Sen S, Sahu NP, Mahato SB (1993) Novel migrated oleanane triterpenoid sapogenins from *Mimusops elengi*. *Tetrahedron* 49(40):9031–9038
- Sen S, Sahu NP, Mahato SB (1995) Pentacyclic triterpenoids from *Mimusops elengi*. *Phytochemistry* 38:205–207

- Shah PJ, Gandhi MS, Shah MB, Goswami SS, Santani D (2003) Study of *Mimusops elengi* bark in experimental gastric ulcers. J Ethnopharmacol 89(2–3):305–311
- Shahwar D, Raza MA (2009) In vitro antibacterial activity of extracts of *Mimusops elengi* against gram positive and gram negative bacteria. Afr J Microbiol Res 3(8):458–462
- Stuart GU (2012) Philippine alternative medicine. Manual of Some Philippine Medicinal Plants. <http://www.stuartxchange.org/OtherHerbals.html>
- van Royen P (1952) Revision of the Sapotaceae of the Malaysian area in a wider sense. III. *Mimusops* L Blumea 6:594–595

Pouteria caimito

Scientific Name

Pouteria caimito (Ruiz & Pav.) Radlk.

Common/English Names

Abiu, Yellow Star Apple.

Synonyms

Achras caimito Ruiz & Pav. basionym, *Achras guapeba* Casar., *Caleatia caimito* (Ruiz & Pav.) Mart. ex Steud. nom. inval., *Guapeba caimito* (Ruiz & Pav.) Pierre, *Guapeba lasiocarpa* (Mart.) Pierre, *Guapeba laurifolia* Gomes, *Guapebeira brasiliensis* Steud., *Guapebeira laurifolia* Gomes, *Labatia caimito* (Ruiz & Pav.) Mart., *Labatia lasiocarpa* Mart., *Labatia reticulata* Mart., *Lucuma caimito* (Ruiz & Pav.) Roem. & Schult., *Lucuma lasiocarpa* (Mart.) A. DC., *Lucuma laurifolia* (Gomes) A. DC., *Lucuma laurifolia* var. *reticulata* (Mart.) A. DC., *Lucuma temare* Kunth, *Pouteria caimito* var. *laurifolia* (Gomes) Baehni, *Pouteria caimito* var. *typica* Baehni nom. inval., *Pouteria lasiocarpa* (Mart.) Radlk., *Pouteria laurifolia* (Gomes) Radlk., *Pouteria leucophaea* Baehni, *Pouteria temare* (Kunth) Aubrév., *Richardella temare* (Kunth) Pierre.

Vernacular Names

Brazil: Abi, Abieiro, Abio, Abiu, Abiurana, Caimito, Camiteiro;
Columbia: Caimito, Caimito Amarilla, Caimo Or Madura Verde;
Ecuador: Caimito, Cauje, Luma;
Peru: Lucuma;
Portuguese: Abiu, Abeiro;
Spanish: Caimito, Caimo, Cauje, Maduraverde;
Trinidad: Yellow Star Apple;
Venezuela: Temare.

Family

Sapotaceae

Origin/Distribution

Abiu is indigenous to the Amazonian region of South America. Wild populations are found in the headwaters of the Amazon. It grows wild in the lower eastern part of the Andes from southwestern Venezuela, Guyana, Para and Brazil to Peru, Columbia, Ecuador . It has also been growing for a very long time in Trinidad. It can now be found growing throughout most of the Amazonia especially northern South America, Central

America, Antilles, and also grown in northern Australia and in Malaysia.

Agroecology

The abiu thrives best in a year-around warm and humid climate with 1,000–3,000 mm mean annual rainfall evenly distributed throughout the year. It occurs from near sea level to an altitude of 650 m in Peru, but in Columbia, it can be grown up to an elevation of 1,900 m. It is rather frost tolerant, withstanding temperatures down to -2°C without appreciable damage. It flourish in full sun and is adaptable to a wider range of soil types particularly moist, deep clay loams with good drainage and it tolerates a wide range of soil pH with an optimum of 5.5–7.5. It is quite drought tolerant and does not shed its leaves when the weather becomes hot and dry with temperatures hovering above 37°C . Abiu is sensitive to saline conditions which can kill the tree and on calcareous soils it suffers from chlorosis of the foliage. Irrigation is required to sustain good growth and fruiting during the dry periods especially on the light, sandy soils.

Edible Plant Parts and Uses

The edible, fresh, translucent, mucilaginous, sweet pulp is eaten mostly eaten out-of-hand especially when chilled, in fruit salads and fruit cocktails. It can also be made into refreshing drinks, ices, sherbets and ice cream.

Botany

The abiu tree is a medium sized, lactiferous, ever-green perennial tree, growing 5–15 m high. Leaves are alternate, short-petioled, green, glabrous, leathery, oblong-lanceolate, 10–25 cm by 40–55 mm in its broadest width, margin undulating and acute apex and tapering base (Plate 1). Flowers are small, white, hermaphrodite, sub sessile to short pedicellate, 1–1.5 mm, borne



Plate 1 Abiu fruit and leaves



Plate 2 Abiu fruit with subsessile stalk

singly or in groups of 2–5 in the axils of leaf scars along the branches between the outer canopy or leafy tip and the main trunk. Each flowering branch can produce between 20 and 280 flowers. Flower consist of four overlapping, light green sepals, 5 mm long, spirally overlapping, cylindrical corolla tube, 5 mm long, light green when young becoming creamy-white to white when mature with free lobes 2 mm long at the top of the corolla tube. Androecium consist of four free epipetalous stamens inserted on the corolla tube near the base, alternating with four staminodes, filaments are white, curved, 4–4.5 mm long topped by dorsifixed, extrose, bilobed, yellowish-brown anthers. Carpel consist of a small greenish-white, pubescent, superior ovary with white, thick style and four-lobed stigma at the apex. Fruit is a berry, green (Plate 1) turning to bright yellow when mature, ellipsoid to globose or oblate, often slightly pointed at the stigma end (nippled), 6–10 cm in diameter (Plates 1–3). The rind is



Plate 3 Harvested abiu fruits

smooth, 5 mm thick, and contains latex which can irritate the lips and taste buds. The pulp is translucent – white, juicy, soft, sweet and mucilaginous. Each fruit has 1–4 large, ellipsoidal, dark-brown seeds, 3.2–3.78 cm long by 1.4–1.6 cm wide, each seed has a large, distinct hilum along the lateral and a distinct micropyle at one end.

Nutritive/Medicinal Properties

Nutrient composition of fresh abiu fruit per 100 g edible portion was reported as: energy 140 cal (588 kJ), protein 1.8 g, fat 0.4 g, carbohydrate 36.3 g, fibre 0.9 g, ash 0.9 g, Ca 22 mg, P 41 mg, Fe 1 mg, vitamin A 130 µg, thiamine 0.02 mg, riboflavin 0.02 mg, niacin 34 mg and vitamin C 43 mg (Leung and Flores 1961). Analysis conducted in Brazil (cited by Morton 1987) reported abiu fruit per 100g edible portion to have the following nutrient values: energy 95 cal, moisture 74.1 g, protein, 2.1 g, lipid 1.1 g, glycerides 22 g, fibre 3.0 g, ash 0.7 g, Ca 96 mg, P 45 mg, Fe 1.8 mg, vitamin B1 0.2 mg, vitamin B2 0.2 mg, niacin 3.4 mg, ascorbic acid 49 mg, lysine 316 mg, methionine 178 mg, threonine 219 mg, tryptophan 75 mg.

The oil components of *P. caimito* fruit was found to be dominated by α -copaene (27.7%), hexadecyl acetate (19.0%) and palmitic acid (12.4%) (Maia et al. 2003). The benzene extract from *Pouteria caimito* fruits showed the presence

of the following triterpenes: α -amyrin, lupeol, erythrodiol, and dammarenediol; and from the bark extract, taraxerol and its acetate, taraxenona and β -sitosterol (Pellicciari et al. 1972).

Oliveira et al. (2007), reported aqueous extract from *P. caimito* fruits exhibited 1-diphenyl-2-picrylhydrazyl (DPPH) radical-scavenging activity with IC_{50} value of 43 mg/mL. Ethanol and aqueous extract of abiu leaves exhibited DPPH radical-scavenging activity with IC_{50} value of 20.2 and 72.9 µg/mL respectively (Castro et al. 2006) compared to the 15 µg/mL for butylated hydroxytoluene (BHT), antioxidant standard.

In Brazilian folkloric medicine, the pulp, because of its mucilaginous nature, is eaten to relieve coughs, fever, bronchitis and other pulmonary complaints. The latex is given as a vermifuge and for diarrhoea and is applied on abscesses.

Other Uses

Abiu provides a dense, heavy, hard timber that can be used in construction.

Comments

Abiu is usually propagated from seeds. It can also be successfully established from green vegetative branches (Almeida et al. 2008) or by inarching and cleft grafting using abiu seedlings as rootstocks (Coronel et al. 1998).

Selected References

- Almeida EJ, Jesus N, Scaloppi EMT, Martins ABG, Araújo MS (2008) Propagation of three abiu genotypes (*Pouteria caimito*) by cutting of herbaceous branches. Acta Amaz 38(1):1–4 (In Portuguese)
- Castro CFS, Silva CAM, Perfeito JP, Santos ML, Resck IS, Paula JE, Silveira D (2006) Avaliação da atividade antioxidante de algumas espécies de Pouteria. In: 29a Reunião Anual da Sociedade Brasileira de Química. Águas de Lindóia
- Coronel RE, Sotto RC, Dela Cruz FS Jr, Banasihan IG (1998) Note: introduction, evaluation and propagation of abiu (*Pouteria caimito* [Ruiz and Favan] Radlk.). Phil Agricult 81(3–4):168–175

- Davidse G, Sánchez MS, Knapp S, Cabrera FC (2009) Cucurbitaceae a Polemoniaceae. *Fl Mesoamer* 4(1):1–855
- Govaerts R, Harvey Y, Jessup L, Pennington TD, Vink W (2012) World checklist of Sapotaceae. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet: <http://apps.kew.org/wcsp/> Retrieved 22 July 2012
- Leung W-TW, Flores M (1961) INCAP-ICNND food composition table for use in Latin America. Institute of Nutrition of Central America and Panama (INCAP), Guatemala City, Guatemala and National Institute of Health (NIH), Bethesda, 145 pp
- Lim TK (1991a) Abiu. A botanical and agronomic review. Northern Territory Department of Primary Industries and Fisheries Technical Bulletin No. 169, 16 pp
- Lim TK (1991b) Abiu. An old/new fruit. Northern Territory Department of Primary Industries and Fisheries Agnote 446.
- Lim TK, Ramsay G (1992) Abiu – a new fruit with potential for the Northern Territory. *ISHS Acta Hort* 321:99–105
- Lorenzi H, Bacher L, Lacerda M, Sartori S (2006) Brazilian fruits & cultivated exotics (for consuming in natura). Instituto Plantarum de Etodos da Flora Ltda, Brazil, 740 pp
- Maia JGS, Andrade EHA, Zoghbi MGB (2003) Volatiles from fruits of *Pouteria pariry* (Ducke) Baehni and *P. caimito* (Ruiz and Pavon.) Rdlkl. *J Essent Oil-Bear Plant* 6:127–129
- Martin FW, Malo SE (1978) Cultivation of neglected tropical fruits with promise. Part 5. The canistel and its relatives. U. S. Department of Agriculture, New Orleans, 12 pp
- Morton JF (1987) Abiu. In: *Fruits of warm climates*. Julia F. Morton, Miami, pp 406–408
- Oliveira G, Troncoso L, Guija E, Nunez M, Flores J, Quiroz K (2007) Capacidad antioxidante de *Pouteria caimito* (caimito) y *Spondias mombin* L. (ubos). *Ann Fac Med Lima*, 68:21
- Pellicciari R, Ardon A, Bellavita V (1972) Triterpenes from *Pouteria caimito*. *Planta Med* 22:196–200
- Pennington TD (1990) Sapotaceae. *Flora neotropica: monograph*, vol 52. New York Botanical Garden, New York, 70 pp
- Pennington TD (1991) The genera of the Sapotaceae. Kew Publishing, Kew, p 307
- Popenoe W (1974) Manual of tropical and subtropical fruits. Hafner Press, New York. Facsimile of the 1920 edition
- Silva CAM, Simeoni LA, Silveira D (2009) Genus *Pouteria*: chemistry and biological activity. *Braz J Pharmacogn* 19(2a):501–509

Pouteria campechiana

Scientific Name

Pouteria campechiana (Kunth) Baehni.

Family

Sapotaceae

Synonyms

Lucuma campechiana Kunth, *Lucuma elongata* (C.F.Gaertn.) Steud., *Lucuma glabrifolia* Pittier, *Lucuma heyderi* Standl., *Lucuma inseparabilis* Dubard, *Lucuma laeteviridis* Pittier, *Lucuma nervosa* A. DC., *Lucuma palmeri* Fernald, *Lucuma rivicoa* var. *angustifolia* Miq., *Lucuma salicifolia* Kunth, *Lucuma sphaerocarpa* A. DC., *Pouteria campechiana* var. *nervosa* (A. DC.) Baehni, *Pouteria campechiana* var. *palmeri* (Fernald) Baehni, *Pouteria campechiana* var. *salicifolia* (Kunth) Baehni, *Pouteria campechiana* var. *typica* Baehni, *Pouteria elongata* (C.F.Gaertn.) Baehni, *Pouteria glabrifolia* (Pittier) Cronquist, *Pouteria laeteviridis* (Pittier) Lundell, *Pouteria mante* Lundell, *Radlkoferella glabrifolia* (Pittier) Aubrév., *Radlkoferella inseparabilis* Pierre nom nud., *Radlkoferella sphaerocarpa* (A. DC.) Pierre, *Richardella campechiana* (Kunth) Pierre, *Richardella nervosa* (A. DC.) Pierre, *Richardella salicifolia* (Kunth) Pierre, *Sapota elongata* C.F.Gaertn. pro. syn., *Sideroxylon campestre* Brandegees, *Vitellaria campechiana* (Kunth) Engl., *Vitellaria nervosa* (A. DC.) Radlk., *Vitellaria salicifolia* (Kunth) Engl., *Vitellaria sphaerocarpa* (A. DC.) Radlk., *Vitellaria tenuifolia* Engl., *Xantolis palmeri* (Fernald) Baehni.

Common/English Names

Canistel, Egg Fruit, Egg Fruit Tree, Mexican Sapodilla, Ti-Es, Yellow Sapote.

Vernacular Names

Bahamas: Mammee Sapota, Eggfruit, Ti-Es, Yellow Sapota;

Belize: Mamey Cerera, Mamey Cerilla, Mamee Ciruela, Kanizte;

Brazil: Canistel, Gema-De-Ovo, Sapota-Amarela;

Colombia: Costiczapotl, Custiczapotl Fruta De Huevo, Zapote Amarillo;

Costa Rica: Canistel, Siguapa, Zapotillo;

Cuba: Canistel, Ti-Es;

El Salvador: Guaicume, Guicume, Zapotillo, Zapotillo Amarillo;

Florida: Egg-Fruit, Canistel, Ti-Es, Yellow Sapote;

French: Canistel, Janne D'oeuf;

German: Gelbe Sapote;

Guatemala: Cakixo, Canizte, Kanis, Kaniste, Hantzé, Kantez, Limoncillo, Mamee Ciruela, Zapotillo De Montana;

Hawaii: Egg-Fruit, Canistel, Ti-Es, Yellow Sapote;

Indonesia: Sawo Mentega;

Jamaica: Egg-Fruit, Canistel, Ti-Es, Yellow Sapote

Mexico: Atzapotl (fruit), Atzapolquahuitl (tree), Caca De Niño, Cozticzapotl, Cucumu, Mamey De Campechi, Mamey De Cartagena, Huicumo, Huicon, Kan 'Iste', Kanixte, Kanizte, Palo Huicon, Zapote Amarillo, Zapote De Niño, Zapote Borracho, Zapote Mante, Zubul;

Nicaragua: Zapote Amarillo;

Philippines: Boracho, Canistel, Tiesa;

Puerto Rico: Egg-Fruit, Canistel, Ti-Es, Yellow Sapote, Huevo Vegetal;

Spanish: Caca De Nini, Cucuma, Custiczapotl, Fruta De Huevo, Guicume, Mamee Ciruela, Mamey De Campechi, Mammee Sapota, Narraco, Sapote-Amarillo, Sapote-Borracho, Zapote Blanco, Zapote De Niño, Zapote Mante, Zapotillo, Zapotillo Blanco Canister, Zapotillo Canister, Zapuyul;

Sri Lanka: Ratalawulu (*Sinhala*), Lavalu;

Thai: To Maa, Lamut Khamen, Khe Maa;

Venezuela: Huevo Vegetal;

Vietnamese: Cây Trúng Gà, Lekima.

Origin/Distribution

Canistel is a native of Central America. It occurs wild only in southern Mexico (including Yucatan), Belize, Guatemala and El Salvador. It is cultivated in its native range and in Costa Rica, Nicaragua, Panama, Puerto Rico, Jamaica, Cuba, the Bahamas, southern Florida and the Florida Keys. It has been introduced into Brazil, the Philippines and later to other Southeast Asian countries and Taiwan and Australia.

Agroecology

The canistel flourishes in a frost free tropical or subtropical climate with hot or warm summers and cool winters. In Florida, it survives winter cold as far north as Palm Beach and Punta Gorda and in protected areas of St. Petersburg. It requires no more than moderate precipitation and does well in regions with a long dry season. It is grown from near sea level to 1,400 m elevation. Canistel is adaptable to a wide range of soils including

calcareous, lateritic, acid-sandy and heavy clays but prefers a fertile, well-drained shallow to deep soil.

Edible Plant Parts and Uses

The ripe fruit pulp is edible fresh, but is not highly regarded as it is dry, not crispy and juicy like so many other fruits and has the consistency and texture of hard boiled egg yolk. It is eaten with salt, pepper and lime or lemon juice or mayonnaise, either fresh or after light baking. The pureed flesh may be used in custards or added to ice cream mix just before freezing. A rich milkshake, or "eggfruit nog", is made by combining ripe canistel pulp, milk, sugar, vanilla, nutmeg or other seasoning in an electric blender. The pulp can be made into canistel pancakes, cupcakes, jam, marmalade and "pie butter" for spreading on toast. One common recipe for canistel pie consists of 1 1/2 cups mashed canistel pulp, 2/3 cup brown sugar, 1/2 teaspoon salt, 1/4 teaspoon nutmeg, 1 teaspoon lime juice, 2 beaten eggs, 2 cups evaporated milk or light cream. The mixture is poured into one crust and baked for 1 h at 121°C. The pulp can be dehydrated, powdered and utilised as a rich food additive or for use in pudding mixes.

Botany

Canistel is a medium sized, erect, evergreen, lactiferous tree 8–20 m high with a 25–60 cm wide, finely-ribbed, dark gray trunk and horizontal branches. It is rich in white gummy latex in every part of the tree. Young branches are velvety brown. The leaves are whorled at the tips of the branches. Lamina is simple, elliptic to oblanceolate or obovate, 6–25 × 2.5–8 cm, glossy, bright green, tapering towards both ends with entire or revolute margins (Plates 1 and 2). The petioles are 1–5 cm long. Flowers are fragrant, axillary, solitary or clustered and borne in the lower leaves on 5–12 mm long pedicels. Flowers are bisexual, five- or six-lobed, cream-colored, silky-hairy, about 8–11 mm long; sepals are ovate to suborbiculate, 5–11 mm long, petals creamy- white, 8–12 mm



Plate 1 Obovoid, beaked fruit and leaves



Plate 2 Ovoid ripe canistels and leaves

long, petaloid staminodes, 2–4 mm. Fruit is a berry, ellipsoid, variable in shape and size, ovoid, subglobose, ellipsoid often beaked, 7–12.5 cm long by 4–7.5 cm wide, with a thin, tough, waxy smooth, lemon-yellow, golden-yellow or pale orange-yellow skin (Plates 1–4). The pulp is yellow, relatively firm, dry to mealy, sweet, more or less musky, with a few fine fibres. Seeds 1–4 hard, freestone, 2–5.3 cm long and 1.25–3.2 cm wide, sub-oval or oblong-oval, with pointed ends, glossy and chestnut-brown except for the straight or curved ventral side which is dull light-brown, tan or greyish-white.

Nutritive/Medicinal Properties

The edible portion constituted up to 70% of fruit weight. Chemical analyses conducted in Cuba and the Philippines showed that 100 g edible portion of ripe fruit contained: water 57.2–60.6 g,

protein 1.7–2.5 g, fat 0.1–0.6 g, carbohydrates 36.7–39.1 g, fibre 0.1–7.5 g, ash 0.6–0.9 g, calcium 26.5–40 mg, phosphorous 30–37.3 mg, iron 0.9–1.1 mg, carotene 0.32 mg, thiamine 0.02–0.17 mg, riboflavin 0.01–0.03 mg, niacin 2.5–3.7 mg and vitamin C 43–58 mg. The energy value is 580–630 kJ/100 g (Morton 1992). Thus, the fruit is rich in carbohydrates, carotene and niacin. Lorenzi et al. (2006) reported the following nutrient value: energy 154.6 cal, Water 60.6 g, Protein 1.68 g, fat 0.13 g, carbohydrate 36.69 g, ash 0.9 g, Ca 26.5 mg, P 37.3 mg, Fe 0.92 mg, vitamin A 0.32 mg, thiamin 0.17 mg, riboflavin 0.01 mg, vitamin C 58.1 mg and niacin 3.72 mg.

P. campechiana fruit had the lowest levels of phenolic antioxidants and the lowest antioxidant activity among three *Pouteria* spp., evaluated (Ma et al. 2004). Seven polyphenolic antioxidants, gallic acid, (+)-gallocatechin, (+)-catechin, (–)-epicatechin, dihydromyricetin, (+)-catechin-3-O-gallate and myricitrin, were isolated and identified.

Ripe egg fruit was found to have a total phenol content of 5.00 mg GAE/g, total flavonoid content of 4.58 mg RE/g; FRAP (ferric reducing antioxidant power) value of 1.00 mmol FeSO₄/g; DPPH value of 92.15% inhibition and AEAC (Ascorbic acid antioxidant capacity) of 1.00 mg ascorbic acid/g respectively (Kubola et al. 2011). Ripe egg fruit was found to contain the following phenolic acids (mg/g): gallic acid 1.36 mg; protocatechuic acid 5.14 mg, *p*-hydroxy benzoic acid nd (not detected), vallinic acid 15.48 mg, chorogenic acid nd, caffeic acid 5.56 mg, syringic acid nd, *p*-coumaric acid 8.84 mg, ferulic acid 50.73 mg, sinapicnic acid nd, and total phenolic acid content 87.11 mg. Ripe egg fruit was found to contain the following flavonoid contents (mg/g dry sample): rutin 20.64 mg, myricetin 55.67 mg, luteolin 13.98 mg, quercetin 23.15 mg, apigenin 0.88 mg, kaempferol 0.78, total flavonoid content 115.1 mg. Ripe egg fruit also contained the following sugar composition (mg/g dw): D(+) raffinose 2.88 mg, D(+) sucrose 96.89 mg, D(+)maltose nd, D(+)glucose 40.11 mg, D(+)galactose nd, D(+)fructose 39.23 mg and total sugars 179.11 mg. Ripe egg fruit contained 1.87 mg/g vitamin C and 3.81/100 g crude fibre.



Plate 3 (a) and (b) Ellipsoid, subglobose and ovoid elongated harvested canistels

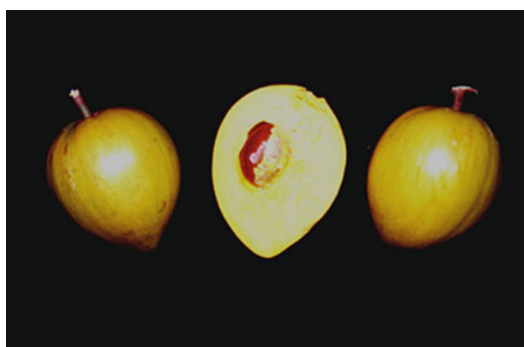


Plate 4 Whole and halved canistel fruit

Canistel fruit is rich in carotenoids. Total carotenoid content in canistel fruit was high and varied from 1.9 to 23.5 mg/g dry weight (DW) (De Lanerolle et al. 2008). The carotenoids were dominated by neoxanthin. Individual carotenoid concentrations varied markedly from specimen to specimen (β -carotene, from traces to 156, ζ -carotene, trace amounts, β -cryptoxanthin, from traces to 1,106 $\mu\text{g/g}$, violaxanthin, from less than 188 to 1,151 $\mu\text{g/g}$, neoxanthin, from 1,594 to 19,270 $\mu\text{g/g}$, unidentified I, from traces to 627 $\mu\text{g/g}$, unidentified II, from 68 to 1,162 $\mu\text{g/g}$ DW). Results showed two extremes of retinol equivalents (RE) in *Pouteria campechiana* (traces and 759–11,813 RE/100 g DW).

Six stilbenes and six flavonoid glycosides were purified and identified from the leaves of *Pouteria campechiana* (Hernandez et al. 2008). The distilbene ampelopsin B was found to arrest mitosis in a cell-based primary screen to monitor

cell-cycle progression and was also determined to be a weak microtubule depolymerizer in a secondary assay.

A decoction of the astringent bark is taken as a febrifuge in Mexico and applied on skin eruptions in Cuba. A preparation of the seeds has been employed as a remedy for ulcers and the fruits for anaemia. Also a derivative of the seed of *Pouteria sapota* appeared to be active against seborrheic dermatitis of the scalp.

Other Uses

In Central America, latex extracted from the tree has been used to adulterate chicle. The fine-grained, compact, strong, heavy and hard timber is used for planks and rafters in construction.

Comments

Canistel can be propagated by using fresh seeds as they lose their viability after extraction from the fruits. Canistel can also be propagated from stem cuttings, budding and grafting.

Selected References

- Davidse G, Sousa SM, Knapp S (editores generales) (1995) Psilotaceae a Salviniaceae. Fl Mesoamer 1(i–xxi):1–470
de Lanerolle MS, Priyadarshani AMB, Sumithraarachchi DB, Jansz ER (2008) The carotenoids of *Pouteria*

- campechiana* (Sinhala: Ratalawulu). J Natl Sci Found Sri Lanka 36(1):95–98
- Govaerts R, Harvey Y, Jessup L, Pennington TD, Vink W (2012) World checklist of Sapotaceae. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet: <http://apps.kew.org/wcsp/> Retrieved 22 July 2012
- Hernández Bermejo JE, León J (eds) (1994) Neglected crops: 1492 from a different perspective. Plant production and protection series no. 26. FAO, Rome
- Hernandez CLC, Villaseñor IM, Joseph E, Tolliday N (2008) Isolation and evaluation of antimutagenic activity of phenolic compounds from *Pouteria campechiana* Baehni. Phil J Sci 137(1):1–10
- Kubola J, Siriamornpun S, Meeso N (2011) Phytochemicals, vitamin C and sugar content of Thai wild fruits. Food Chem 126:972–981
- Lorenzi H, Bacher L, Lacerda M, Sartori S (2006) Brazilian fruits & cultivated exotics (for consuming in natura). Instituto Plantarum de Estudos da Flora Ltda, Brazil, 740 pp
- Ma J, Yang H, Basile MJ, Kennelly EJ (2004) Analysis of polyphenolic antioxidants from the fruits of three *Pouteria* species by selected ion monitoring liquid chromatography-mass spectrometry. J Agric Food Chem 52(19):5873–5878
- Martin FW, Malo SE (1978) Cultivation of neglected tropical fruits with promise. Part 5. The canistel and its relatives. U. S. Department of Agriculture, New Orleans, 12 pp
- Morton JF (1987) Canistel. In: Fruits of warm climates. Julia F. Morton, Miami, pp 402–405
- Morton JF (1992) *Pouteria campechiana* (Kunth) Baehni. In: Verheij EWM, Coronel RE (eds) Plant resources of south-east Asia, No. 2. Edible fruits and nuts. Prosea Foundation, Bogor, pp 258–259
- Orwa C, Mutua A, Kindt R, Jamnadass R, Anthony S (2012) Agroforestree database: a tree reference and selection guide version 4.0. <http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp>
- Pennington TD (1990) Sapotaceae. Flora neotropica: monograph, vol 52. New York Botanical Garden, New York, 70 pp
- Silva CAM, Simeoni LA, Silveira D (2009) Genus *Pouteria*: chemistry and biological activity. Rev Bras Farmacogn 19(2):501–509
- Standley PC, Williams LO (1967) Sapotaceae. In: Standley PC, Williams LO (eds) Flora of Guatemala – Part VIII, Number 3. Fieldiana, Bot 24(8/3):211–244

Pouteria sapota

Scientific Name

Pouteria sapota (Jacq.) H.E. Moore & Stearn.

Synonyms

Achras mammosa Bonpl. ex Miq. nom. illeg., *Bassia jussaei* Griseb., *Calocarpum huastecanum* Gilly, *Calocarpum mammosum* var. *bonplandii* (Kunth) Pierre, *Calocarpum mammosum* var. *candollei* (Pierre) Pierre, *Calocarpum mammosum* var. *ovoideum* (Pierre) Pierre, *Calocarpum sapota* (Jacq.) Merr., *Calospermum mammosum* var. *bonplandii* (Kunth) Pierre, *Calospermum mammosum* var. *candollei* Pierre, *Calospermum mammosum* var. *ovoidea* Pierre, *Calospermum parvum* Pierre, *Lucuma bonplandii* Kunth, *Sapota mammosa* Mill., *Sideroxylon sapota* Jacq.

Family

Sapotaceae

Common/English Names

Lava Sapote, Mamey Colorado, Mamey Sapote, Mamee Apple, Mammee Sapote, Mamee Zapote, Marmalade Plum, Marmalade Tree, Red Sapote, Sapote, True Sapote, Zapotillo.

Vernacular Names

Brazil: Mamei, Mamey Sapote;
Columbia: Zapote De Carne;
Costa Rica: Mamey, Zapote Colorado;
Cuba: Mamey Colorado, Mamey;
El Salvador: Zapote Grande;
Ecuador: Mamey Colorado;
French: Sapotier, Sapotier Jaune D'oeuf, Grand Sapotillier, Grosse Sapote;
German: Große Sapote, Mamey-Sapote, Marmeladen-Pflaume;
Guadeloupe: Sapote À Crème;
Haiti: Sapotier Jaune D'oeuf, Grand Sapotillier;
Indonesia: Ciko Mama;
Jamaica: Marmalade Fruit, Marmalade Plum;
Malaysia: Chico-Mamey, Chico-Mamei;
Martinique: Grosse Sapote;
Mexico: Chachaas, Chachalhaas, Tezonzapote, Zapote;
Nicaragua: Guaicume;
Panama: Mamey, Mamey De La Tierra;
Philippines: Chico-Mamei, Chico-Mamey, Mamei (Tagalog);
Portuguese: Zapote De Carne, Mamey Mamey De La Tierra;
Spanish: Mamey Colorado, Mamey Rojo, Mamey Zapoteo, Sapota, Sapote, Sapote Colorado, Zapota Grande, Zapote;
Venezuela: Zapote;
Vietnamese: Tru'ng Ga.

Origin/Distribution

Mamey sapote is indigenous to Central America – Belize, El Salvador, Guatemala, Honduras, Nicaragua Puerto Rico and Mexico. It was long cultivated by the ancient Mayans in Mexico and has now naturalized in tropical America and the West Indies. The tree is cultivated in central America, south America, the Caribbean, and South Florida for its fruit, which is commonly eaten in many Latin American countries.

Agroecology

Mamey sapote is a tropical species. It thrives best in humid tropical or near tropical lowlands with warm temperatures between 25 and 33°C and with fairly well distributed mean annual rainfall of 800–250 mm. It is sensitive to freezing temperatures, waterlogged conditions and prolonged drought. It does not tolerate low temperature; temperature below 15°C depresses fruit development and yield. Cold winds are detrimental and near zero or sub zero temperatures will kill young tree trees. Brief dry periods will cause shedding of leaves. It grows from near sea level to 1,400 m altitude.. The mamey sapote grows well in a wide variety of well-drained soils, from heavy clays to the limestone and infertile sandy soils. It grows in the heavy clays of Puerto Rico, the sandy clays of Guatemala and even in the sandy soils of Florida in the United States. It does best on the heavy soils–deep clay and clay loam. It is intolerant of constantly wet or flooded soil conditions which impedes root development and enhances root rots by soil-borne fungi.

Edible Plant Parts and Uses

The ripe fruit pulp is eaten fresh out of hand or spooned out from the half-shell. The flavour of the pulp is sweet and has been described as similar to a combination of pumpkin, chocolate and almond or akin to a mixture of sweet potato, avocado and honey. The pulp is made into milkshakes,

smoothies, ice cream or frozen as sherbet, sauces and when cooked it is acceptable as apple puree for use in confectionary. The fruit is also preserved, made into jams and jelly and the fibrous fruits are set aside for processing. The pulp has been imported into Florida by a prominent dairy company for processing and preparing a special “Spanish sherbet”. In Cuba, a thick sapote preserve called “*crema de mamey colorado*” is much relished. The pulp is sometimes employed as a filler in making guava cheese. The oily large kernel of the seed is also edible. The decorticated seeds, called *zapoyotas*, *sapuyules*, or *sapuyulos*, strung on sticks or cords, are widely sold in the Isthmus of Tehuantepec, Mexico, and in other Central American countries. The seed kernel can be boiled, roasted, finely ground and mixed with cocoa for making chocolate or made into confectionary. Around Oaxaca, in southern Mexico, the powdered kernel is mixed with parched corn, or cornmeal, sugar and cinnamon and prepared as a nutritious beverage called “pozol”. The seed kernel yields 45–60% of a white, semi-solid, vaseline-like oil which is edible when freshly extracted and refined.

Botany

Mamey sapote is an erect, lactiferous tree with a spreading open crown (Plate 1), thick central trunk, often narrowly buttressed and a few large branches, growing to 12–18 m sometimes reaching 30–40 m high. Leaves are large, 10–30 cm by 4–10 cm wide, simple, obovate to oblanceolate, with broadly-acuminate apex, tapering base, entire margin, prominent depressed mid-rib and lateral veins, glossy green above, paler green beneath, pubescent becoming glabrous with age (Plates 2 and 3). Leaves are clustered at the end of branches and borne on 2–5 cm long petioles (Plate 1). Flowers are small, white to pale creamy-white, bisexual, subsessile, pentamerous, five fertile stamens, five staminodes, one ovary, style and stigma. Flowers are abundantly produced in fascicles of 5–6 in the axils of fallen leaves along the smaller branches. Fruit is a berry, subglobose, ovoid to ellipsoid, 7–25 cm in length, 8–12 cm



Plate 1 Open canopy with leaves clustered toward the shoot tip



Plate 2 Leaves and immature fruits

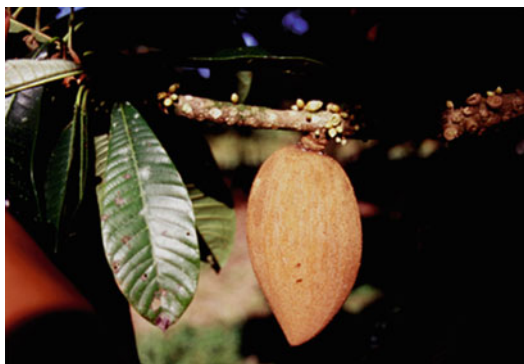


Plate 3 Close-up of leaf and fruit

wide, often bluntly pointed at the apex and with a persistent calyx at the base, weighing 0.3–2.7 kg. The rind is woody, rough, scurfy, russet-brown and 1–2 mm thick. The fruit pulp is deep orange, salmon-pink or reddish brown in colour, smooth to finely granular in texture, aromatic, sweet, soft and firm enclosing 1–4 large, 5–8 cm long,



Plate 4 Harvested ripe fruits

glossy-dark brown, ellipsoid (Plates 1–4), pointed seeds with a light brown hilum on the ventral side.

Nutritive/Medicinal Properties

Food value of raw mamey sapote fruit (refuse 29% seed and skin) per 100 g edible portion was reported as follows: water 62.43 g, energy 134 kcal (561 kJ), protein 2.12 g, total lipid (fat) 0.60 g, ash 1.10 g, carbohydrate 33.76 g; fibre (total dietary) 2.6 g, minerals – calcium 39 mg, iron 1.00 mg, magnesium 30 mg, phosphorus 28 mg, potassium 344 mg, sodium 10 mg, vitamins – vitamin C (total ascorbic acid) 20 mg, thiamin 0.010 mg, riboflavin 0.020 mg, niacin 1.80 mg, vitamin A 410 IU (21 µg RAE); amino acids – tryptophan 0.023 g, threonine 0.058 g, isoleucine 0.046 g, leucine 0.084 g, lysine 0.096, methionine 0.016 g, phenylalanine 0.053 g, tyrosine 0.055 g, valine 0.077 g, arginine 0.055 g, histidine 0.042 g, alanine 0.115 g, aspartic acid 0.532 g, glutamic acid 0.216 g, glycine 0.057 g, proline 0.057 g and serine 0.227 g (USDA 2012). From the ripe fruits of red mamey (*Pouteria sapota*) an A-provitamin carotenoid, sapotexanthin, was elucidated as (all-E,5'R)-β,κ-caroten-6'-one (Murillo et al. 2011).

Twenty-four volatile components were identified in the aroma concentrate of sapote fruit (Pino et al. 2006). The major constituents found in sapote fruit volatiles were benzaldehyde (21.5%), hexanal (12.7%) and hexadecanoic acid (12.7%).

Three aromatic glycosides, lucumin, lucuminamide and lucuminic acid, were isolated from the seeds (Takeda et al. 1997). The fatty acids in the seed kernel were primarily oleic acid 50%, stearic acid 27.2% and palmitic acids 12.0% (Solis-Fuentes et al. 2001; Solis-Fuentes and Duran-de-Bazua 2003). The solid fat contents of the seed kernel at 21.1°C was 6.6%.

Of three *Pouteria* species, *P. sapota* fruit had the highest polyphenol level and highest antioxidant activity (Ma et al. 2004). Seven polyphenolic antioxidants, gallic acid, (+)-galocatechin, (+)-catechin, (–)-epicatechin, dihydromyricetin, (+)-catechin-3-*O*-gallate, and myricitrin, were isolated and identified. Antioxidant activity of *P. sapota* was also reported in the ethyl acetate fraction of methanol extract of the fruit (Mahattanatawee et al. 2006) and from the methanol and acetone extracts of the fruit juice (Franco 2006).

Mamey sapote is the corner stone of holistic, Cuban traditional medicine. It is used extensively as a panacea for gastro-intestinal maladies. In southern Cuba, the mamey is also used to treat headaches and venereal diseases. Mamey has been reported being used as an antiseptic during the Spanish-American war. In the Antilles, the pulp of the fruit is used as a sedative cataplasm; and an infusion of the bark is prescribed as a pectoral. In Costa Rica a “tea” of the bark and leaves is administered in arteriosclerosis and hypertension. The milky sap is emetic and anthelmintic and has been used as a poultice to remove warts and fungal growths on the skin.

A seed infusion is used as an eyewash in Cuba. The seed coat was used by the Aztecs as a remedy for epilepsy, and in Costa Rica it is considered a cure for colds. In Mexico, the pulverized seed coat is reported to be a remedy for coronary trouble and, taken with wine, is said to be helpful against kidney stones and rheumatism. The seed kernel is regarded as a digestive; the oil is said to be diuretic. In Santo Domingo, the seed kernel oil is used as a skin ointment and tonic, and as a hair dressing believed to stop falling hair. In Guatemala and El Salvador, the oil from the seed is used as a skin tonic, to prevent baldness, to reduce muscular pain and to treat rheumatic ailments. In Mexico, two or three pulverized kernels are combined with 10 oz (300 g) castor oil for

application to the hair. In 1970, clinical tests at the University of California at Los Angeles failed to reveal any hair-growth promoting activity but confirmed that the oil of sapote seed was effective in stopping hair-fall caused by seborrheic dermatitis. The oil is employed as a sedative in eye and ear ailments. The seed residue after oil extraction is applied as a poultice on painful skin afflictions.

Other Uses

The tree is used as shade for coffee. The tree provides fine-grained, compact, hard, heavy, strong, easy to work and fairly durable reddish-brown timber but is seldom exploited as timber. The wood can be used for furniture, but mostly serves for building carts, and for shelving and house frames. The nectar of the flowers is gathered by honeybees. The seeds contain a white semi-solid oil called *sapuyucol* or *zapoyola*, which was used in olden times to fix paintings and colours on gourds and other handicrafts. The edible vaseline-like oil from the seed kernel is sometimes used in making soap and is considered to have a greater potential in the soap industry, in cosmetics and pharmaceutical products. The seeds have served as a source of Noyeau scent in perfumery. In Costa Rica, during the nineteenth century, the seeds were used as a linen starch.

Pouteria sapota defatted meal is a good source of the enantioselective enzyme, (R)-oxynitrilase (Solis et al. 2004). This enzyme is used to prepare (R)-cyanohydrins –optically active cyanohydrins intermediates to produce chiral compounds: α -hydroxyacids and their esters, β -amino alcohols, β -hydroxy- α -amino acids, α -hydroxyaldehydes and α -hydroxyketones which can be used as pharmaceutical and agrochemicals (Solis et al. 1998).

Comments

The milky latex of the tree is highly irritant to the eyes and caustic and vesicant on the skin. The leaves are reportedly poisonous and the seeds are reported to have stupefying properties due to its HCN content.

Selected References

- Almeyda N, Martin FW (1976) The Mamey Sapote. U. S. Department of Agriculture, Agric Res Serv, 13 pp
- Campbell CW, Lara SP (1982) Mamey sapote cultivars in Florida. Proc Fla State Hort Soc 95:114–115
- Franco EM (2006) Actividad antioxidante in vitro de las bebidas de frutas. Bebidas -Alfa Editores Técnicos (In Spanish)
- Govaerts R, Harvey Y, Jessup L, Pennington TD, Vink W (2012) World checklist of Sapotaceae. Facilitated by the Royal Botanic Gardens, Kew. Published on the internet: <http://apps.kew.org/wcsp/> Retrieved 22 July 2012
- Hernández Bermejo JE, León J (eds) (1994) Neglected crops: 1492 from a different perspective. Plant production and protection series no. 26. FAO, Rome
- Kennard WC, Winters HF (1960) Some fruits and nuts for the tropics. U.S.D.A. Agric. Res. Serv., Misc. Publ. No. 801. USA Department of Agriculture, Washington, DC, pp 1–135
- Lorenzi H, Bacher L, Lacerda M, Sartori S (2006) Brazilian fruits & cultivated exotics (for consuming in natura). Instituto Plantarum de Etodos da Flora Ltda, Brazil, 740 pp
- Ma J, Yang H, Basile MJ, Kennelly EJ (2004) Analysis of polyphenolic antioxidants from the fruits of three *Pouteria* species by selected ion monitoring liquid chromatography-mass spectrometry. J Agric Food Chem 52(19):5873–5878
- Mahattanatawee K, Manthey JA, Luzio G, Talcott ST, Goodner K, Baldwin EA (2006) Total antioxidant activity and fiber content of select Florida-grown tropical fruits. J Agric Food Chem 54:7355–7363
- Moore HE, Stearn WT (1967) The identity of *Achras zapote* L. and names for sapodilla and the sapote. Taxon 16:382–395
- Morton JF (1987) Sapote. In: Fruits of warm climates. Julia F. Morton, Miami, pp 398–402
- Murillo E, McLean R, Britton G, Agócs A, Nagy V, Deli J (2011) Sapotexanthin, an A-provitamin carotenoid from red mamey (*Pouteria sapota*). J Nat Prod 74(2):283–285
- Narciso A, Franklin WM (1976) Cultivation of neglected tropical fruits with promise. Part 2. The mamey sapote. Agricultural Research Service, US Department of Agriculture, Washington, DC
- Orwa C, Mutua A, Kindt R, Jamnadass R, Anthony S (2012) Agroforestree database: a tree reference and selection guide version 4.0 (<http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp>)
- Oyen LPA (1992) *Pouteria sapota* (Jacq.) H. E. Moore & Stearn. In: Verheij EWM, Coronel RE (eds) Plant resources of south-east Asia no. 2. Edible fruits and nuts. PROSEA Foundation, Bogor, pp 259–262
- Pennington TD (1990) Sapotaceae. Flora neotropica: monograph, vol 52. New York Botanical Garden, New York, 770 pp
- Pino JA, Marbot R, Sauri E, Zumarraga C (2006) Volatile components of sapote [*Pouteria sapota* (Jacq.) H. E. Moore et Stern] fruit. J Essent Oil Res 18:22–23
- Popenoe W (1950) Central American fruit culture. Ceiba 1:269–367
- Silva CAM, Simeoni LA, Silveira D (2009) Genus *Pouteria*: chemistry and biological activity. Rev Bras Farmacogn 19(2):501–509
- Solis A, Luna H, Perez HI, Manjarrez N, Sánchez R, Albores-Velasco M, Castillo R (1998) New sources of (R)-oxynitrilase: capulin (*Prunus capuli*) and mamey (*Mammea americana*). Biotechnol Lett 20(12): 1183–1185
- Solis A, Luna H, Manjarrez N, Perez HI (2004) Study on the (R)-oxynitrilase activity of *Pouteria sapota*. Tetrahedron 60:10427–10431
- Solis-Fuentes JA, Duran-de-Bazua C (2003) Characterization of eutectic mixtures in different natural fat blends by thermal analysis. Eur J Lipid Sci Technol 105:742–748
- Solis-Fuentes JA, Tapia-Santos M, Duran-de-Bazua MC (2001) Oil from the zapote mamey almond, and analysis of its extraction conditions and yields. Inf Tecnol 12:23–28
- Standley PC, Williams LO (1967) Sapotaceae. In: Standley PC, Williams LO (eds) Flora of Guatemala – Part VIII, Number 3. Fieldiana, Bot 24(8/3):211–244
- Takeda T, Gonda R, Hatano K (1997) Constitution of lucumin and its related glycosides from *Calocarpum sapota* Merrill. Chem Pharm Bull 45:697–699
- U.S. Department of Agriculture, Agricultural Research Service (USDA) (2012) USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory Home Page, <http://www.ars.usda.gov/ba/bhnrc/ndl>

Pouteria viridis

Scientific Name

Pouteria viridis (Pittier) Cronquist.

Synonyms

Achradelpha viridis (Pittier) O.F.Cook,
Calocarpum viride Pittier.

Family

Sapotaceae

Common/English Names

Green Sapote.

Vernacular Names

Belize: Red Faisan, White Faisan;
Costa Rica: Zapote, Zapote Blanco, Zapote De Castilla, Zapote De Montana, Zapote Injerto, Zapote Rojo, Zapote Verde;
Czech: Sapota Zalená;
Eastonian: Roheline Marmelaadipuu;
El Salvador: Zapote Injerto, Zapote Verde;
Guatemala: Injerto, Injerto Verde, Chul (Mam), Ixulul (Jacalteco), Raxtul (Quecchi), Raxtulul (Poconchi), Tulul (Tzutuhil);

Honduras: Zapote Injerto, Zapote Verde, Zapotillo Calenturiento;

Mexico: Chulul;

Nicaragua: Zapote Amarillo, Zapote De Montana, Zapote Mico, Zapote Negro, Zapote Real, Zapote Verde.

Origin/Distribution

The species is indigenous to Central America from south-east Mexico to Costa Rica. The tree is found in Guatemala, Mexico, El Salvador, Honduras, Nicaragua and Costa Rica.

Agroecology

The tree is restricted to a tropical or near-tropical climate. In its native range, it occurs in tropical forest up to altitudes of 900–2,100 m. Green sapote is tolerant to brief periods of frost. It will grow well on most soils but is intolerant of water-logging. It thrives in soils with pH 5.6–7.5.

Edible Plant Parts and Uses

The pulp of ripe fruit is eaten fresh out of hand, but the pulp is also used in making desserts, drinks and preserves. The pulp is moist, sweet and softer than the mamey sapote. The seeds are edible and are often roasted. The latex (chicle)

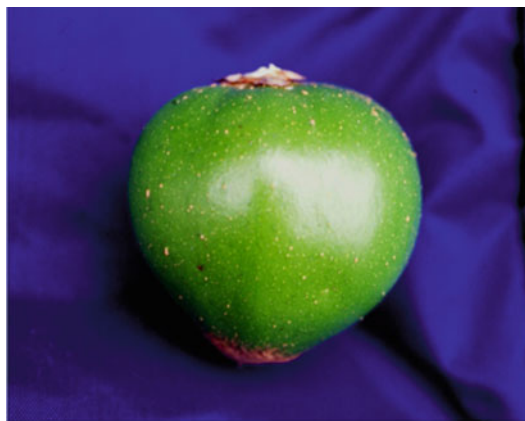


Plate 1 Immature green sapote fruit

from the tree is also collected on commercial scale and marketed like that from the sapodilla for use in chewing gum.

Botany

A medium to large, erect, perennial, evergreen or deciduous, lactiferous and unarmed tree, 12–24 (–40) m high with narrowly spreading crown and densely brown pubescent young branches. Leaves clustered at the tips of flowering branches and irregularly alternate on non-fruiting branches on 1–2 cm long petioles, simple, oblanceolate, 10–25 cm long by 5–7 cm wide, margin entire, obtuse or acute and apiculate at the tip, tapering to the base, almost glabrous above and whitish-tomentose or soft pilose basally. Flowers borne in fascicles of 2–5 at defoliated nodes below the leaves, sessile or short-pedicellate; sepals 9–10 rounded, closely imbricate, densely sericeous; corolla tubular 10 mm long, five-ovate-rounded lobes, pinkish or ivory and pubescent; staminodia pubescent, stamens glabrous; ovary sericeous at the base of the style. Fruit subglobose to ovoid, pointed at the tip with persistent calyx, 8–12.5 cm long and 6–8 cm in diameter, with thin, olive-green or yellow-green rind tinged yellow or red-brown and clinging tightly to the deep orangey brown to salmon-coloured, sweet, juicy flesh. Seed 1 or 2, dark brown, glossy, elliptic or ovate seeds to 5 cm long, with a large, dull, grayish hilum on one surface.

Nutritive/Medicinal Properties

The nutrient composition of green sapote fruit per 100 g edible pulp was reported from analyses made in Guatemala by Morton (1987) as: moisture 68.1–69.5 g, protein 0.152–0.283 g, fat 0.24–0.28 g, fibre 1.2–1.6 g, ash 0.69–1.38 g, Ca 18.6–35.7 mg, P 22.1–23.6 mg, Fe 0.57–0.74 mg, carotene 0.031–0.069 mg, thiamine 0.009–0.011 mg, riboflavin 0.027 mg, niacin 1.88–1.189 mg, and ascorbic acid 49.9–62.3 mg. Ripe fruit has a Brix (total soluble solids) of 29% (Crane et al. 2011).

Seven polyphenols were found in *P. viridis* fruit: gallic acid 2.82 ppm, (+)-galocatechin 47.26 ppm, (+)-catechin 27.32 ppm, (–)-epicatechin 5.91 ppm, dihydromyricetin 4.68 ppm, (+)-catechin-3-*O*-gallate 2.73 ppm, and myricitrin 7.34 ppm (Ma et al. 2004). The ethyl acetate soluble fraction of *P. viridis* displayed antioxidant activity with IC₅₀ value of 52.6 µg/mL in the DPPH assay. All seven polyphenol also showed DPPH radical scavenging activity.

P. viridis plant parts have been used in traditional medicine (Azurdia 2005). The seed oil has been used as a hair dressing to prevent hair loss. A decoction of the bark can also help to heal skin diseases. Verrucas and fungal infections of the skin have been treated by applying the latex.

Other Uses

P. viridis is a suitable species for reforestation and can mitigate soil erosion and contribute to soil improvement.

The wood is reddish, fine-grained, compact, strong, durable, fairly heavy; occasionally used in construction, building carts, carpentry, turnery, and for furniture and panelling.

Comments

The plant is propagated mostly from seeds. Plants can also be raised by grafting on mamey sapote seedlings. The grafted plants start bearing much earlier than the seedlings which may take even up to 7–8 years.

Selected References

- Azurdia C (2005) Tres Especies Centro Americanas De *Pouteria*: *P. campechiana*, *P. sapota*, Y. *P. viridis*. University of Southampton, International Centre for Underutilised Crops, Southampton, 257 pp
- Crane JH, Balerdi CF, Cambell CW, Regalado R (2011) Evaluation of fruit from a green sapote (*Calocarpum viride* Pitt.) selection at the University of Florida Tropical Research and Education Center, Homestead. Proc Fla State Hort Soc 114:5–6
- Govaerts R, Harvey Y, Jessup L, Pennington TD, Vink W (2012) World checklist of Sapotaceae. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet: <http://apps.kew.org/wcsp/> Retrieved 22 July 2012
- Kennard WC, Winters HF (1960) Some fruits and nuts for the tropics. USDA Agric Res. Serv., Misc. Publ. No. 801. USA Department of Agriculture, Washington, DC, pp 1–135
- Ma J, Yang H, Basile MJ, Kennelly EJ (2004) Analysis of polyphenolic antioxidants from the fruits of three *Pouteria* species by selected ion monitoring liquid chromatography-mass spectrometry. J Agric Food Chem 52(19):5873–5878
- Martin FW, Malo SE (1978) Cultivation of neglected tropical fruits with promise, Part 5. The canistel and its relatives. U. S. Department of Agriculture, New Orleans, 12 pp
- Morton JF (1987) Sapote. In: Fruits of warm climates. Julia F. Morton, Miami, pp 398–402
- Pennington TD (1990) Sapotaceae. Flora neotropica: monograph, vol 52. New York Botanical Garden, New York, 770 pp
- Pennington TD (1991) The genera of the Sapotaceae. Kew Publishing, London, 307 pp
- Standley PC, Williams LO (1967) Sapotaceae. In: Standley PC, Williams LO (eds) Flora of Guatemala – Part VIII, Number 3. Fieldiana, Bot 24(8/3):211–244
- Thomson PH (1973) The green sapote. California rare fruit growers yearbook, California, vol 5, pp 41–48
- Whitman WF (1965) The green sapote, a new fruit for south Florida. Proc Fla State Hort Soc 78:330–336

Synsepalum dulcificum

Scientific Name

Synsepalum dulcificum (Schumach. & Thonn.) Daniell.

Synonyms

Bakeriella dulcifica (Schumach. & Thonn.) Dubard, *Bumelia dulcifica* Schumach. & Thonn. (basionym), *Pouteria dulcifica* (Schumach. & Thonn.) Baehni, *Richardella dulcifica* (Schumach. & Thonn.) Baehni, *Sideroxylon dulcificum* (Schumach. & Thonn.) DC., *Synsepalum glycydora* Wernham.

Family

Sapotaceae

Common/English Names

Magic Berry, Miracle Berry, Miracle Fruit, Miraculous Berry, Sweet Berry.

Vernacular Names

French: Fruit Miraculaix;
German: Wunderbeere;
West Africa: Taami, Asaa, Ledidi.

Origin/Distribution

It is a native of tropical west and west central Africa. It is occasionally cultivated from Ghana to Nigeria, with experimental plantations in tropical America. It has been introduced into many southeast Asian countries, Australia and the USA.

Agroecology

The plant is tropical in its requirements requiring a warm to hot, wet to humid environment free from frost. It will grow in full sun but thrives best under partial shade on well-drained, acidic soil with pH from 4.5 to 5.8. It is intolerant of alkaline conditions and water-logging.

Edible Plant Parts and Uses

The fruit is edible and has remarkable effects as after eating the fruit sour things will instantly taste sweet. Eating even the sourest of lemons or limes, one will taste only sugary sweetness. The effect lasts an hour or two. In this manner it can be used for “sweetening” palm wine, sour fruits and other drinks or food. It is not a sweetener per se but has been used to sweeten bitter medicines. This effect is due to an active glycoprotein, miraculin in the fruit flesh which is also an appetite depressant.

Botany

A bushy, evergreen shrub to 4 m high. Leaves are alternate, clustered at the branch tip, on short petioles; lamina 5–15 cm long, 2–4 cm wide, obovate-lanceolate to broadly lanceolate, bluntly pointed at apex, tapering towards the base, glossy green, with eight pairs of lateral veins (Plate 1). Flowers are bisexual, white, small, solitary or in small clusters of 2–4 on slender pedicels in leaf axils. Calyx is five-lobed, 5 mm long, ribbed with triangular lobes; corolla as long as calyx, white, tubular, 5-parted. small, 6–7.5 mm, with 5 mm long, ribbed, 5-lobed calyx 4–5 lobed, white. Fruit is an ovoid to oblong berry, 2–2.5 cm long, 1 cm wide, finely pubescent, with a persistent protruding style, green turning bright red when ripe (Plates 1 and 2) and contain a single dark brown



Plate 2 Close-up of ripe miracle fruit

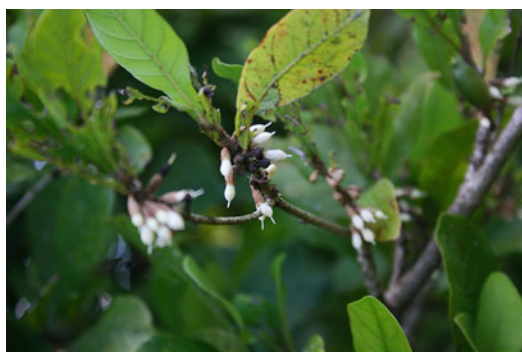


Plate 1 Fruit and leaves of miracle fruit



ellipsoid seed enclosed by the white fleshy translucent, insipid pulp.

Nutritive/Medicinal Properties

Miracle fruit was found to contain anthocyanin and flavonol pigments which could have potential to be used as natural food colorants. The red pigments of miracle fruit (14.3 mg/100 g fresh wt) were identified as cyanidin-3-monogalactoside, cyanidin-3-monoglucoside, cyanidin-3-monoarabinoside, delphinidin-3-monogalactoside and delphinidin-3-monoarabinoside existing in a

ratio of 188:62:9:5:2, respectively (Buckmire and Francis 1976). The major flavonol pigments were quercetin-3-monogalactoside, kaempferol-3-monoglucoside, myricetin-3-monogalactoside and traces of similar flavonols. The aglycones quercetin, kaempferol and myricetin were also isolated and identified. Ficumone, a 2-oxetanone isolated from the fruits of *Synsepalum dulcificum* and characterised as (R*)-4-hydroxy-2-oxetanone (Cheng et al. 2010).

An amide, dihydro-feruloyl-5-methoxytyramine, along with 13 known compounds, including (+)-syringaresinol, (+)-epi-syringaresinol, 4-acetonyl-3, 5-dimethoxy-*p*-quinol, *cis-p*-coumaric acid, *trans-p*-coumaric acid, *p*-hydroxybenzoic acid, syringic acid, vanillic acid, veratric acid, *N-cis*-feruloyltyramine, *N-trans*-feruloyltyramine and *N-cis*-caffeoyltyramine were isolated from the stems of *Synsepalum dulcificum* (Wang et al. 2011).

Sweetening Activity

The active substance, responsible for the remarkable 'sweetening' effect of miracle fruit was found to be a basic glycoprotein. The molecular weight of the glycoprotein was 24.6 kDa including 3.4 kDa (13.9% of the weight) of sugar constituted (on molar ratio) of glucosamine (31%), mannose (30%), fucose (22%), xylose (10%) and galactose (7%) (Theerasilp and Kurihara 1988). The substance was isolated by Prof. Kenzo Kurihara, a Japanese scientist, who named it miraculin after the miracle fruit when he published his work in Science in 1968 (Kurihara and Beidler 1968; Kurihara and Terasaki 1982). Application of the protein to the tongue modifies the taste so that one tastes sour substances as sweet. Later his group purified and sequenced miraculin in 1989. Miraculin was found to be a glycoprotein consisting of 191 amino acids and some carbohydrate chains (Theerasilp et al. 1989). Miraculin was found to occur as a tetramer (98.4 kDa), a combination of four monomers group by dimer. Within each dimer 2 miraculin glycoproteins were linked by a disulfide bridge.

Studies by other Japanese scientists found that the initial taste responses were localized in the fronto-parietal opercular/insular cortex of the human brain which was reported as the primary

taste area (Yamamoto et al. 2006). They postulated that the qualitative aspect of taste is processed in the primary taste area and the affective aspect is represented by the pattern of activation among the different cortical areas. In a separate study scientist found that miracle fruit adds sweetness to acids without directly blocking sour receptor sites. The reduction in sourness after miracle fruit resulted from mixture suppression, i.e., the mutual suppression usually observed between different qualities in a mixture.

In a randomized cross over design study, subjects that consumed miracle fruit prior to consuming lemon juice-based popsicle with a sour, low-sugar (142 J) version (DIET) rated the popsicle as sweeter (Wong and Kern 2011). Subjects did not detect a difference in sweetness for lemon juice based popsicles sweetened normally with sucrose (REG) compared to DIET with miracle fruit. Consumption of DIET with miracle fruit produced lower energy intake compared to REG with (−1,017 J) and without (−955 J) miracle fruit. Their results suggested that miracle fruit could enhance the sweetness of a low sugar dessert while limiting energy intake in comparison to a higher calorie, sucrose-sweetened popsicles.

Antioxidant Activity

Methanol fruit extract and chloroform pulp extract of *S. dulcificum* were found to have DPPH scavenging activity in-vitro (Chen et al. 2009).

The free antioxidant activities in miracle fruit skin and pulp were comparable, and were significantly greater than that in seeds (Inglett and Chen 2011). Although skin had considerably higher antioxidant activity than seeds, 49.45% free antioxidant activity, 76.41% bound antioxidant activity, and 58.56% of total antioxidant activity were contributed by seeds due to about 66% of solid of total solids. Skin contained almost three times more free phenolic acid than the pulp and four times that of the seeds. Skin contributed 43.96% of free phenolic compounds with 15.91% of freeze-dried solids due to its high phenolic content. The free flavonoid content in

the skin was markedly higher than that in the seed and pulp. The skin contributed about 52% of total flavonoid with 15.91% of dried solids.

Thirteen compounds isolated from miracle fruit stem namely including dihydro-feruloyl-5-methoxytyramine (1), (+)-syringaresinol (2), (+)-epi-syringaresinol (3), 4-acetonyl-3,5-dimethoxy-*p*-quinol (4), *cis-p*-coumaric acid (5), *trans-p*-coumaric acid (6), *p*-hydroxybenzoic acid (7), syringic acid (8), vanillic acid (9), veratric acid (10), *N-cis*-feruloyltyramine (11), *N-trans*-feruloyltyramine (12) and *N-cis*-caffeoyltyramine (13), exhibited moderate DPPH, ABTS radical scavenging, metal chelating and reducing power (Wang et al. 2011).

Antidiabetic Activity

Research in Taiwan reported that miraculin could improve insulin resistance (Chen et al. 2006). They demonstrated that oral administration of miracle fruit powder decreased the plasma glucose in a dose-dependent manner for 150 min in rats fed fructose-rich chow for 4 weeks. Oral administration of miracle fruit (0.2 mg/kg) to fructose-rich chow fed rats, three times daily for 3 days, reversed the elevated value of the glucose-insulin index, indicating miracle fruit to have the ability to improve insulin sensitivity. Their results suggested that miracle fruit may be used as an adjuvant for treating diabetic patients with insulin resistance because this fruit has the ability to improve insulin sensitivity.

Anti-tyrosinase Activity

Methanol fruit extract and chloroform pulp extract of *S. dulcificum* were found to have anti-tyrosinase using in-vitro mushroom tyrosinase assay (Chen et al. 2009). The 13 compounds isolated from miracle fruit stem reduced mushroom tyrosinase activity (Wang et al. 2011). Of 13 compounds, (+)-syringaresinol and (+)-epi-syringaresinol exhibited significant inhibition of human melanoma proliferation.

Other Uses

The plant is planted as a garden plant.

Comments

Miracle fruit is propagated by seeds and cuttings.

Selected References

- Bartoshuk LM, Gentile RL, Moskowitz HR, Meiselman HL (1974) Sweet taste induced by miracle fruit (*Synsepalum dulcificum*). *Physiol Behav* 12(3): 449–456
- Buckmire RE, Francis FJ (1976) Anthocyanins and flavonols of miracle fruit, *Synsepalum dulcificum* Schum. *J Food Sci* 41(6):1363–1365
- Chen C-C, Liu IM, Cheng J-T (2006) Improvement of insulin resistance by miracle fruit (*Synsepalum dulcificum*) in fructose-rich chow-fed rats. *Phytother Res* 20:987–992
- Chen CY, Wu PY, Huang TS, Lin CW, Li YC, Chou RH, Chang HW, Wang HM (2009) The sour taste-modifying protein (miraculin), tyrosinase inhibitors and antioxidants from *Synsepalum dulcificum*. *Curr Nutr Food Sci* 5(3):172–179
- Cheng MJ, Lo WL, Huang LY, Wang CJ, Chen CY (2010) Isolation of a 2-oxetanone from the fruits of *Synsepalum dulcificum*. *Nat Prod Res* 24(19):1850–1853
- Facciola S (1990) *Cornucopia*. A source book of edible plants. Kampong Publ., Vista, 677 pp
- Govaerts R, Harvey Y, Jessup L, Pennington TD, Vink W (2011) World checklist of Sapotaceae. Facilitated by the Royal Botanic Gardens, Kew. Published on the internet: <http://apps.kew.org/wcsp/>. Retrieved 22 May 2011
- Huxley AJ, Griffiths M, Levy M (eds) (1992) The new RHS dictionary of gardening, 4 vols. MacMillan, London
- Inglett GE, Chen D (2011) Contents of phenolics and flavonoids and antioxidant activities in skin, pulp, and seeds of miracle fruit. *J Food Sci* 76(3): C479–C482
- Kurihara K, Beidler LM (1968) Taste-modifying protein from miracle fruit. *Science* 161(3847):1241–1243
- Kurihara Y, Terasaki S (1982) Isolation and chemical properties of multiple active principles from miracle fruit. *Biochim Biophys Acta* 719(3):444–449
- Mabberley DJ (1997) The plant-book, 2nd edn. Cambridge University Press, Cambridge, 858 pp
- Martin FW, Campbell CW, Ruberte R (1987) Perennial edible fruits of the tropics: an inventory. Agriculture Handbook No. 642. U.S. Department of Agriculture, Washington, DC
- Theerasilp S, Kurihara Y (1988) Complete purification and characterization of the taste-modifying protein, miraculin, from miracle fruit. *J Biol Chem* 263(23):11536–11539
- Theerasilp S, Hitotsuya H, Nakajo S, Nakaya K, Nakamura Y, Kurihara Y (1989) Complete amino acid sequence and structure characterization of the taste-modifying protein, miraculin. *J Biol Chem* 264(12):6655–6659
- Wang HM, Chou YT, Hong ZL, Chen HA, Chang YC, Yang WL, Chang HC, Mai CT, Chen CY (2011) Bioconstituents from stems of *Synsepalum dulcificum* Daniell (Sapotaceae) inhibit human melanoma proliferation, reduce mushroom tyrosinase activity and have antioxidant properties. *J Taiwan Inst Chem Eng* 42(2):204–211
- Wong JM, Kern M (2011) Miracle fruit improves sweetness of a low-calorie dessert without promoting subsequent energy compensation. *Appetite* 56(1): 163–166
- Yamamoto C, Nagai H, Takahashi K, Nakagawa S, Yamaguchi M, Tonoike M, Yamamoto T (2006) Cortical representation of taste-modifying action of miracle fruit in humans. *Neuroimage* 33(4):1145–1151

Illicium verum

Scientific Name

Illicium verum Hook. f.

Synonyms

Illicium san-ki Perrottet.

Family

Schisandraceae, also placed in Illiciaceae.

Common/English Names

Badian Star Anise, Chinese Aniseed, Chinese Anise, Chinese Star Anise, Indian Anise, Star Anise, Star Aniseed, True Star Anise.

Vernacular Names

Brazil: Anis Da China, Anis Da Sibéria, Anis Estrellado, Anis Estrelado, Badiana, Funcho Da China (**Portuguese**);

Bulgarian: Anason Zvezdoviden;

Croatian: Zvezdasti Anis;

Chinese: Ba Jiao, Ba Jiao Hui Xiang, Da Hui Xiang (**Mandarin**); Bat Gok, Bart Gok, Pa-Chiao, Pak Kok, (**Cantonese**), Peh Kah (**Hokien**);

Czech: Badyán, Badyáník, Badyáník Pravý;

Danish: Sterneanis, Stjerneanis;

Dutch: Steranijs;

Eastonian: Harilik Tähtaniisipuu;

Finnish: Taehtianis, Tähtianis;

French: Anis De Sibérie, Anis Étoilé, Anis De La Chine, Badiane, Badiane De Chine, Badianier, Fenouil De Chine;

German: Badian, Chinesischer Sternanis, Sternanis, Sternanisbaum; Anasphal;

Hungarian: Badián, Csillagánizs, Kínai Ánizs, Kínai Csillagánizs;

India: Anasphal, Badayan (**Hindu**), Chainaa Sompū, Chakramaggi, Kankola, Maraat Moggu (**Kannada**), Takkolappottil, Takkolapputtill (**Malayalam**), Anasphal, Baadiyan, Bardan (**Marathi**), Badian Khatai (**Punjabi**), Takkola, Takkolakam (**Sanskrit**), Anasipoo, Anasi Poo, Anasuppan, Annaci, Annacippu, Annasippu, Anusappu, Anusuppu, Takkolam (**Tamil**), Anas Poovu, Anasapurvem, Anasapuveru, Kuppi (**Telugu**), Badyani (**Urdu**);

Indonesia: Bunga Lawang, Adas Cina, Pe-Ka;

Iranian: Badiyan Romi;

Italian: Anice Della China, Anice Stellato, Badiana;

Japanese: Sutaan Anisu, Tou Shikimi, Kai-Ko, Dai Uikio, Hakkaku Uikio, Haku Uikio;

Khmer: Phka Cann, Poch Kak Lavhak, Innish Tähtianis;

Korean: Taehoihyang;

Latvian: Badjans;

Macedonian: Badijan;

Malaysia: Bunga Lawang, Adas China, Bunga Lawang (**Malay**);

Norwegian: Stjerneanis;
Persian: Bádián-I-Khatai;
Philippines: Anis, Sanque, Sanke (Tagalog, Cebuano);
Polish: Anyz Gwiazdkowaty, Badian Właściwy, Gwiazdkowy;
Portuguese: Anis-Da-China, Anis Estrelado;
Romania: Anason Stelat;
Russian: Bad'ian Nastoiashchii, Badyan, Svezdchatyj Anis, Zvezdchatyi Anis, Zvezdāatyj Anis;
Slovačina: Zvezdni Janež;
Slovenia: Anízovca Pravého, Anízovec Pravy, Badián, Badiánu, Hviezdicovy Aníz;
Spanish: Anís De China, Anís De La China, Anís Estrellado, Badián Anís Estrellat (Catalan);
Swedish: Stjärnanis, Stjaernanis, Äkta Stjärnanis, Kinesisk Stjärnanis, Ostindisk Stjärnanis;
Thailand: Dok Chan, Poy Kak, Chinpaetklip;
Turkish: Anason Tchini, Çin Anason;
Vietnam: Hoa Hôi, Cái Hôi, Hôi, Hoi Sao, Đại Hôi, Bát Giác Hôi Hương, Bát Giác Hương, Mac Chac, Mac Hôi, (Tay), Pit Coc (Dao).

Origin/Distribution

Star anise is native to southern China and Vietnam. It is today grown almost exclusively in southern China, Indo-China, and Japan.

Agroecology

Star anise is sub-tropical in growth requirements, growing in areas of annual mean temperatures of 12–22 °C and annual rainfall of 1,400–2,400 mm at altitudes of 300–2,000 m. It grows best on ferrallitic soils derived from mica schists, clayish sandstone with an acidic pH range of 4–5.8. It abhors calcareous soils. It is shade tolerant when young and light demanding when older.

Edible Plant Parts and Uses

Dried ripe, star anise fruit and seed are used as important spice in Asian cooking especially in Chinese, Indian and Vietnamese cuisines. Star

anise is the dominant ingredient of the traditional five-spice powder (Mandarin *wu xiang fen*, Cantonese *ngh heung fan*) of Chinese and Vietnamese cooking. This spice mixture comprises star anise, cassia (or cinnamon), cloves, fennel and Sichuan pepper. Optionally, galangal, black cardamom, ginger and liquorice may be added. Five spice powder is often added to a batter made from egg white and cornstarch, which is used to coat meats and vegetables to keep them moist and succulent during deep-frying. Meat is also frequently coated with a mixture of corn starch and five spice powder and deep-fried. The subtle aroma of five spice powder is particularly effective in steamed foods. Steamed pork belly where the meat is marinated in soy sauce and garlic, coated by a mixture of five-spice powder and ground, toasted rice and steamed is a popular delicacy. In Chinese cooking star anise is added to beef, chicken, pork or duck dishes usually with dark soya soy. It flavours marbled eggs, a decorative Chinese *hors d'oeuvre* or snack. Chinese stocks and soups very often contain star anise. The fruit has also been chewed as a breath freshener e.g. by the Mandarins in China. Star anise is also one of the ingredients used to make the broth for the Vietnamese rice noodle soup called “*pho*” cooked with thin slices of beef. Star anise is also used in Thailand: In the North, it is often employed in long-simmered stews; and in the tropical South, it is a common flavoring for ice black tea; sometimes other flavors viz. cinnamon, licorice, vanilla and orange are added; the tea is relished with crushed ice, sugar and evaporated milk.

In Indian cuisine, star anise is the major component of *garam masala* in curries. It is used as a spice in preparation of *Biryani* in Andhra Pradesh, a south Indian State. In northern India, where it is used as an ingredient of *Masala Chai*. Star anise is less important in Persian and Pakistani cuisine.

Star anise fruit and oil are used as flavouring agent in beverages – soft drinks, herbal teas, brandy, anise-flavoured liqueurs (such as anisette, pastis, Pernod, Galliano, Sambuca and other types of absinthe); chewing gum, confectionery, bakery products, puddings, gelatine, fruit compotes, jam sweet eat, pickles, meat and meat products.



Plate 1 Young tree of star anise



Plate 2 Star anise leaves



Plate 3 Young and mature star anise fruits

Botany

A medium-sized, branched, evergreen, perennial tree growing to 6–10-(15) m high with white to greyish white bark (Plate 1). Branches are glabrous, greenish when young turning greyish-brown with age. Leaves are alternate, usually crowded at the end of branches, petiole, short, reddish on young foliage (Plates 1 and 2). Leaf lamina simple, entire, glossy green, glabrous, coriaceous, glandular-punctate, lanceolate to oblong lanceolate, 6–12 cm by 2.5–4 cm, apex acute. Flowers are axillary, bisexual, regular, solitary or in 2–3 fascicles, 1–1.7 cm across, whitish pink to greenish yellow, perianth lobes 7–12 and stamens 11–20 arranged spirally, carpels usually 8, free arranged in a whorl. Fruit is a capsule-like follicle, 2.5–4 cm diameter consisting of usually 8 follicles (6–12) arranged in star-shaped manner around a central axis, green



Plate 4 Dried star anise fruit and seeds

turning to brown when mature (Plate 3). Follicle is boat shaped about 2 cm long with one seed (Plate 4). Seed is compressed ovoid, shiny glabrous, 7–10 × 4–6 × 2.5–3 mm, light brown to reddish brown, with oily endosperm.

Nutritive/Medicinal Properties

Star anise fruit was found to contain catechins, protoanthocyanidin, volatile oil, fixed oil and mineral chemicals. Volatile oil extracted from star anise fruit was found to contain 41 compounds including 14 hydrocarbon components and 22 oxygenated hydrocarbon derivatives, and a small amount of nitrogenous compounds (Yan et al. 2002). The main component was anethole, accounting for 76.23%, mainly *trans*-anethole and a small amount of *cis*-anethole, and the other components such as anisyl acetone, anisaldehyde, *p*-allylanisole, *p*-cumin aldehyde and *p*-allylphen comprising more than 10%. Terpeneol, linalool and estragol were also present. The fruit also contained 1,4-cineole, β -bisabolene, β -farnesene, α -copaene, *cis*-bergamotene, *trans*- α -bergamotene, caryophyllene, nerolidol, methyl anisate, *trans*-methyl isoeugenol, cadinene, foeniculin, δ -3-carene, D- α -pinene, phellandrene, hydroquinone and safrole. The following compounds were isolated from *Illicium verum* and their structures were elucidated as: compounds illicinoline A, 3,3',4',5,7-pentahydroxyflavone, quercetin, betulinic acid, shikimic acid and β -sitosterol (Yang et al. 2009).

Forty nine compounds were separated and identified in star anise, (Gholivand et al. 2009). The major compounds comprised *trans*-anethole (81.4.0%), limonene (6.50%), chavicol (2.10%), and anisaldehyde (1.81%). In a more recent analysis, 22 compounds were identified in the essential oil of star anise, representing 94.6% of the whole composition of the oil (Huang et al. 2010). The most abundant component was *trans*-anethole (89.5%). Other main components included 2-(1-cyclopentenyl)-furan (0.9%) and *cis*-anethole (0.7%). Other compounds included: isobornyl thiocyanacetate 0.4%, limonene 0.4%, γ -terpineol 0.4%, δ -3-carene 0.3%, linalool 0.3%, camphene 0.2%, terpinen-4-ol 0.2%, β -myrcene 0.1%, α -phellandrene 0.1%, *p*-cymene 0.1%, *trans*-ocimene 0.1%, γ -terpinene 0.1%, terpinolene 0.1%, β -elemene 0.1%, cyperene 0.2%, β -caryophyllene 0.1%, α -caryophyllene 0.1%, (+)-9-epiledene 0.1% and cubebene 0.1%. In another analysis,

16 compounds were identified, predominated by *trans*-anethole (90.82%) followed by estragole (3.68%) (Dzamic et al. 2009). Other compounds included foeniculin (1%), linalool (0.79%), *p*-anisaldehyde (0.78%), limonene (0.67%), *cis*-anethole (0.41%), β -caryophyllene (0.30%), anisylacetone (0.24,%), α -terpineol (0.21%), *trans*- α -bergamotene (0.17%), α -pinene (0.13%), terpinen-4-ol (0.12%), α -phellandrene (0.11%), α -muurolol (0.07%) and *p*-cymene (0.06%). *Trans*-anethole (89.5%), 2-(1-cyclopentenyl)-furan (0.9%) and cisanethole (0.7%) were found to be the main components among 22 identified compounds in star anise fruit oil, which accounted for 94.6% of the total oil (Huang et al. 2010).

The major chemical components in volatile oil were found to be different in different star anise varieties (Liu 2009). Results indicated that yield of volatile oil was the highest in var. Jiao-hua followed by Gan-zhi and Da-hong exhibited the lowest yield. A total of 19 components were identified in star anise seed oils. Major chemical components identified were: feniculin (49.77%), α -bergamotene (21.52%) and 4-methoxycinnamaldehyde (14.80%) in Da-hong star anise seed oil; feniculin (47.50%), n-hexadecanoic acid (16.61%) and 4-methoxycinnamaldehyde (4.96%) in Jiao-hua star anise seed oil. The chemical components in volatile oil of Gan-zhi star anise seed were quite complex.

Numerous phytochemicals including volatiles, seco-prezizaane-type sesquiterpenes, phenylpropanoids, lignans, flavonoids and other constituents were identified from *I. verum* (Wang et al 2011). Numerous pharmacological studies demonstrated its crude extracts and active compounds to possess diverse pharmacological properties, especially in antimicrobial, antioxidant, insecticidal, analgesic, sedative and convulsive activities. In addition, it is the major source of shikimic acid, a primary ingredient in the anti-flu drug (Tamiflu). Star anise essential oil is rich in *trans*-anethole and is mainly used in food and pharmaceutical industries. Star anise oil exhibits high antioxidant, antimicrobial, insecticidal and fumigant activities

The dichloromethane extract of the leaves of *Illicium verum* yielded the ring A-cleaved

seco-cycloartane: 3,4-seco-(24Z)-cycloart-4(28), 24-diene-3,26-dioic acid, 26-methyl ester, which is the 26-methyl ester of nigranoic acid (Sy and Brown 1998).

Pharmacological properties of star anise are presented below.

Antioxidant Activity

Star anise powder and its ethanol/water (80:20)-soluble fraction showed strong antioxygenic activity in refined sunflower oil while the petroleum ether fraction exhibited marginal antioxygenic activity and the water-soluble fraction was practically devoid of any activity in sunflower oil (Padmashree et al. 2007). Star anise powder and its ethanol/water also exhibited strong antioxidant activity when evaluated by linoleic acid peroxidation, β -carotene-linoleate and 1, 1-diphenyl-2-picryl hydrazyl (DPPH) methods. Its volatile oil also exhibited antioxygenic activity and the activity did not seem to be concentration-dependent. Twenty-five compounds were identified in the star anise volatile oil.

The ethyl acetate extracts of *I. verum* showed marked antioxidant potential (DPPH radical scavenging activity) and could be developed as a natural source of antioxidants (Yang et al. 2012). The ethyl acetate fractions contained substantially high levels of total phenolics (4.5 g gallic acid/100 g dry weight) and total flavonoids (6.9 g quercetin/100 g dry weight). The antioxidant activity was attributed to anisyl acetone and anisyl aldehyde.

Antiviral Activity

Star anise fruit also contain shikimic acid (3,4,5-Trihydroxy-1-cyclohexene-1-carboxylic acid) (Chien et al. 2006) which is the base material for the production of the anti influenza viral drug, oseltamivir (Tamiflu). Oseltamivir has been shown to be effective in the treatment and prevention of epidemic influenza infection in adults, adolescents and children (≥ 1 year) (Ward et al. 2005). Although oseltamivir has not been approved for

prophylactic use in children, it has been shown to be effective. Oseltamivir is also active against avian influenza virus strains. Tamiflu® (Roche Laboratories) is an antiviral drug which has gained popularity with the recent spread of the bird flu (H5N1).

Six phenylpropanoids and seven phytoquinoids isolated from three *Illicium* species including *I. verum* displayed inhibitory activities against Epstein-Barr virus early antigen (EBV-EA) activation induced by 12-O-tetradecanoylphorbol-13-acetate in Raji cells (Itoigawa et al. 2004). All tested compounds showed inhibitory activity against the EBV-EA activation even at 1×10^{-6} mol ratio, and the inhibitory activity of their compounds were found to be more than that of β -carotene. Two phenylpropanoids having prenyl group, 4-allyl-2-methoxy-6-(3-methyl-2-butenyl) phenol (3) and 4-allyl-2,6-dimethoxy-3-(3-methyl-2-butenyl)phenol (4), showed more potent activities as anti-tumour promoters (IC_{50} of 224 and 217 mol ratio/TPA, respectively).

Amongst the following compounds isolated from star anise roots: illiverin A (1), tashironin A (8), 4-allyl-2-(3-methylbut-2-enyl)-1,6-methylenedioxybenzene-3-ol (2), illicinole (3), 3-hydroxy-4,5-methylenedioxyallyl-benzene (4), (-)-illicinone-A (5), 4-allyl-4-(3-methylbut-2-enyl)-1,2-methylenedioxycyclohexa-2,6-dien-5-one (6), 3,4-seco-(24 Z)-cycloart-4(28),24-diene-3,26-dioic acid, 26-methyl ester (7) and tashironin (9); compounds 5 and 7 demonstrated moderate anti-HIV activity with EC_{50} values of 16.0 and 5.1 μ M with SI values of 18.2 and 15.6, respectively (Song et al. 2007).

Anticancer Activity

Star anise also possesses anticancer activities. Star anise exhibited anti-carcinogenic potential in N-nitrosodiethylamine (NDEA) initiated and phenobarbital (PB) promoted hepato-carcinogenesis (Yadav and Bhatnagar 2007). The treatment with star anise throughout for 20 weeks or during the promotion stage (6–20 weeks) significantly reduced the nodule incidence and nodule multiplicity in the rats and lipid peroxidation (LPO)

in liver and erythrocytes. The treatment with star anise also restored the liver and erythrocyte super-oxide dismutase (SOD) activities to normal in the carcinogenesis-induced rats. The liver catalase (CAT) activity and liver glutathione (GSH) level increased in all the treated groups. These results indicated that star anise treatment reduced tumour burden, lowered oxidative stress and increased the level of phase II enzymes, which may contribute to its anti-carcinogenic potential.

Septic Shock Preventative Activity

Two known racemic mixtures of phenylpropanoids, [1-(4'-methoxyphenyl)-(1 R,2 S and 1 S,2 R)-propanediol (1) and 1-(4'-methoxyphenyl)-(1 R,2 R and 1 S,2 S)-propanediol (2)], along with two known phenylpropanoid glucosides, [1-(4'-methoxyphenyl)-(1 S,2 R)-propan-1-ol 2-O- β -D-glucopyranoside (3) and 1-(4'-methoxyphenyl)-(1 R,2 S)-propan-1-ol 2-O- β -D-glucopyranoside (5)], and two new phenylpropanoid glucosides, [1-(4'-methoxyphenyl)-(1S,2 S)-propan-1-ol 2-O- β -D-glucopyranoside (4) and 1-(4'-methoxyphenyl)-(1 R,2 R)-propan-1-ol 2-O- β -D-glucopyranoside (6)] isolated from star anise fruit were found to act as preventive agents against lethality due to septic shock (Lee et al. 2003). Among them, compound 1 exhibited the highest survival rate in a dose-dependent manner (100% with a dose of 10 mg/kg against 40% for the control experiment) and showed a reduction of the plasma alanine aminotransferase (ALT) value on the in-vivo assay model of septic shock induced by tumour necrosis factor (TNF)-alpha.

Antiinflammatory Activity

Star anise also possesses anti-inflammatory activity. Two phenylpropanoids, 1-allyl-3,5-dimethoxy-4-(3-methyl-but-2-enyloxy)benzene and 4-allyl-2,6-dimethoxy-3-(3-methyl-2-butenyl)phenol, and two phytoquinoids, 4 R-(–)-illicinone-A and 2 S,4 R-(–)-illicinone-B isolated from *Illicium* plant species significantly inhibited histamine release from rat basophilic leukemia (RBL-2 H3)

cells stimulated with A23187 (Matsui et al. 2007). Furthermore, these compounds caused a decline in TNF-alpha levels in culture supernatants of RBL-2 H3 cells following treatment. The results indicated that these compounds might be useful as antiinflammatory agents against mast cell-mediated inflammatory diseases.

Antimicrobial Activity

Star anise has been shown to possess potent antimicrobial properties. Chemical studies indicated that a major portion of this antimicrobial property was due to anethole present in the dried fruit. Anethole was found to be effective against bacteria, yeast and fungal strains (De et al. 2002). The evaluation of antibacterial activity of six methanolic extracts of crude drugs including *Illicium verum* fruits against anaerobic and facultative aerobic periodontal bacteria revealed that methanol extract of *I. verum* fruit was not very active though it had a particular good activity against *Eikenella corrodens* (Iauk et al. 2003). The crude ethanolic extract from the fruit of *Illicium verum* showed antimicrobial activity against *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Candida albicans*, *Aspergillus flavus* and *Trichophyton mentagrophytes* (Nanthachit 2002). Further extractions from the fruit yielded three parts: hexane, dichloromethane and methanolic extracts. Crude hexane and dichloromethane extracts showed antifungal activity against *T. mentagrophytes* while crude dichloromethane and methanolic extracts showed antibacterial activity against *Staphylococcus aureus*. From spectroscopic evidence, the active compound in the hexane extract appeared to be anethole and its antifungal activity was determined by using the agar dilution method. The MIC against *C. albicans*, *A. flavus* and *T. mentagrophytes* was found to be 2,500, 2,500 and 625 mg/mL, respectively.

The supercritical CO₂ and ethanol extracts of *Illicium verum* was found to show substantial antibacterial activity against 67 clinical drug-resistant isolates, including 27 *Acinetobacter baumannii*, 20 *Pseudomonas aeruginosa*, and 20 methicillin-resistant *Staphylococcus aureus* (Yang

et al. 2010). The diethyl ether fraction obtained from partition extraction and supercritical CO₂ extracts revealed an antibacterial activity with a minimum inhibitory concentration value of 0.15–0.70 and 0.11 mg/mL, respectively. The diethyl ether fraction of *I. verum* showed synergetic effects with some commercial antibiotics. The chemical components of the extracts were identified as (E)-anethole, anisyl acetone, anisyl alcohol, and anisyl aldehyde; and they exhibited antibacterial activity against different clinical isolates. *I. verum* essential oil as well as *trans*-anethole were found to have antifungal activity (Huang et al. 2010). Both inhibited the growth of plant pathogens, *Pythium aphanidermatum* and *Botryodiplodia theobromae*.

Anticholinesterase Activity

Standardized extracts of *I. verum* and its oil were found to have cholinesterase (AChE) and butyrylcholinesterase inhibitory (BChE) activity (Bhadra et al. 2011). The compound anethole was found to contribute to the anticholinesterase activity of *I. verum*, with more specificity towards AChE. IC₅₀ for AChE and BChE inhibitory activity of anethole was 39.89 and 75.35 µg/mL, whereas for the oil, 36.00 and 70.65 µg/mL respectively.

Antiangiogenic Activity

Seven of 58 plant materials from Vietnamese medicinal plants including fruits and stem of *Illicium verum* showed strong to moderate inhibitory activity on the tube-like formation induced by human umbilical venous endothelial cells in the in-vitro angiogenesis assay (Nam et al. 2003).

Analgesic Activity

Veranisatin A and the related compound, anisatin, were found to decrease mice locomotion enhanced by methamphetamine at oral doses of 0.1 and 0.03 mg/kg, respectively, and demonstrated the analgesia on acetic acid-induced writhing and tail

pressure pain at almost similar doses (Nakamura et al. 1996).

Adverse Effects

On the downside, three neurotropic sesquiterpenoids, veranisatins A, B and C, were isolated from star anise (Nakamura et al. 1996). Veranisatins elicited convulsion and lethal toxicity in mice at a dose of 3 mg/kg (p.o.), and at lower doses they caused hypothermia. Okuyama et al. (1993) earlier also reported on the convulsant activity of veranisatin A and B, isolated from star anise.

Chinese star anise is used in many cultures. Caribbean and Hispanic cultures use a tea infusion of its star-shaped fruit as treatment for infant colic and like-wise used in France (Biessels et al. 2002; Garzo Fernández et al. 2002; Minodier et al. 2003). A closely related species, Japanese star anise (*Illicium anisatum* L.), however, has been reported to cause neurologic and gastrointestinal toxicities (Biessels et al. 2002; Garzo Fernández et al. 2002; Minodier et al. 2003; Ize-Ludlow et al. 2004a). Possible adulteration of *I. verum* with *I. anisatum* has led to recalls of these products in several countries (Minodier et al. 2003; Ize-Ludlow et al. 2004a). Symptoms consisted of signs of acute-onset irritability, jitteriness, tremors or spasms, hypertonia, hyperexcitability with crying, clonus or myoclonus, increased deep tendon reflexes, nystagmus, vomiting, and seizures (Minodier et al. 2003; Ize-Ludlow et al. 2004a). Analysis by LC-MS of the sesquiterpene lactone fraction of each sample of star anise tea to test for contamination with *I. anisatum* revealed the presence of anisatin, neoanisatin, and veranisatins A, B, and C (Ize-Ludlow et al. 2004b). Anisatin and neoanisatin are potent neurotoxins found in *I. anisatum* (Yamada et al. 1968). Although *I. verum* is considered safe for consumption, this species also contains the toxic compounds, veranisatin A, B, and C (Nakamura et al. 1996). Based on these cases and the finding of *I. verum* contamination, the researchers recommended against administering star anise to infants and asserted that stricter regulation may be warranted.

Traditional Medicinal Uses

In many cultures worldwide, star anise has been used for its carminative, anodyne, stimulant, flatulent colic, indigestion, infantile catarrh, bronchitis, rheumatism, earache, stomachic, eupeptic, antibacterial, odontalgic, stimulant and diuretic medicinal properties in traditional medicine. In Asia, it is used as a tea to combat colic, lumbago, epigastric pain and rheumatism and the seeds are used as eupeptic, sometimes chewed after meals to aid digestion. It is a common flavouring for medicinal teas, cough mixtures and pastilles. It is taken internally in the treatment of abdominal pain, digestive disturbances and complaints such as lumbago. In Malaysia, the Malays use star anise to combat stomach ache due to the accumulation of intestinal gas, headache, and to promote vitality. The fruit is used as a galactagogue to stimulate milk production, promote menstruation, facilitate childbirth, increase libido and alleviate symptoms of male climacteric. It is found to be useful in flatulence, spasmodic pains and dysentery. It relieves colic and is a common ingredient of cough lozenges and cattle sprays. The essential oil is also used as a bronchial expectorant for upper respiratory tract congestion and gastrointestinal spasmolytic. The oil is employed as an applicant in rheumatism, as an antiseptic, useful against fevers, scabies, body lice, bedbugs, and highly useful in constipation and insomnia. A homeopathic remedy is prepared from the seed.

Other Uses

Star anise essential oil is used to impart aroma to soaps, perfumes, dental cream and flavour tobacco. The fruit is also used in potpourris. Star anise has been shown to have insecticidal action against Japanese termite *Reticulitermes speratus* Kolbe (Park and Shin 2005) and adult German cockroaches (*Blattella germanica*) (Chang and Ahn 2002). In a fumigation test with female cockroaches, (E)-anethole from fruit of star anise was much more effective in closed cups than in open ones, indicating that the insecticidal activity of the compound was largely attributable to

fumigant action. (E)-anethole and DDVP caused 100% mortality at 0.398 and 0.051 mg cm⁻² at 4 and 1 h after treatment, respectively.

Chinese star anise also has mosquitocidal activity. Studies in Thailand reported that star anise essential oil exhibited adulticidal activity against *Aedes aegypti*, with an LC₅₀ in the female laboratory strain of 8.52 and 8.83 µg/mg in the female field strain (Chaiyasit et al. 2006). The results pointed to the promising potential of plant essential oils such as star anise as an alternative in developing and producing mosquito adulticides in controlling and eradicating mosquito vectors. *Illicium verum* was one of three carminative plants that showed marked larvicidal effects against fourth instar larvae of *Culex quinquefasciatus* with LC₅₀ of 54.11 ppm. (Pitasawat et al. 1998).

Both the essential oil from star anise fruit and *trans*-anethole a major constituent, exhibited potent inhibitory effect against all test fungi indicating that most of the observed antifungal properties was due to the presence of transanethole in the oil, which could be developed as natural fungicides for plant disease control in fruit and vegetable preservation (Huang et al. 2010). Among them, *Alternaria solani*, *Bipolaris maydis*, *Fusarium graminearum*, *Pythium aphanidermatum* and *Rhizoctonia solani* were the relatively sensitive fungi with IC₅₀ values as 0.09, 0.07, 0.08, 0.09 and 0.08 mg/mL, respectively. The positive control procymidone or carbendazim at 5 µg/mL completely inhibited the growth of all test fungi.

The fragrant wood is used for wood can be used for construction, furniture and pulping. The tree is planted in land reclamation and soil erosion control as it has good effects on soil and water conservation. It is often intercropped with some other tree species such as *Canarium album*, mandarin orange and tea.

Comments

Cases of neurotoxic intoxication in the administration of Chinese star anise (*I. verum*) adulterated by Japanese star anise (*Illicium anisatum*) had been reported in infants (Ize-Ludlow et al. 2004a, b). Seven cases of adverse neurologic

reactions in infants were observed with the home administration of star anise tea. Japanese star anise is reported to cause neurologic and gastrointestinal toxicities. The toxicity of *Illicium anisatum*, also known as Shikimi, had been reported to be caused by its content of potent neurotoxins (anisatin, neoanisatin, and pseudo-anisatin), due to their activity as non-competitive antagonists of GABA (gamma-aminobutyric acid) receptors (Perret et al. 2011). The main reasons underlying the frequent contaminations are the strong macroscopic resemblance of the two substances, as well as the fact that the fruits are often sold partially broken or in ground form. Thus, in most cases, chemical analysis is required to determine the possible adulterations. There is a dire need for better control of the substances by global health authorities.

Selected References

- Bhadra S, Mukherjee PK, Kumar NS, Bandyopadhyay A (2011) Anticholinesterase activity of standardized extract of *Illicium verum* Hook. f. fruits. *Fitoterapia* 82(3):342–346
- Biessels GJ, Vermeij FH, Leijten FS (2002) Epileptic seizure after a cup of tea: intoxication with Japanese star anise. *Ned Tijdschr Geneeskd* 146:808–811
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula. Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Chaiyasit D, Choochote W, Rattanachanpichai E, Chaithong U, Chaiwong P, Jitpakdi A, Tippawangkosol P, Riyong D, Pitasawat B (2006) Essential oils as potential adulticides against two populations of *Aedes aegypti*, the laboratory and natural field strains, in Chiang Mai province, northern Thailand. *Parasitol Res* 99(6):715–721
- Chang KS, Ahn YJ (2002) Fumigant activity of (E)-anethole identified in *Illicium verum* fruit against *Blattella germanica*. *Pest Manag Sci* 58(2):161–166
- Chevallier A (1996) The encyclopedia of medicinal plants. Dorling Kindersley, London, 336 pp
- Chien NQH, Van Cuong DTM, Thuy P, Tuan TTT, Vu LA, Van Hung PXN (2006) Isolation of shikimic acid from Vietnamese star anise. *Tap Chi Hoa Hoc* 44(6):745–748
- Chopra RN, Nayar SL, Chopra IC (1986) Glossary of Indian medicinal plants (including the supplement). Council of Scientific and Industrial Research, New Delhi
- De M, De AK, Sen P, Banerjee AB (2002) Antimicrobial properties of star anise (*Illicium verum* Hook f.). *Phytother Res* 16(1):94–95
- Dzamic A, Sokovic M, Ristic MS, Grijic-Jovanovic S, Vukojevic J, Marin PD (2009) Chemical composition and antifungal activity of *Illicium verum* and *Eugenia caryophyllata* essential oils. *Chem Nat Comp* 45(2):259–261
- Foundation for Revitalisation of Local Health Traditions (2012) FRLHT Database. <http://envis.frlht.org>
- Garzo Fernández C, Gómez Pintado P, Barrasa Blanco A, Martínez Arrieta R, Ramírez Fernández R, Ramón Rosa F, Grupo de Trabajo del Anis Estrellado (2002) Cases of neurological symptoms associated with star anise consumption used as a carminative. *An Esp Pediatr* 57(4):290–294 (In Spanish)
- Gholivand MB, Rahimi-Nasrabadi M, Chalabi H (2009) Determination of essential oil components of star anise (*Illicium verum*) using simultaneous hydrodistillation-static headspace liquid-phase microextraction-gas chromatography mass spectrometry. *Anal Lett* 42(10):1382–1397
- Huang Y, Zhao J, Zhou L, Wang J, Gong Y, Chen X, Guo Z, Wang Q, Jiang W (2010) Antifungal activity of the essential oil of *Illicium verum* fruit and its main component *trans*-anethole. *Molecules* 15(11):7558–7569
- Iauk L, Lo Bue AM, Milazzo I, Rapisarda A, Blandino G (2003) Antibacterial activity of medicinal plant extracts against periodontopathic bacteria. *Phytother Res* 17(6):599–604
- Itoigawa M, Ito C, Tokuda H, Enjo F, Nishino H, Furukawa H (2004) Cancer chemopreventive activity of phenylpropanoids and phytoquinoids from *Illicium* plants. *Cancer Lett* 214(2):165–169
- Ize-Ludlow D, Ragone S, Bruck IS, Bernstein JN, Duchowny M, Garcia Peña BM (2004a) Neurotoxicities in infants seen with the consumption of star anise tea. *Pediatrics* 114(5):e653–e656
- Ize-Ludlow D, Ragone S, Bruck IS, Duchowny M, Garcia Peña BM (2004b) Chemical composition of Chinese star anise (*Illicium verum*) and neurotoxicity in infants. *JAMA* 291(5):562–563
- Lee SW, Li G, Lee KS, Jung JS, Xu ML, Seo CS, Chang HW, Kim SK, Song DK, Son JK (2003) Preventive agents against sepsis and new phenylpropanoid glucosides from the fruits of *Illicium verum*. *Planta Med* 69(9):861–864
- Liu HX (2009) Chemical component analysis of volatile oil from *Illicium verum* Hook. f. seed by gas chromatography-mass spectrometry. *Food Sci* 30(22):305–308
- Liu Y, Xia N, Saunders RMK (2008) Illiciaceae. In: Wu ZY, Raven PH, Hong DY (eds) *Flora of China*, vol Menispermaceae through Capparaceae, 7. Science Press/Missouri Botanical Garden Press, Beijing/St. Louis
- Lo VN (1999) *Illicium verum* Hook. f. In: de Guzman CC, Siemonsma JS (eds) *Plant resources of south-east Asia* no. 13. Spices. Prosea, Bogor, pp 130–134
- Matsui T, Ito C, Itoigawa M, Okada T, Furukawa H (2007) Anti-inflammatory activity of phenylpropanoids and phytoquinoids from *Illicium* species in RBL-2 H3 cells. *Planta Med* 73(7):662–665

- Minodier P, Pommier P, Moulène E, Retornaz K, Prost N, Deharo L (2003) Star anise poisoning in infants. *Arch Pediatr* 10(7):619–621 (In French)
- Morton JF (1976) *Herbs and spices*. Golden Press, New York, 160 pp
- Nakamura T, Okuyama E, Yamazaki M (1996) Neurotropic components from star anise (*Illicium verum* Hook. fil.). *Chem Pharm Bull*(Tokyo) 44(10):1908–1914
- Nam NH, Kim HM, Bae KH, Ahn BZ (2003) Inhibitory effects of Vietnamese medicinal plants on tube-like formation of human umbilical venous cells. *Phytother Res* 17(2):107–111
- Nanthachit K (2002) Antimicrobial activity of the fruit of *Illicium verum* Hook. *Chiang Mai Med Bull* 41(4):169–172
- National Institute of Materia Medica (1999) *Selected medicinal plants in Vietnam*, vol 2. Science and Technology Publishing House, Hanoi, 460 pp
- Okuyama E, Nakamura T, Yamazaki M (1993) Convulsants from star anise (*Illicium verum* Hook. f.). *Chem Pharm Bull* 41:1670–1671
- Orwa C, Mutua A, Kindt R, Jamnadass R, Anthony S (2012) Agroforestry database: a tree reference and selection guide. version 4.0 (<http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp>)
- Padmashree A, Roopa N, Semwal AD, Sharma GK, Agathian G, Bawa AS (2007) Star-anise (*Illicium verum*) and black caraway (*Carum nigrum*) as natural antioxidants. *Food Chem* 104(1):59–66
- Park IK, Shin SC (2005) Fumigant activity of plant essential oils and components from garlic (*Allium sativum*) and clove bud (*Eugenia caryophyllata*) oils against the Japanese termite (*Reticulitermes speratus* Kolbe). *J Agric Food Chem* 53(11):4388–4392
- Perret C, Tabin R, Marcoz JP, Llor J, Cheseaux JJ (2011) Apparent life-threatening event in infants: think about star anise intoxication! *Arch Pediatr* 18(7):750–753 (In French)
- Pitasawat B, Choochote W, Kanjanapothi D, Panthong A, Jitpakdi A, Chaithong U (1998) Screening for larvicidal activity of ten carminative plants. *Southeast Asian J Trop Med Public Health* 29(3):660–662
- Porcher MH et al (1995–2020) Searchable world wide web multilingual multiscript plant name database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Song WY, Ma YB, Bai X, Zhang XM, Gu Q, Zheng YT, Zhou J, Chen JJ (2007) Two new compounds and anti-HIV active constituents from *Illicium verum*. *Planta Med* 73(4):372–375
- Sy LK, Brown GD (1998) A seco-cycloartane from *Illicium verum*. *Phytochemistry* 48(7):1169–1171
- Wang GW, Hu WT, Huang BK, Qin LP (2011) *Illicium verum*: a review on its botany, traditional use, chemistry and pharmacology. *J Ethnopharmacol* 136(1):10–20
- Ward P, Small I, Smith J, Suter P, Dutkowski R (2005) Oseltamivir (Tamiflu) and its potential for use in the event of an influenza pandemic. *J Antimicrob Chemother* 55(Suppl 1):i5–i21
- Yadav AS, Bhatnagar D (2007) Chemo-preventive effect of Star anise in N-nitrosodiethylamine initiated and phenobarbital promoted hepato-carcinogenesis. *Chem Biol Interact* 169(3):207–214
- Yamada K, Takada S, Nakamura S, Hirata Y (1968) The structures of anisatin and neoanisatin: toxic sesquiterpenes from *Illicium anisatum* L. *Tetrahedron* 24:199–229
- Yan J-H, Xiao X-X, Huang K-L (2002) Component analysis of volatile oil from *Illicium verum* Hook. f. *J Cent South Univ Technol* 9(3):173–176
- Yang CH, Chang FR, Chang HW, Wang SM (2012) Investigation of the antioxidant activity of *Illicium verum* extracts. *J Med Plant Res* 6(2):314–324
- Yang J, Min Y, Zhang L, Liu W (2009) Chemical constituents of *Illicium verum* from Pingbian. *J Honghe Univ* 5:14–15
- Yang JF, Yang CH, Chang HW, Yang CS, Wang SM, Hsieh MC, Chuang LY (2010) Chemical composition and antibacterial activities of *Illicium verum* against antibiotic-resistant pathogens. *J Med Food* 13(5):1254–1262
- Yeung H-C (1985) *Handbook of Chinese herbs and formulas*. Institute of Chinese Medicine, Los Angeles

Capsicum annuum

Scientific Name

Capsicum annuum L.

Synonyms

Capsicum annuum var. *acuminatum* Fingerh., *Capsicum annuum* var. *aviculare* auct., *Capsicum annuum* var. *cerasiforme* (Mill.) Irish, *Capsicum annuum* var. *conoides* (Mill.) Irish, *Capsicum annuum* var. *fasciculatum* (Sturtev.) Irish, *Capsicum annuum* var. *grossum* (L.) Sendtn., *Capsicum annuum* var. *longum* Sendtn., *Capsicum cerasiforme* Mill., *Capsicum conoides* Mill., *Capsicum cordiforme* Mill., *Capsicum frutescens* var. *cerasiforme* (Mill.) L. H. Bailey, *Capsicum frutescens* var. *conoides* (Mill.) L. H. Bailey, *Capsicum frutescens* var. *fasciculatum* (Sturtev.) L. H. Bailey, *Capsicum frutescens* var. *grossum* (L.) L. H. Bailey, *Capsicum frutescens* var. *longum* (Sendtn.) L. H. Bailey, *Capsicum grossum* L., *Capsicum petenense* Standl., *Capsicum indicum* Lobel., *Capsicum indicum* Dierb., *Capsicum hispidum* Dunal, *Capsicum longum* de Candolle.

Family

Solanaceae

Common/English Names

African Pepper, Bell Pepper, Capsicum Pepper, Cayenne, Cayenne Pepper, Cherry Pepper, Chili, Chili Pepper, Chilli, Chilly Pepper, Chitlepin, Christmas Pepper, Cone Pepper, Green Capsicum, Green Pepper, Halapenos, Hungarian Pepper, Jalapeno Pepper, Long Pepper, Mississippi Sport Pepper, Numex, Ornamental Pepper, Paprika, Pimento Pepper, Pod Pepper, Red Cone Pepper, Red Pepper, Sweet Pepper, Wrinkled Pepper.

Vernacular Names

Afrikaans: Rissie;

Albanian: Specë, Speci;

Amharic: Yafranĵ Karya;

Arabic: Fulful Baladî, Fulful Ahhmar, Fulful Halou, Fulaifilah Halwa;

Armenian: Garmir Bghbegh, Karmir Pghpegh;

Azeri: İstiot, Qırmızı Bibər;

Austria: Paprika;

Basque: Piperrautsa;

Brazil: Pimenta, Pimentão;

Breton: Pimant Dous;

Belgium: Peper;

Bulgarian: Cherven Piper, Piperka;

Catalan: Pebrotera;

Chinese: Chiao-Tzu, Ch'ing Chiao, Dàng Lùhng Jiù, Hai-Chiao, Hai-Jiao, Jiao-Zi, La Chiao, La Jiao, Qing Jiao, Tian Jiao, Tìhm Jiù;

Croatian: Paprika, Piperka;

Czech: Paprika, Paprika-Koření, Paprika Roční, Paprika Seta, Prášková Paprika, Sladká;

Danish: Chilipeber, Paprika, Peberfrugt, Sød Peberspansk Peber;

Dutch: Paprika, Spaanse Peper, Spaanse Peper Soort;

Egypt: Felfel Achdar, Filfile Achdar;

Esperanto: Paprika, Unujara Kapsiko;

Estonian: Harilik Parika, Punapipar;

Farsi: Paprika;

Finnish: Paprika, Ruokapaprika, Vi Hannes paprika;

French: Piment Annuel, Gros Piment, Piment Doux, Paprika De Hongrie, Piment, Piment De Cayenne, Piment Des Jardins, Piment Doux, Piment Doux D'Espagne, Piment Ornamental, Piment Rouge, Poivron Doux, Poivre D'Espagne, Poivre De Cayenne, Poivre De Guinee, Poivron;

Galician: Pementón;

Georgian: Bulgaruli;

German: Cayennepfeffer, Chile, Chili, Chilie, Chillie, Chillie, Einjähriger Schotenpfeffer, Gemüsepaprika, Gewürzpaprik Paprika, Indischer Pfeffer, Paprika, Paprika-Schote, Peperoni, Pepperoni, Pfefferoni, Pfefferschoten, Roter Piment, Spanischer Pfeffer, Türkischer Pfeffer, Zier-Paprika;

Greek: Pipera, Piperia, Piperies;

Hebrew: Pilpel, Pilpelet Hagina;

Hungarian: Bell Paprika, Csemegepaprika, Édes Paprika, Étkezési Paprika, Fűszerpaprika, Jalapeño, Közönséges Paprika, Paprika, Piros Paprika, Termesztett Paprika, Új-Mexikói Paprika;

Icelandic: Paprikuduft;

India: Molar (Gujarati), Degi Mirch, Deshi Mirch, Desi Mirch, Hara Mirch, Mithi Mirch, Shimlaa Mirch (Hindu), Hasimenasina Kayi (Kannada), Degi Mirch, Shimlaa Mirch (Urdu);

Indonesia: Cabai, Cabe, Cabe Manis, Cabai Manis, Lombok;

Iraq: Filfil, Fûlfûl;

Italian: Peperone, Pepperoncini, Pepperoncino, Pimento;

Japanese: Banshō, Bansho, Papurika, Peppaa, Tougarashi;

Kazakh: Buriş, Qızıl Buriş;

Korean: Namcho, Papurika, Pimang;

Laos: Mak Pet Nyai, Mak Pet Wan;

Latvian: Dārzenpipari, Paprika;

Lebanese: Felfel Lelece;

Lithuanian: Paprika;

Macedonia: Piper, Piperka;

Malaysia: Cabai, Cili, Chili, Chili Manis, Cili Manis Lada;

Maldives Islands: Rihamirus (Dhivehi);

Maltese: Bżar Ikkulurit, Bżar Helu;

Nepal: Bhede Khursani, Khursaani;

Norwegian: Paprika, Spanskpepper, Søtpepper;

Papiamento: Promenton, Promèntòn;

Philippines: Sili (Bikol), Kalubengan Kalubsengan (Bontok), Sili (Iloko), Sile, Sili, Sileng-Haba, Sileng Mahahaba Siling Pangsigang (Tagalog);

Polish: Papryka, Papryka Roczna; Pieprzowiec Roczny;

Portuguese: Colorau, Pimentão, Pimentão Doce, Pimento, Pimentos, Pimento De Caiena, Pimento Doce;

Quechuan: Uchu;

Romanian: Ardei, Ardei Dulce, Ardei Gras, Boia De Ardei, Boia Dulce

Russian: Perets Krasnyj, Perets Zelënyi;

Serbian: Paprika, Crvena Paprika;

Slovaščina: Paprika, Sorta, Začimbna Mleta Paprika;

Slovenčina: Paprika, Paprika Ročná, Paprika Sladká, Paprika Štiplavá;

Spanish: Ají, Chile, Chile Jalapeño, Guindilla, Hocico De Buey, Paprika, Pasilla, Pebrotera, Pimienta, Pimiento, Pimiento Dulce, Pimiento Morrón, Pimentón, Poblano, Serrano;

Swahili: Mpilipili, Mpilipili Hoho;

Swedish: Paprika, Peppar, Spanskpeppar;

Swiss: Poivre D'Espagne;

Tajik: Qalamfur;

Thai: Prik Yuak, Prik luean;

Tigrinya: Gue, Gwie, Peperoni;

Turkish: Biber, Kırmızı Biber, Pul Biber, Türk Biberi;

Uzbek: Qalampir;

Vietnamese: Ot, Of Tau, Cat At;

Yiddish: Paprike, Zis Feferl.

Origin/Distribution

C. annuum has its centre of diversity in Mexico and northern Latin America. It was introduced all over the world where it is now extensively grown worldwide as a spice and medicine. Today, it can be found growing in tropical and temperate areas around the world.

Agroecology

C. annuum requires a well structured, well-drained, friable, sandy loam with a pH between 6.5 and 7.5. They require warm temperatures, weed control, irrigation and insect and disease management for maximum fruit production. Added organic matter will increase water holding capacity and supply nutrients and minerals for optimum production. It is intolerant of high salt content in the soil and frost.

Edible Plant Parts and Uses

Capsicum annuum and *C. frutescens* are the most consumed spices in the world. The fruits are used for fresh consumption – raw or cooked, and they are sold as frozen, canned, dried (whole or crushed pieces) and pickled fruit. The fruit is also processed as fermented products, powders, sauces, salsas and colouring agents. The seed oil is edible and used for flavouring and seasoning. Chilli in the form of powder or paste is a vital ingredient for curries. Fermented sweet peppers (*torshi felfel*) are produced in west Asia and Africa.

Fresh market types such as bell peppers, cuban, and squash, are usually non-pungent, and eaten raw, stir-fried, or prepared in some fashion to season a culinary dish.

Processing fruit type can be grouped into two main categories. The first consists of a fresh product that is frozen, canned, or pickled examples include the pimento, jalapeño, serrano, pepperoncini, yellow wax, and the New Mexican. The second group consists of those used as a dehydrated product such as New Mexican, cayenne, ancho,

pasilla, mirasol, piquin, and de arbol A green. Paprika and paprika oleoresin are currently used in a wide assortment of foods.

In southeast Asia and PNG the young leaves and flowers are eaten as potherb or added to soups and stew.

Botany

Small, branched, mostly erect, annual or perennial herbaceous shrub, 30–80cm tall (Plates 1 and 14) with a short or deep tap root. Stems glabrescent. Leaves alternate, solitary or paired; petiole 4–7cm; leaf blade oblong-ovate, ovate, or ovate-lanceolate, 4–13×1.5–4cm, glabrescent, base narrowed, margin entire and wavy, apex short acuminate or acute (Plates 1, 2 and 14). Inflorescences solitary flowers or 1–2-flowered clusters. Pedicel bent at apex, 1–2cm. Flowers small, off-white, pendent. Calyx campanulate, 2–3×3 mm five-toothed, undulate, green. Corolla rotate, five-lobed white, 10 mm. Stamens 5, inserted, anthers bluish/purplish, 1.8–2 mm. Ovary superior, 2–3 locular with numerous ovules, style short with capitate stigma. Fruit a berry, pericarp fleshy and firm, hollow, pendent, green when young to mostly red orange, yellow, white, brown or purple in cultivation), when mature, variously shaped, up to 15cm (Plates 1–17). Colour changes in most commercial cultivars are green to red, green to yellow or green to orange. Usually, fruits of the purple and white varieties have these colours as they develop, and therefore do not have a green stage. Seeds are pale yellow, discoid or reniform, 3–5 mm across.

Nutritive/Medicinal Properties

Fruit Nutrients and Phytochemicals

The proximate nutrient values per 100 g edible portion of raw, sweet green pepper; sweet red pepper; and sweet, yellow pepper respectively based on USDA National Nutrient Database for Standard Reference, Release 25, 2012 were reported as follows:



Plate 1 Cayenne chilli plant



Plate 2 Chilli flowers and leaves used as vegetables



Plate 3 Cayenne pencil chilli

water 93.89, 92.21, 92.02 g; energy 20 (84), 31 (129), 27 kcal (112 kJ); protein 0.86, 0.99,



Plate 4 Malaysian spicy short chilli



Plate 5 Thai large white chilli



Plate 6 Sabah small white chilli

1.00 g; total lipid 0.17, 0.30, 0.21 g; ash 0.43, 0.47, 0.45 g; carbohydrate 4.64, 6.03, 6.32 g; total dietary fibre 1.7, 2.1, 0.9 g; total sugars 2.40, 4.20, 0.0 g; sucrose 0.11, 0 g, nd (not-determined); glucose 1.16, 1.94 g, nd; fructose 1.12, 2.26 g, nd; minerals – Ca 10, 7, 11 mg; Fe, 0.34,



Plate 7 Large yellow bullhorn chilli



Plate 8 Large red bullhorn chilli



Plate 9 Jalapeno chilli



Plate 10 Serrano chilli



Plate 11 Red banana chilli



Plate 12 Green banana chilli

0.43, 0.46 mg; Mg 10, 12, 12 mg; P 20, 26, 24 mg; K 175, 211, 212 mg; Na 3, 4, 2 mg; Zn 0.13, 0.25, 0.17 mg; Cu 0.066, 0.017, 0.107 mg; Mn 0.122, 0.112, 0.117 mg; Se 0.0, 0.1, 0.3 µg; F 2 µg, nd, nd; vitamins – vitamin C 80.4, 127.7, 183.5 mg; thiamine, 0.057, 0.054, 0.028 mg; riboflavin



Plate 13 Spicy hot dried chilli



Plate 16 Yellow capsicum peppers



Plate 14 Green capsicum plant with fruits



Plate 17 Orange capsicum peppers



Plate 15 Red capsicum peppers

0.028, 0.085, 0.025 mg; niacin 0.480, 0.979, 0.890 mg; pantothenic acid 0.099, 0.317, 0.168 mg; vitamin B-6 0.224, 0.291, 0.168 mg; total folate 10, 46, 26 µg; total choline 5.5, 5.6, 0.0 mg; betaine 0.1, 0.1, 0.0, 0 mg; vitamin A 370, 3131, 200 IU; vitamin A 18 µg RAE, 157 µg RAE, 10 µg; β-carotene 208 µg g, 1,624, 12 µg; α-carotene 21, 20 µg, nd; β-cryptoxanthin 7,

490 µg, nd; lutein + zeaxanthin 341, 51 µg, nd; vitamin E (α-tocopherol) 0.37, 1.58, 0.0 mg; β-tocopherol 0, 0.05, 0.0 mg; γ-tocopherol 0.0, 0.14, 0.0 mg; δ-tocopherol 0.0, 0.01, 0.0 mg; vitamin K (phylloquinone) 7.4, 4.9, 0 µg; lipids – total saturated fatty acids 0.058, 0.027, 0.031 g; 16:0 (palmitic acid) 0.050, 0.025 g, nd; 18:0 (stearic acid) 0.08, 0.02 g, nd; total monounsaturated fatty acids 0.08, 0.003 g, nd; 16:1 (palmitoleic acid) 0.01, 0 g, nd; 18:1 (oleic acid) 0.08, 0.02 g nd; total polyunsaturated fatty acids 0.062, 0.070 g, nd; 18:2 (linoleic acid) 0.054, 0.045 g, nd; 18:3 (linolenic acid) 0.08, 0.025 g, nd; phytosterols 9 mg, nd, nd; amino acids – tryptophan 0.012, 0.012, 0.013 g; threonine 0.036, 0.040, 0.037 g; isoleucine 0.024, 0.021, 0.032 g; leucine 0.036, 0.036, 0.052 g; lysine 0.039, 0.036, 0.044 g; methionine 0.007, 0.006, 0.012 g; cystine

0.012, 0.019, 0.019 g; phenylalanine 0.092, 0.050, 0.031 g; valine 0.036, 0.031, 0.042 g; arginine 0.027, 0.036, 0.048 g; histidine 0.010, 0.017, 0.020 g; alanine 0.036, 0.026, 0.041 g; aspartic acid 0.208, 0.284, 0.143 g; glutamic acid 0.194, 0.211, 0.132 g; glycine 0.030, 0.028, 0.037 g; proline 0.024, 0.024, 0.044 g; and serine 0.054, 0.050, 0.040 g.

The proximate nutrient values per 100 g edible portion of raw, Jalapeno pepper and raw Serrano pepper respectively based on USDA National Nutrient Database for Standard Reference, Release 25, 2012 were reported as follows:

Water 91.69, 90.25 g; energy 29 (119), 32 kcal (134 kJ); protein 0.91, 1.74 g; total lipid 0.37, 0.44 g; ash 0.53, 0.87 g; carbohydrate 6.50, 6.70 g; total dietary fibre 2.8, 3.7 g; total sugars 4.12, 3.83 g; glucose 1.48 g, nd, fructose 2.63 g, nd; minerals – Ca 12, 11 mg; Fe 0.25, 0.86 mg; Mg 15, 22 mg; P 26, 40 mg; K 248, 305 mg; Na 3, 10 mg; Zn 0.14, 0.26 mg; Cu 0.046, 0.129 mg; Mn 0.097, 0.187 mg; Se 0.4, 0.4 µg; vitamins – vitamin C 118.6, 44.9 mg; thiamine 0.040, 0.054 mg; riboflavin 0.070, 0.081 mg; niacin 1.280, 1.537 mg; pantothenic acid 0.315, 0.200 mg; vitamin B-6 0.419, 0.505 mg; total folate 27, 23 µg; total choline 7.5, 8.9 mg; vitamin A 1,078, 937 IU; vitamin A 54, 47 µg RAE; β-carotene 561, 534 µg; α-carotene 67, 18 µg; β-cryptoxanthin 105, 40 µg; lutein+zeaxanthin 861, 544 µg; vitamin E (α-tocopherol) 3.58, 0.69 mg; β-tocopherol 0.17 mg, nd; γ-tocopherol 0.5 mg, nd; δ-tocopherol 0.01 mg, nd; vitamin K (phylloquinone) 18.5, 11.8 µg; phyosterols nd, 6 mg, campesterol nd, 2 mg, β-sitosterol nd, 3 mg; lipids – total saturated fatty acids 0.092, 0.059 g; 4:0 (butanoic acid) 0.04, 0 g; 10:0 (capric acid) 0.02, 0 g; 12:0 (lauric acid) 0.003, 0 g; 14:0 (myristic acid) 0.008, 0.001 g; 16:0 (palmitic acid) 0.052, 0.043 g; 17:0 (margaric acid) 0.001 g, nd; 18:0 (stearic acid) 0.16, 0.010 g; 20:0 (arachidic acid) 0.004 g, nd; 22:0 (behenic acid) 0.003 g, nd; total monounsaturated fatty acids 0.029, 0.023 g; 16:1 (palmitoleic) 0.003 g, 0.002; 18:1 (oleic acid) 0.025, 0.021 g; total polyunsaturated fatty acids 0.112, 0.222 g; 18:2 (linoleic acid) 0.062, 0.216 g; and 18:3 (linolenic acid) 0.05, 0.006 g. Ascorbic acid, provitamin A, protein, and some minerals

were affected by bell pepper (*Capsicum annuum*) genotypes and color stages ($R^2=0.96$), but fat or moisture was not (Simonne et al. 1997). Ascorbic acid increased as color developed in some cultivars, but remained unchanged or decreased in others. Black, purple, and white bell peppers contained lower ascorbic acid levels compared to the green, yellow, red, brown, or orange bell peppers. Provitamin A increased as colour developed in most cultivars except for yellow varieties. Brown peppers had the highest provitamin A activity compared to other coloured peppers. Of five major breeding Turkish cultivars of *C. annuum*, the cultivars 730 F1 and 1,245 F1 had the highest content of carotenoids (2,310–2,390 mg/kg in dry basis), capsaicinoids (471.3–688.1 mg/kg in dry basis), vitamin A (218.8–243.0 µg RAE/100 g in wet basis) and vitamin C (63.1–64.9 mg/100 g in wet basis).

During ripening, the total carotenoid content was increased approximately 300-fold from 1.94 mg/100 g (white) – 607.78 mg/g dw (deep red) fruits of *Capsicum annuum* cv. Bovet 4 (Deli and Tóth 1997). The colour of *C. annuum* cv. Bovet paprika could range from white, pale yellow, yellow, orange, red to deep red, depending on the concentration of red and yellow carotenoids. The ratio of the quantity of red pigment to that of yellow pigments increased from 0.05 to 1.41. The following carotenoids in decreasing concentrations were found in ripened fruits (deep red), capsanthin 45.29%, zeaxanthin 8.09%, cucurbitaxanthin 6.11%, capsorubin 4.93%, β-carotene 4.8%, mutatoxanthin 2 3.05%, capsanthin 3,6-epoxide 2.96%, β-cryptoxanthin 2.55%, 13-*cis*-capsanthin 2.53%, 9-*cis*-capsanthin 2.52%, karpoxanthin 2.03%, capsanthin-5,6-epoxide 1.51%, cucurbitaxanthin B 1.04%, luteoxanthin 1 0.82%, luteoxanthin 2 0.76%, antheroxanthin 0.72%, nigroxanthin 0.67%, violaxanthin 0.59%, cryptocapsin 0.58%, capsanthone 0.44%, cycloviolaxanthine 0.44%, *cis*-β-carotene 0.44%, *cis*-cryptoxanthine 0.42%, trihydroxy- κ 0.30%, lutoxanthin 0.28%, α-carotene 0.25%, 13-*cis*-zeaxanthine 0.25%, 9-*cis*-zeaxanthine 0.21%, α-cryptoxanthine 0.19% and mutatoxanthin 1 0.03%. Neoxanthine, auroxanthine 1, auroxanthine 2, lutein were not detected in the red and

deep red stages whilst auroxanthine 1, auroxanthine 2 and lutein were found only in the white and yellow unripe stages. In the unripe fruits, the main carotenoids were lutein, zeaxanthin which decreased as ripening proceeded and β -carotene.

Ripening fruit of five *C. annuum* cultivars (Numex, Mana, Belrubi, Delfin, and Negral) showed the typical and characteristic pattern of carotenoid biosynthesis for the *Capsicum* genus (Hornero-Méndez et al. 2000). In the five cultivars, lutein and neoxanthin, both characteristic chloroplast pigments, decreased in concentration with ripening and eventually disappeared. Beta-carotene, antheraxanthin, and violaxanthin increased in concentration, and other pigments were biosynthesized de novo: zeaxanthin, β -cryptoxanthin, capsanthin, capsorubin, capsanthin-5,6-epoxide, and cucurbitaxanthin A. Quantitatively, Negral cultivar showed the highest increase in total carotenoid content (48.39-fold), followed by Mana and Delfin with 38.03- and 36.8-fold, respectively, and by Belrubi and Numex with 28.03- and 23.48-fold, respectively. In all the red varieties, there was an inverse relationship between total carotenoid content and the red to yellow isochromic pigment fraction ratio (R/Y) and the capsanthin-to-zeaxanthin ratio (Caps/Zeax). The cultivar Mana had the highest total carotenoid content (13,208 mg/kg dwt), but the lowest R/Y (1.25) and Caps/Zeax (3.38) ratios, which are therefore the parameters to improve. The cultivar Negral had a high carotenoid content (8,797 mg/kg dwt) and high R/Y and Caps/Zeax ratios and could be used for transfer of these characters in direct crosses with the cultivar Mana. The cultivar Numex had the highest Caps/Zeax ratio (7.17) and would be an ideal progenitor for this character. Changes in the fractions of free and partially and totally esterified carotenoids in the five *C. annuum* cultivars were found to be similar between varieties, reflecting the constitutive nature of esterification as part of the ripening process (Hornero-Méndez and Mínguez-Mosquera 2000). From the first stages of ripening, the fraction of totally esterified pigments (zeaxanthin diester, β -cryptoxanthin diester, capsanthin diester, and capsorubin diester) comprised almost 50% of the total carotenoid content. The proportion of the

partially esterified pigment fraction (zeaxanthin monoester, capsanthin monoester, and capsorubin monoester) in the total carotenoid content increased, with a gradual decrease in the fraction of free pigments (β -cryptoxanthin, β -carotene, zeaxanthin, capsanthin, and capsorubin). In the fully ripe stage, a balance was reached between the three esterification fractions (free, partially esterified, and totally esterified), which appeared to be largely independent of variety.

Thirty-four carotenoids were identified in the *Capsicum annuum* var. *lycopersiciforme rubrum* during ripening (Deli et al. 2001a). The total carotenoid content of the ripe fruits was about 1.3/100g of dry weight, of which capsanthin constituted 37%, zeaxanthin 8%, cucurbitaxanthin A 7%, capsorubin 3.2%, and β -carotene 9%. The remainder was composed of capsanthin 5,6-epoxide, capsanthin 3,6-epoxide, 5,6-diepikarboxanthin, violaxanthin, antheraxanthin, β -cryptoxanthin, and several *cis* isomers and furanoid oxides. The main carotenoids in the yellow pepper (F(1) Amanda hybrid) of *C. annuum* were violaxanthin (27.1–36.6 μ g/g), lutein (5.3–9.3 μ g/g), and β -carotene (1.6–3.9 μ g/g) (de Azevedo-Meleiro and Rodriguez-Amaya, 2009). Neoxanthin, (Z)-violaxanthin, (Z)-antheraxanthin, (Z)-lutein, α -cryptoxanthin, β -cryptoxanthin, ζ -carotene, α -carotene, and phytofluene were also found as minor carotenoids. In red pepper (F(1) Magali hybrid) of *C. annuum*, the major carotenoids were capsanthin (29.2–36.2 μ g/g), lutein (5.8–8.7 μ g/g), β -carotene (5.1–6.8 μ g/g), and violaxanthin (1.8–3.6 μ g/g). Minor carotenoids were capsorubin, β -apo-8'-carotenal, antheraxanthin, zeaxanthin, and β -cryptoxanthin.

Eleven apocarotenoids (1–11) including five new compounds, 4, 6, 9, 10 and 11, were isolated from the fruits of the red tomato-shaped paprika *Capsicum annuum* (Maoka et al. 2001b). The structures of new apocarotenoids were determined to be apo-14'-zeaxanthinal (4), apo-13-zeaxanthinone (6), apo-12'-capsorubinal (9), apo-8'-capsorubinal (10), and 9,9'-diapo-10,9'-retrocarotene-9,9'-dione (11). The other six known apocarotenoids were identified to be apo-8'-zeaxanthinal (1), apo-10'-zeaxanthinal (2), apo-12'-zeaxanthinal (3), apo-15-zeaxanthinal (5),

apo-11-zeaxanthinal (7), and apo-9-zeaxanthinone (8). They also isolated a new carotenoid, capsanthone 3,6-epoxide with the structure of (3S,5R,6S,5'R)-3,6-epoxy-5,6-dihydro-5-hydroxy-beta, kappa-carotene-3',6'-dione (Maoka et al. 2001a). Capsanthone 3,6-epoxide was assumed to be an oxidative metabolite of capsanthin 3,6-epoxide in paprika. Two new carotenoids 1 and 2 were isolated as minor components from the ripe fruits of paprika (*Capsicum annuum*) (Maoka et al. 2004). The structures of 1 and 2 were determined to be (3R,5'R)-3-hydroxy- β , κ -caroten-6'-one and (5'R)-3,4-didehydro- β , κ -caroten-6'-one, respectively. Capsanthin, capsanthin 3'-ester and capsanthin 3,3'-diester were found to be major carotenoids in paprika fruit *Capsicum annuum* (Maoka et al. 2001b). From the ripe fruits of red paprika (*Capsicum annuum*) prenegroxanthin, a minor carotenoid was isolated and, identified as (all-E,3R,3'S,6'S)- β , γ -carotene-3,3',6'-triol (Deli et al. 2001b). Carotenoids isolated from paprika oleoresin using supercritical carbon dioxide and co-solvent extraction included red carotenoids (capsorubin, capsanthin, zeaxanthin, β -cryptoxanthin) and small amounts of β -carotene (Jarén-Galán et al. 1999). The technique removed the paprika oil and β -carotene during the first extraction step, allowing for second-stage oleoresin extracts with a high pigment concentration (200% relative to the reference) and a red:yellow pigment ratio of 1.8.

The anthocyanin isolated from violet to black pigmentation in pepper fruit (*Capsicum annuum*) was identified to be delphinidin-3-*p*-coumaroylrutinoside-5-glucoside (Lightbourn et al. 2008). Leaf tissue of a black-pigmented foliage genotype contained the same anthocyanin found in fruit but at a considerably higher concentration in comparison to violet and black fruit tissue. Fruit chlorophyll concentration was approximately black fruit had 14-fold higher fruit chlorophyll concentration in comparison to violet fruit which had little chlorophyll. Beta-carotene, lutein, violaxanthin, and neoxanthin carotenoid concentrations in black fruit were also significantly higher in comparison to violet fruit. High concentrations of delphinidin in combination with chlorophyll and accessory carotenoid pigments produced the

characteristic black pigmentation observed in fruits and leaves of selected genotypes. Anthocyanins were concentrated in the outer mesocarp of violet and black fruit and in the palisade and mesophyll cells of black leaves. A water-soluble polysaccharide isolated from the hot water extract of green *Capsicum annuum* fruits was found to consist of 3-O-acyl-L-rhamnose, D-methyl galacturonate, 6-O-methyl-D-galactose in a molar proportion of nearly 1:2:1 (Mondal et al. 2009).

The total phenolics content of green, yellow, orange, and red sweet peppers (*Capsicum annuum*) determined by the Folin-Ciocalteu method were 2.4, 3.3, 3.4, and 4.2 μmol catechin equivalent/g fresh weight, respectively (Sun et al. 2007). The red sweet pepper had significantly higher total phenolics content than the green sweet bell pepper. Among the four different coloured sweet peppers, red pepper contained a higher level of β -carotene (5.4 $\mu\text{g/g}$), capsanthin (8.0 $\mu\text{g/g}$), quercetin (34.0 $\mu\text{g/g}$), and luteolin (11.0 $\mu\text{g/g}$). The yellow pepper had the lowest β -carotene content (0.2 $\mu\text{g/g}$), while the green one had undetectable capsanthin and the lowest content of luteolin (2.0 $\mu\text{g/g}$).

The yield and variation in carotenoid, tocopherol, and capsaicinoid contents and composition of ground paprika (*C. annuum*) was found to be affected by the extraction conditions with SC-CO₂ and subcritical propane (Gnayfeed et al. 2001). SC-CO₂ was inefficient in the extraction of diesters of xanthophylls even at 400 bar and 55°C, whereas tocopherols and capsaicinoids were easily extracted under these conditions. Under mild conditions subcritical propane was superior to SC-CO₂ in the extraction of carotenoids and tocopherols but less efficient in the extraction of capsaicinoids. The maximum yields of oleoresin were 7.9 and 8.1% of ground paprika by SC-CO₂ and subcritical propane, respectively.

Total phenol content was correlated with ascorbic acid ($R^2=0.97$) and free sugars ($R^2=0.80$) in the *Capsicum* germplasm tested that included four accessions of *Capsicum chinense*; five accessions of *C. baccatum*; six accessions of *C. annuum*; and two of *C. frutescens*

(Antonious et al. 2006). Concentrations of total phenols (1.4, 1.3, and 1.3 mg/g fruit) and ascorbic acid (1.6, 1.2, and 1.3 mg/g fruit) were significantly greater in PI-633757, PI-387833, and PI-633754, respectively, compared to other accessions analyzed. Total capsaicinoids concentrations were greatest (1.3 mg/g fruit) in PI-438622 and lowest (0.002 mg/g fruit) in Grif-9320.

Capsaicinoids namely capsaicin, dihydrocapsaicin, nordihydrocapsaicin, homocapsaicin, homodihydrocapsaicin, and nonivamide were found in fresh peppers (*C. annuum* – Anaheim, red chilli, green chilli, green bell pepper, yellow bell pepper; *C. chinense*– Habañero), oleoresin capsicum, and pepper spray products (Reilly et al. 2001). Fresh Habañero (Utah) pepper was found to have 510 µg/g total capsaicinoid, 3.6% nordihydrocapsaicin, 1.4% nonivamide, 61% capsaicin, 32% dihydrocapsaicin, 0.9% homocapsaicin and 1.1% homodihydrocapsaicin. Fresh Anaheim (Maryland) pepper was found to have 87 µg/g total capsaicinoid, 6.3% nordihydrocapsaicin, 0.42% nonivamide, 60% capsaicin, 30% dihydrocapsaicin, 2.6% homocapsaicin and 1.4% homodihydrocapsaicin. Fresh red chilli (New Mexico) was found to have 83 µg/g total capsaicinoid, 11% nordihydrocapsaicin, 0.6% nonivamide, 56% capsaicin, 29% dihydrocapsaicin, 1.0% homocapsaicin and 1.8% homodihydrocapsaicin. Fresh green chilli (Utah) was found to have 19 µg/g total capsaicinoid, 22% nordihydrocapsaicin, 2.7% nonivamide, 21% capsaicin, 46% dihydrocapsaicin, 0.9% homocapsaicin and 7% homodihydrocapsaicin. Green bell pepper (Utah) was found to have 0.0049 µg/g total capsaicinoid, 13.1% nordihydrocapsaicin, 7.2% nonivamide, 27% capsaicin, 52% dihydrocapsaicin, homocapsaicin not detected (ND), and homodihydrocapsaicin ND. Yellow bell pepper (Utah) was found to have 0.0018 µg/g total capsaicinoid, nordihydrocapsaicin ND, nonivamide ND, 37% capsaicin, 63% dihydrocapsaicin, homocapsaicin ND and homodihydrocapsaicin ND. In all samples, capsaicin and dihydrocapsaicin constituted 60–90% of the total capsaicinoid concentration, followed by nordihydrocapsaicin (2–20%), homocapsaicin (1–5%), homodihydrocapsaicin (1–5%), and

nonivamide (1–5%). Capsaicin and dihydrocapsaicin were the most abundant capsaicinoid analogues present in the extracts of fresh peppers and comprised 60–90% of the total capsaicinoid concentration.

Capsaicin, nonivamide, and dihydrocapsaicin have been reported to have the most pungent capsaicinoid analogues 100, 100, and 75% relative pungencies, respectively (Nelson 1919; Jones and Pyman 1925; Walpole et al. 1993). Nordihydrocapsaicin, homocapsaicin, and homodihydrocapsaicin exhibited relative pungencies that ranged between 20 and 50% that of capsaicin (Nelson 1919; Jones and Pyman 1925; Walpole et al. 1993). A new capsaicin derivative, 6' '7' '-dihydro-5',5' "-dicapsaicin (1), and a known capsaicin metabolite, ω-hydroxycapsaicin (2), were isolated from *Capsicum annuum* fruit (Ochi et al. 2003). Compound 1 showed almost the same antioxidant activity as capsaicin, but did not have a pungent taste.

The total capsaicinoid levels in extracts of the fresh peppers was reflective of the relative “hotness” of the pepper (habañero > anaheim = red-chili > green-chili > green bell > yellow bell) (Reilly et al. 2001). The sum of contents of capsaicin and dihydrocapsaicin in the extracts of fresh pepper reflected the relative pungency of the pepper type and appeared to dictate the pungency of the fruit. For example, extracts of habañero peppers (the “hottest” pepper) contained approximately 90% capsaicin and dihydrocapsaicin, while extracts of the milder green-chili pepper contained about 65% capsaicin and dihydrocapsaicin. Five capsaicinoids: nordihydrocapsaicin, capsaicin, dihydrocapsaicin, an isomer of dihydrocapsaicin, and homodihydrocapsaicin were identified in three Spanish varieties of hot peppers (Barbero et al. 2006).

Eight capsaicinoids, pungent secondary metabolites were found in various parts of the pepper fruit (pericarp, placenta, seeds, and in the top, middle, and base parts of whole peppers) in 17 species of *Capsicum* peppers and in 23 pepper-containing foods (Kozukue et al. 2005). The compounds were: capsaicin, dihydrocapsaicin, homocapsaicin-I, homocapsaicin-II, homodihydro-

capsaicin-I, homodihydrocapsaicin-II, nonivamide, and nordihydrocapsaicin. The concentration found ranged from 0.5 to 3,600 µg of capsaicin equivalent/g of product. Hot chillies (*C. annum*) showed the highest concentration of capsaicin (4249.0 µg/g) and the highest pungency level (67984.60 SHU), whereas green peppers had the lowest detected concentration (1.0 µg/g); green peppers, red peppers and yellow peppers were non-pungent (Al Othman et al. 2011). The mean consumption of peppers for Riyadh city population was determined to be 15.5 g/person/day while the daily capsaicin intake was 7.584 mg/person/day. The concentrations (µg/g) of capsaicin, dihydrocapsaicin, and Scoville heat units (SHU) and level of pungency in the analyzed *C. annum* pepper samples were reported as: hot chilli – 4249.0 µg/g capsaicin, 4482.2 µg/g dihydrocapsaicin, 67984.60 SHU (highly pungent); red chilli – 309.3 µg/g capsaicin, 238.2 µg/g dihydrocapsaicin, 4949.08 SHU (moderately pungent); green chilli – 138.5 µg/g capsaicin, 146.4 µg/g dihydrocapsaicin, 2216.58 SHU (mildly pungent); green pepper – 1.0 µg/g capsaicin, dihydrocapsaicin nd (not detected), 0 SHU (non-pungent); red pepper – capsaicin nd, dihydrocapsaicin nd, 0 SHU (non-pungent); yellow pepper – capsaicin nd, dihydrocapsaicin nd, 0 SHU (non-pungent).

Capsaicin and dihydrocapsaicin were the dominant capsaicinoids detected in methanol extract of fresh fruits of *Capsicum chinense*, *C. frutescens*, *C. baccatum*, *C. annum*, and *C. pubescens* (Antonious and Jarret 2006); nordihydrocapsaicin was also detected. Capsaicin concentrations were typically greater than dihydrocapsaicin. Concentrations of total capsaicinoids varied from not detectable to 11.2 mg/fruit. Statistical analysis revealed that accession PI-441624 (*C. chinense*) had the highest capsaicin content (2.9 mg/g fresh fruit) and accession PI-497984 (*C. frutescens*) had the highest dihydrocapsaicin content (2.3 mg/g fresh fruit). Accessions PI-439522 (*C. frutescens*) and PI-497984 contained the highest concentrations of total capsaicinoids. Ten cultivars out of 35 cultivars tested: 18 cultivars of *C. annum*, 7 of *C. baccatum*, 5 of *C. chinense*, 4 of *C. frutescens*, and 1 of *C. pubescens* contained capsiconinoids

(Tanaka et al. 2009). Capsiconinoid Baccatum (CCB) (*C. baccatum* var. *praetermissum*) showed the highest capsiconinoid content (3,314 µg/g DW) and Charapita (*C. chinense*) had the second highest content. The other eight cultivars had much lower capsiconinoid content than these two cultivars (<300 µg/g DW). The capsiconinoid content in *C. baccatum* fruits was found to increase until 30 days after flowering (DAF) and to decrease rapidly until 40 DAF. Capsiconinoids had been reported to have agonist activity for transient receptor potential vanilloid type 1 (TRPV1).

Two new glucosides of capsaicin and dihydrocapsaicin, capsaicin-β-D-glucopyranoside (1) and dihydrocapsaicin-β-D-glucopyranoside (2), were discovered in the fruit of the *Capsicum annum* cultivar 'High Heat' (Higashiguchi et al. 2006). The glucosides were also detected in various pungent cultivars of *C. annum*, *Capsicum frutescens*, and *Capsicum chinense*. However, they were not detected in non-pungent cultivars of *C. annum*. Additionally, a positive correlation was observed between the quantity of the capsaicinoids, capsaicin, and dihydrocapsaicin and their glucosides. Five major glycolipid classes (acylated steryl glucoside, steryl glucoside, monogalactosyldiacylglycerol, digalactosyldiacylglycerol, and glucocerebroside) were extracted from fruit pastes of red bell pepper (Yamauchi et al. 2001). The molecular species of steryl glucoside were β-sitosteryl and campesteryl glucosides, and those of the acylated steryl glucoside were their fatty acid esters. The dilinolenoyl species was predominant in monogalactosyldiacylglycerol in addition to small amounts of another five molecular species, whereas digalactosyldiacylglycerol consisted of seven molecular species varying in their degree of unsaturation. The glucocerebroside class contained at least seven molecular species. A new lignan glycoside and a known one, icariside E(5) were isolated from *C. annum* fruits (Lee et al. 2009).

A acyclic diterpene glycoside, capsianside A was obtained from fresh fruit of *Capsicum annum* var. *fasciculatum* (Yahara et al. 1988). Three new glycosides, capsosides A (1) and B (2) and capsianoside VII (3), along with seven known

compounds (4–10) were isolated from ripe fruits of *Capsicum annuum* var. *acuminatum* (Iorizzi et al. 2001). Nine flavonoid and phenolic acid glycosides were isolated from pericarp of hot pepper fruits (*Capsicum annuum*) (Materska et al. 2003b). They were identified as *trans-p*-ferulylalcohol-4-O-(6-(2-methyl-3-hydroxypropionyl) glucopyranoside); luteolin-7-O-(2-apiofuranosyl-4-glucopyranosyl-6-malonyl)-glucopyranoside; *trans-p*-feruloyl- β -D-glucopyranoside; *trans-p*-sinapoyl- β -D-glucopyranoside; quercetin 3-O- α -L-rhamnopyranoside-7-O- β -D-glucopyranoside; luteolin 6-C- β -D-glucopyranoside-8-C- α -L-arabinopyranoside; apigenin 6-C- β -D-glucopyranoside-8-C- α -L-arabinopyranoside; and luteolin 7-O-2-(β -D-apiofuranosyl)- β -D-glucopyranoside. In another paper, Materska et al. (2003a) determined nine derivatives of phenolic acids – ferulic and sinapic, as well as flavonoids – quercetin, luteolin and apigenin, in the pericarp of red pepper fruit cv. Bronowicka Ostra. They were: *trans-p*-feruloyl- β -D-glucopyranoside; *trans-p*-ferulylalcohol-4-O-6-(2-methyl-3-hydroxypropionyl) glucopyranoside; *trans-p*-sinapoyl- β -D-glucopyranoside; quercetin 3-O- α -L-rhamnopyranoside-7-O- β -D-glucopyranoside; quercetin 3-O- α -L-rhamnopyranoside; luteolin 6-C- β -D-glucopyranoside-8-C- α -L-arabinopyranoside; luteolin 7-O-[2-(β -D-apiofuranosyl)- β -D-glucopyranoside]; luteolin-7-O-(2-apiofuranosyl-4-glucopyranosyl-6-malonyl) glucopyranoside and apigenin 6-C- β -D-glucopyranoside-8-C- α -L-arabinopyranoside were elucidated. The greatest contents in pericarp of hot pepper fruit var. Bronowicka Ostra were sinapic acid glucoside followed by ferulic acid glucoside, luteolin apiosylglucoside and quercetin rhamnoside. The lowest level was found for apigenin 6-C- β -D-glucopyranoside-8-C- α -L-arabinopyranoside. Two fractions of phenolics, flavonoids (with phenolic acids) and capsaicinoids, were isolated from the pericarp of pepper fruit of four *C. annuum* cultivars (Bronowicka Ostra, Cyklon, Tornado, and Tajfun) at two growth stages (green and red) (Materska and Perucka 2005). Contents of nine compounds determined in the flavonoid and phenolic acid fraction were: *trans-p*-feruloyl- β -D-glucopyranoside, *trans-p*-

sinapoyl- β -D-glucopyranoside, quercetin 3-O- α -L-rhamnopyranoside-7-O- β -D-glucopyranoside, *trans-p*-ferulyl alcohol-4-O-[6-(2-methyl-3-hydroxypropionyl) glucopyranoside, luteolin 6-C- β -D-glucopyranoside-8-C- α -L-arabinopyranoside, apigenin 6-C- β -D-glucopyranoside-8-C- α -L-arabinopyranoside, luteolin 7-O-[2-(β -D-apiofuranosyl)- β -D-glucopyranoside], quercetin 3-O- α -L-rhamnopyranoside, and luteolin 7-O-[2-(β -D-apiofuranosyl)-4-(β -D-glucopyranosyl)-6-malonyl]- β -D-glucopyranoside. The main compounds of this fraction isolated from red pepper were sinapoyl and feruloyl glycosides, and the main compound from green pepper was quercetin-3-O-L-rhamnoside. Capsaicin and dihydrocapsaicin were the main components of the capsaicinoid fraction.

Six acyclic diterpene glycosides, called capsianosides XIII (2), XV (3), IX (4), XVI (5), X (6) and VIII (7) together with known capsianoside II (1) were isolated from the fruits of paprika *Capsicum annuum* L. var. *grossum* Bailey and jalapeño *Capsicum annuum* L. var. *annuum* (Lee et al. 2006). Four acyclic diterpene glycosides named capsianosides (1–4), together with 12 known compounds, were isolated from the fresh sweet pepper fruits of *Capsicum annuum* (De Marino et al. 2006). Acyclic diterpene glycosides, named capsianosides I', II, III (1), C (2), D (3), E (4) and F (5), were isolated from the dried hot red pepper fruits of *Capsicum annuum* used in Kimchi (Lee et al. 2007b). Three acyclic diterpene glycosides, called capsianosides XVII (1), V methyl ester (2) and XIV (3) together with capsianosides I and II were isolated from the aerial parts of paprika and pimienta (a small sweet red pepper) (Lee et al. 2008).

A capsiate-like substance, named nordihydrocapsiate was isolated from the fruits of a nonpungent cultivar, CH-19 Sweet, of pepper (*Capsicum annuum*) and its structure of 1 was determined to be 4-hydroxy-3-methoxybenzyl 7-methyloctanoate (Kobata et al. 1999). Forty-nine samples representing distinct morphotypes of four cultivated species (*C. annuum* var. *annuum*, *C. annuum* var. *glabriusculum*, *C. baccatum*, *C. chinense*, and *C. frutescens*) were found to contain detectable levels (11–369 μ g/g) of a capsinoid, E-capsiate

(Singh et al. 2009). Nine of the E-capsiate-containing samples also had dihydrocapsiate (18–86 µg/g).

Nineteen new thiols (nine aliphatic saturated and unsaturated thiols, two mercapto-ketones, three mercapto-alcohols, two dithiols, two methylthio-thiols, and one thiophene-thiol) and two new dithiolanes were found as volatile sulphur compounds in red bell pepper (*C. annuum*) (Naef et al. 2008). All of them were structurally related to the unsaturated C7- and C9-ketones. Additionally, the already known (3 E)-3-hepten-2-one (1), the unsaturated C9-ketones 1-nonen-4-one (2), (2 E)-2-nonen-4-one (3), and (2 E,5 E)-2,5-nonadien-4-one (4), 2-methoxy-3-isobutylpyrazine (5), and heptane-2-thiol (6), were also identified. Volatile sulphur compounds isolated from bell pepper fruit included mercapto-ketones: 4-sulfanyl-2-heptanone and 2-sulfanyl-4-heptanone; the mercapto-alcohols: 4-sulfanyl-2-heptanol and 2-sulfanyl-4-heptanol, and heptane-2,4-dithiol, derived from their corresponding cysteine-S-conjugates (Starkenmann and Niclass 2011). The cysteine-S-conjugates identified included S-(3-hydroxy-1-methylhexyl)-L-cysteine; S-(3-hydroxy-1-propylbutyl)-L-cysteine; S-(3-oxo-1-propylbutyl)-L-cysteine; and (2R,2'R)-3,3'-(4-hydroxyheptane-2,6-diyl) bis(sulfanediyl) bis(2-aminopropanoic acid). Also, 3-sulfanyl-1-hexanol was also detected and the occurrence of S-(1(2-hydroxyethyl)butyl)-L-cysteine confirmed. The cysteine-S-conjugates were present at concentrations in the range of 1–100 µg/kg.

Sixty-five volatile compounds were isolated from “Padrón-type” peppers, a small variety of *Capsicum annuum* including hydrocarbons, terpenes, alcohols, phenols, ethers, aldehydes, ketones, esters, pyrroles, pyrazines, and sulfurous compounds (Oruña-Concha et al. 1998). Fresh whole, homogenized, and freeze-dried peppers had different characteristic volatile-component profiles, whereas frozen peppers had a highly variable volatile-component profile. The following compound were identified from fresh whole fruits: ethanol; pentane; 2-methyl-1,3-butadiene (=isoprene); hexane; 2-methyl furan; benzene; heptane; 1,4-dioxane methyl cyclohexane;

1-methyl-1 H-pyrrole; dimethyl disulfide; methyl-benzene; hexanal; 2-hexanal; 3-hexen-1-ol; 1-hexanol; 1,2-dimethyl-benzene; tricylene; α-pinene; 2,3,6-trimethyl-1,4,6-heptatriene; limonene; δ-3-carene; dihydro-myrcenol; α,α-dimethyl-benzenemethanol; linalool; nonal; 2,6,-dimethyl-2,4,6-octatriene and 2-isobutyl-3-methoxypyrazine. The following compounds were identified in homogenised fruit: 1-pentene; pentane; 2-methyl-1,3-butadiene (=isoprene); 1,3-pentadiene; hexane; 2-methyl furan; benzene; heptanes; 1,4-dioxane; 1-methyl-1 H-pyrrole; dimethyl disulfide; methyl-benzene; hexanal; 2-hexanal; 3-hexen-1-ol; 1-hexanol; 1,2-dimethyl-benzene; isocitonen; 2,6-dimethyl-1,7-octadiene; tricylene; α-pinene; 3,7-dimethyl-1,6-octadiene; 1-ethyl-4-methyl-benzene; phenol; p-menth-2-ene; pinane; decane; carane; 1,3,5-trimethyl-benzene; limonene; 1,8-cineole; δ-3-carene; dihydro-myrcenol; 2-isobutyl-3-methoxypyrazine and methyl-salicylate. Sixty-four volatile compounds were identified in Calabrian *Capsicum annuum* (hot pepper), the main classes being alcohols, aldehydes, terpenes and aliphatic branched-chain hydrocarbons (Ziino et al. 2009). The ‘Naso di cane’ (*C. annuum* var. *abbreviatum*) variety contained the lowest amount of volatiles, especially alcohols and aldehydes, while the highest levels of capsaicin and dihydrocapsaicin were found in ‘Vulcan’ and ‘Corno di capra’ varieties.

Important major volatile aroma compounds in fresh chilli (*Capsicum annuum* var *annuum* cv. Kulai) were identified as hexanal, 2-isobutyl-3-methoxypyrazine, 2,3-butanedione, 3-carene, *trans*-2-hexenal and linalool (Mazida et al. 2005). During ripening, hexanal (green aroma) and 2-isobutyl-3-methoxypyrazine (grassy aroma) were found to be significantly decreased. Sweet, fruity attributes represented by such compound as 2,3-butanedione, 3-carene, *trans*-2-hexenal and linalool were found to increase during ripening. One hundred and forty volatile constituents were identified in chile pepper (*Capsicum annuum* L. var. *glabriusculum*) at two ripening stages (green and red), of which hexyl isopentanoate, hexyl 2-methylbutanoate, limonene, hexyl isohexanoate, (E)-2-hexenal, isopentyl

isopentanoate and (Z)-3-hexenyl isopentanoate predominated (Forero et al. 2009). During fruit maturation, the majority of volatile compounds decreased. In general, green chile peppers had higher amounts of esters, with their fruity odour notes, than red fruits. Based on the amount of total volatiles, which was higher at the green stage in comparison with the mature red stage, it was concluded that the green stage was better in terms of its flavour than the red stage.

More than 300 volatile constituents were detected in the ripe fruits of 16 *Capsicum* accessions from the *annuum-chinense-frutescens* complex (Rodríguez-Burruezo et al. 2010). Esters and terpenoids were the main groups, although other minor compounds, such as nitrogen and sulfur compounds, phenol derivatives, norcarotenoids, lipoxygenase derivatives, carbonyls, alcohols, and other hydrocarbons, were also identified. The sniffing test revealed that the diversity of aromas found among the studied cultivars was due to qualitative and quantitative differences of, at least, 23 odour-contributing volatiles (OCVs). *C. chinense*, and *C. frutescens* accessions, with fruity/exotic aromas, were characterized by a high contribution of several esters and ionones and a low or nil contribution of green/vegetable OCVs. Different combinations of fruity/exotic and green/vegetable OCVs would explain the range of aroma impressions found among *C. annuum* accessions. Buttery et al. (1969) identified about 60 volatile compounds in green bell peppers (*C. annuum* var. *grossum*, Sendt), among which they identified an alkyl-methoxypyrazine, 3-isobutyl-2-methoxypyrazine. A new aroma compound 2-Heptanethiol was indentified as a constituent of red and green bell pepper extracts (Simian et al. 2004). Fresh bell pepper (*C. annuum*) fruits of different cultivars were found to have several odour compounds in common: 2,3-butanedione (caramel), 1-penten-3-one (chemical/pungent/spicy), hexanal (grassy), 3-carene (red bell pepper, rubbery), (Z)- β -ocimene (rancid, sweaty), octanal (fruity), and 2-isobutyl-3-methoxypyrazine (green bell pepper) (Luning et al. 1994). During bell pepper maturation, the volatile compounds with green-related odour notes decreased or even disappeared. Only contents of

(E)-2-hexenal and (E)-2-hexenal with almond, fruity, sweet odours were higher at the red ripening stages. Contents of glucose, fructose, ascorbic, citric, and oxalic acid in different Dutch bell pepper cultivars decreased significantly after drying, while the levels of sucrose, malic, fumaric, and *cis*-aconitic acid increased (Luning et al. 1995a). The majority of volatile compounds evaporated during drying. Gas chromatography-sniffing port analysis revealed that compounds with mainly “fresh” odour notes like lettuce/grassy/green bell pepper ((Z)-2-3-hexenal), fruity/almond ((E)-2-hexenal), fruity (octanal), lettuce/green bell pepper ((Z)-3-hexenol), and grassy/green bell pepper ((Z)-2-hexenal) decreased or disappeared after drying. Another group of compounds increased or were formed during drying, like 4-octen-3-one, (E)-2-heptenal, (E)-2-octenal, (E,Z)- and (E,E)-2,4-heptadienal, decanal, and (E)-2-nonenal; most were known as autoxidation products of unsaturated fatty acids. The increased levels of 2-methylpropionic and 2-methylbutyric acid and 3-methylbutyric acid, 2-methylpropanal, and 2-methylbutana and 3-methylbutanal appeared to be caused by Strecker degradation. Gas chromatography-sniffing port analysis showed that the latter three compounds had distinct cacao, sweaty, and spicy odour characteristics. In another study, hot-air drying of bell peppers (*Capsicum annuum*) decreased levels of the odour compounds (Z)-3-hexenal, 2-heptanone, (Z)-2-hexenal, (E)-2-hexenal, hexanol, (Z)-3-hexanol, (E)-2-hexenol, and linalool, which have green, vegetable-like, fruity, and floral notes, while intensity scores of corresponding sensory aroma attributes also decreased (Luning et al. 1995b). The aroma of rehydrated dried samples was mainly characterized as savory, rancid/sweaty, sweet/sickly, hay-like, cacao, caramel, and nutty. Drying increased the levels of 2-methylpropanal, 2-and 3-methylbutanal, which have cacao, spicy, and rancid/sweaty odor notes. Thirty-five and 42 odour-active compounds were detected in Hungarian sweet bell pepper powder (HBP) and Moroccan sweet bell pepper powder (MBP), respectively. Another research reported 46 compounds in commercially dried bell-peppers, 12 of which

possessed odours: 2-methylpropanal (chocolate); 2- and 3-methylbutanal (chocolate); 2,3-butadi-one (caramel/butter); 1-penten-3-one (plastic/chemical); hexanal (grassy/green); heptanal (lemon/orange); β -ocimene (fish/rotten/sickly); *trans*-3-hepten-2-one (mushrooms); dimethyltrisulphide (rotten/onion/leek); 2-methoxy-3-isobutylpyrazine (bell pepper); and β -cyclocitral (fruity) (Van Ruth and Roozen 1995). Zimmermann and Schieberle (2000) identified 35 and 42 odour-active compounds in Hungarian sweet bell pepper powder (HBP) and Moroccan sweet bell pepper powder (MBP), respectively. β -ionone (violet-like), 4-hydroxy-2,5-dimethyl-3(2H)-furanone (furanol; caramel-like), 3-hydroxy-4,5-dimethyl-2(5H)-furanone (Sotolon; seasoning-like), 2-methylbutanoic acid and 3-methylbutanoic acid had the highest odour activities among the 33 odorants that could be identified in the HBP. All odorants identified in the HBP were also characterized as odour-active volatiles in the MBP. The overall different aroma of the Moroccan sample could be attributed to the lower FD (flavour dilution) factors of the five key odorants mentioned above plus to the higher FD factors of ten odorants not present among the aroma compounds of the HBP, e.g. (Z)-1,5-octadien-3-one. In total, 20 odour-active volatiles were reported here for the first time as volatile bell pepper constituents. Fructose and (E)-2-hexen-1-ol were highly correlated with aroma, fruity/apple taste and sweetness in fresh sweet pepper and *p*-menth-1-en-9-al, (E)- β -ocimene, (Z)-2-penten-1-ol and (E)-geranylacetone with sweet fruity/apple taste (Eggink et al. 2012).

A total of 67 volatile components were identified Chinese traditional pickled peppers including 7 acids, 6 alkanes, 14 alcohols, 9 esters, 11 terpenes, 3 aldehydes, 5 ketones, 7 phenols and 5 miscellaneous compounds (Xiao et al. 2010). Of 45 volatile compounds detected, the majority of odour-active components included acetic acid, 2-ethyl phenol, L-linalool, tridecane, butyl butanoate, δ -3-carene. The individual concentrations of the volatile compounds such as acetic acid, ethanol, 1-propanol, L-linalool, hexyl 2-methyl butyrate and hexyl pentanoate corresponded well to the intensities of

related attributes in the correlation analysis. Due to their high concentration level and low threshold value, these compounds played an important role in the final aromatic profile of the pickled peppers.

Volatile compounds formed during heating of paprika (*Capsicum annuum*) spice powder indicated a decrease in spice paprika quality due to Maillard reaction, hydrolytic reactions, and oxidative degradation reactions of lipids such as fatty acids and carotenoids (Cremer and Eichner 2000). Some of these compounds formed included Strecker aldehydes acetaldehyde (AA), 2-methylpropanal (2-MP), 3-methylbutanal (3-MB), and 2-methylbutanal; acetone, methanol and dimethyl sulphide. The formation of hexanal and 6-methyl-5-hepten-2-one and beta-ionone was also found. During heating, the concentration of hexanal increased rapidly. The formation of 6-methyl-5-hepten-2-one confirmed *Capsicum annuum* fruits to contain lycopene.

Phytochemicals from Other Plant Parts

Three new steroid glycosides of the spirostan series designated capsicosides A1, B1, and C1 were isolated from a methanolic extract of the roots of red pepper (*C. annuum*) (Gutsu et al. 1986). Complete acid hydrolysis of these glycosides yielded a single aglycon, gitogenin. Two tigogenin glycosides and two diosgenin glycosides were isolated from a methanolic extract of bush red pepper (*C. annuum*) roots (Gutsu et al. 1987). Capsicoside A2 was elucidated as (25R)-5 α -spirostan-3 β -ol 3-O- β -D-galactopyranoside; capsicoside B2 as (25R)-5 α -spirostan-3 β -ol 3-O-[O- β -D-glucopyranosyl(1 $\rightarrow$ 4)- β -D-galactopyranoside]; capsicoside A3 as (25R)-spirost-5-en-3 β -ol 3-O- β -D-galactopyranoside, and capsicoside B3 was identical with funkioside C. Two steroid glycosides named capsicosides C2 and C3 were isolated from *C. annuum* roots (Gutsu and Kintya 1989). Capsicoside C2 was derived from tiogenin glycoside peracetate and on complete hydrolysis of capsicoside C2, the aglycone tigogenin was obtained. Capsicoside C3 was obtained from diosgenin glycoside peracetate (oxirane) and on complete hydrolysis

of capsicoside C3, the aglycone diosgenin was obtained.

Analysis of the two principal capsaicinoids in fruits of *Capsicum annuum* cv Padrón showed that the content of capsaicin was always higher than that of dihydrocapsaicin (Estrada et al. 2002). Capsaicinoids were also found to be present in vegetative organs, such as stem and leave with dihydrocapsaicin being more abundant. Capsaicinoids were not detected in the stem and leaves of floral bud-deprived plants, suggesting that they did originate from the fruit. Annexin 24(Ca32) was purified as a native protein from bell pepper (*Capsicum annuum*) (Hofmann et al. 2000). Characterization of this plant annexin using biophysical methods revealed calcium-dependent binding to phospholipid vesicles with preference for phosphatidylcholine over phosphatidylserine and magnesium-dependent phosphodiesterase activity in-vitro as shown with adenosine triphosphate as the substrate.

Stem and roots of *C. annuum* contained sesquiterpenoids and other compound: capsidiol, 13-hydroxycapsidiol, canusesnols A–E belonging to eudesmane type; eremophiline type congeners sharing their skeleton with capsidiol e.g. compound F=11-carboxy-11-demethyl-1-epi-capsidiol; vetispirane type canusesnols I and J representing 4-epimers of 15-dihydrolubimin and 13,15-dihydroxysolavetivone compounds (Kawaguchi et al. 2004). The following compounds: 7'-(4'-hydroxyphenyl)-N-[(4-methoxyphenyl)ethyl]propenamide (1), 7'-(3',4'-dihydroxyphenyl)-N-[(4-methoxyphenyl)ethyl]propenamide (2), N-*p-trans*-coumaroyltyramine (3), N-*trans*-caffeoyltyramine (4), β -sitostenone (5), ferulic acid (6), hydroferulic acid (7), 5-hydroxy-3,4-dimethoxycinnamic acid (8), veratic acid (9), vanillic acid (10), isovanillic acid (11), syringic acid (12), (+)-syringaresinol (13), and pheophorbide a (14) were isolated from the stems of *Capsicum annuum* (Chen et al 2011).

Three acyclic diterpene glycosides, capsianosides, a monomeric capsianodeVI (1), and two dimeric diterpene glycosides, capsianosides G (2) and H (3), along with capsianosides II, A, B, C and D were isolated from the leaves and stem

of *Capsicum annuum* var. *fasciculatum* and *C. annuum* var. *conoides* (Yahara et al. 1991). Alpha-tocopherol, phytol and vitamin E quinone were isolated for the first time from the leaves of *C. annuum* (Cho et al. 2009).

A eudesmane sesquiterpenoid, *cis*-9,10-dihydrocapsenone, was isolated in small amounts from unelicited cell suspension cultures of *Capsicum annuum* (Whitehead et al. 1987). Cycloartenol and cycloartanol were found to be the major components of the 4,4-dimethylsterol fraction separated from the seeds of red pepper (*Capsicum annuum*) (Itoh et al. 1977).

Four new steroidal glycosides, named capsicosides A–D together with proto-degalactotigonin, were isolated from the roots and seeds of *Capsicum annuum* var. *conoides* and *Capsicum annuum* var. *fasciculatum* (Yahara et al. 1994). The structures of capsicosides A–D were shown to be furostanol glycosides corresponding to gitogenin and tigogenin oligoglycosides. Capsicoside A was regarded as the same compound as the previously described capsicoside. A 4 α -methylsterol was isolated from *Capsicum annuum* seeds and was identified as 4 α -methyl-5 α -cholest-8(14)-en-3 β -ol (Matsumoto et al. 1983). Three furostanol saponins named capsicoside E (1), capsicoside F (2), and capsicoside G (5) were obtained from the seeds of *Capsicum annuum* var. *acuminatum* along with known oligoglycosides (3, 4, and 6–10) (Iorizzi et al. 2002). The structures of these furostanol oligoglycosides were elucidated as 26-O- β -D-glucopyranosyl-22-O-methyl-5 α -furost-25(27)-en-2 α ,3 β ,22 ξ ,26-tetraol-3-O- β -D-glucopyranosyl(1 $\rightarrow$ 3)- β -D-glucopyranosyl(1 $\rightarrow$ 2)-[β -D-glucopyranosyl(1 $\rightarrow$ 3)]- β -D-glucopyranosyl(1 $\rightarrow$ 4)- β -D-galactopyranoside (1); 26-O- β -D-glucopyranosyl-(25R)-5 α -furost-20(22)-en-2 α ,3 β ,26-triol-3-O- β -D-glucopyranosyl(1 $\rightarrow$ 3)- β -D-glucopyranosyl(1 $\rightarrow$ 2)-[β -D-glucopyranosyl(1 $\rightarrow$ 3)]- β -D-glucopyranosyl(1 $\rightarrow$ 4)- β -D-galactopyranoside (2); and 26-O- β -D-glucopyranosyl-(25R)-5 α -furosta-3 β ,22 ξ ,26-triol-3-O- β -D-glucopyranosyl(1 $\rightarrow$ 3)- β -D-glucopyranosyl(1 $\rightarrow$ 2)-[β -D-glucopyranosyl(1 $\rightarrow$ 3)]- β -D-glucopyranosyl(1 $\rightarrow$ 4)- β -D-galactopyranoside (5).

A 9-kDa lipid transfer proteins, designated Ca-LTP(1) was isolated from *Capsicum annuum* seeds (Diz et al. 2011). It occurred in three isoforms with isoelectric points (pIs) of 6.0, 8.5 and 9.5. It was mainly localized within dense vesicles. The proximate analysis (on dry weight basis) of sweet pepper seeds were determined as 70.95%, ash 4.88%, fat 19.57%, crude protein 19.28%, and carbohydrate 56.3% (Embaby and Mokhtar 2011). potassium was the most abundant element, followed by phosphorus and sodium. Also, zinc, iron, copper, and manganese were detected. the major limiting amino acid was valine and the major fatty acid was linoleic acid in sweet pepper oil (71.55%). Antinutritional compounds, including, phytic acid, trypsin inhibitor, and tannins, were detected in the seeds.

Capsaicinoids, Capsinoids and Biological Activities

Capsaicinoids from chilli peppers such as dihydrocapsaicin, nordihydrocapsaicin, homodihydrocapsaicin, and homocapsaicin, etc. have been reported to exert multiple pharmacological and physiological effects that impart analgesic, anti-cancer, antiinflammatory, antioxidant, anti-obesity (Luo et al. 2011), antidiabetic, and hypolipidemic/antihypercholesterolemic activities. Capsaicinoids also have benefits on cardiovascular and gastrointestinal system and for may have the potential value in clinic for pain relief, cancer prevention and weight loss (See notes under *Capsicum frutescens*). CH-19 Sweet peppers (*Capsicum annuum*) were found to be the source of nature capsinoids, sharing similar structure with capsaicinoids and consisting of capsiate, dihydrocapsiate, and nordihydrocapsiate, etc (Luo et al. 2011). Studies have found that capsinoids possess the biological properties of antitumour, antioxidant and antiobesity. Since capsinoids are less toxic and less pungent than capsaicinoids and degrade readily in normal aqueous conditions, they may have advantages over capsaicinoids in clinical applications such as cancer prevention and weight loss.

Antioxidant Activity

The concentration of antioxidant compounds carotenoids, vitamins, polyphenols and other compounds and their associated antioxidant activity in *C. annuum* fruits had been reported to be influenced by genotype, growing conditions, growing and harvesting seasons, maturity stages and modes of drying and processing.

Major pepper flavonoids in fresh pepper (*Capsicum annuum*) cultivars “jalapeño”. “yellow wax”, “Chile”, “ancho” and “serrano” were quercetin and luteolin which were present in conjugate forms (Lee et al. 1995). “Chile”, “yellow wax” and “ancho” peppers had greater flavonoid and ascorbic acid contents and antioxidant activities than “jalapeño” peppers. Sep-Pak C18(tm) bound phenolic compounds, including flavonoids, correlated well with antioxidant activity ($R^2=0.86$). Luteolin had highest antioxidant activity followed by capsaicin and quercetin on equimolar basis. The concentrations of carotenoids, flavonoids, total soluble reducing equivalents, phenolic acids, ascorbic acid in different pepper types (*Capsicum annuum*, *Capsicum frutescens*, and *Capsicum chinense*) were found to increase with fruit maturity (Howard et al. 2000). Peppers contained high levels of L-ascorbic acid and carotenoids at maturity, contributing 124–338% of the RDA for vitamin C and 0.33–336 RE/100 g of provitamin A activity, respectively. Levels of phenolic acids, capxanthin, and zeaxanthin generally increased during maturation, whereas the level of lutein declined. Flavonoid concentrations varied greatly among the pepper types analysed and were negatively correlated to antioxidant activity under the conditions of the β -carotene-linoleic assay. Significant increases in antioxidant activity were observed in pepper juice models in response to increasing dilution factors and the presence of EDTA, indicating a pro-oxidant effect due to metal ions in the system. In-vitro models showed that increasing levels of flavonoids in combination with constant levels of caffeic and ascorbic acid gave a resultant antioxidant activity that was either additive of the two compounds or competi-

tive in their ability to scavenge peroxy radicals. The antioxidant and anticancer activities of *C. annuum* cv. ST4712 (CLST) were substantially higher than those of *C. annuum* cv. Cupra and *C. annuum* cv. Orange glory (Jeong et al. 2011). The high activities of the CLST were attributed to the much higher concentration of quercetin derivatives in CLST.

Studies on the antioxidant activity in red pepper fruits (*Capsicum annuum*) varieties Bronowicka Ostra, Cyklon, Tornado, and Tajfun found that the fractions of capsaicinoids had similar antioxidant activity as the flavonoid fractions depending on the level of capsaicinoids (Perucka and Materska 2003). Fruits with lower content of capsaicinoids were also characterized by lower antioxidant activities, reduced vitamin E and provitamin A content, but higher vitamin C content as compared to the fruits of hot varieties. A comparison of the capsaicinoid fraction with the flavonoid and phenolic acid fractions from red fruit of four *C. annuum* cultivars (Bronowicka Ostra, Cyklon, Tornado, and Tajfun) with respect to their antioxidant activity gave similar results (Materska and Perucka 2005). A high correlation was found between the content of these compounds and the antioxidant activity of both fractions as elucidated by heat-induced oxidation in the β -carotene-linoleic acid system and the anti-radical activity by the 1,1-diphenyl-2-picrylhydrazyl (DPPH) decoloration test. The highest antioxidant activity in the β -carotene-linoleic acid system was found for *trans-p*-sinapoyl- β -D-glucopyranoside, which was lower than the activity of free sinapic acid. Quercetin 3-O- α -L-rhamnopyranoside had the highest antiradical activity in the DPPH system, which was comparable to the activity of quercetin. The activities of capsaicin and dihydrocapsaicin were similar to that of *trans-p*-feruloyl-D-glucopyranoside in the DPPH model system. The free radical scavenging abilities of four different colored (green, yellow, orange, and red) sweet bell peppers determined DPPH method were lowest for the green sweet pepper (2.1 μ mol Trolox equivalent/g) but not significantly different from the other three peppers (Sun et al. 2007). All four coloured peppers exhibited significant abilities in preventing

the oxidation of cholesterol or docosahexaenoic acid (DHA) (C22:6) during heating. However, these four peppers did not show significant differences in their abilities in preventing cholesterol oxidation. The green sweet pepper showed slightly higher capability in preventing the oxidation of DHA compared to the other three peppers.

Red pepper (*Capsicum annuum*) pericarp and red pepper seed extracts exhibited strong antioxidant activity as evaluated by including 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging, superoxide anion radical scavenging, hydroxyl radical scavenging, [2,2'-azino-bis(3-ethylbenzthiazoline-6-sulphonic acid)] (ABTS) radical scavenging, ferrous chelating activity, superoxide dismutase (SOD) activity and reducing power assays (Sim and Sil 2008). The red pepper pericarp extract exhibited strong ferrous chelating activity and high scavenging activity against free radicals, including both the hydroxyl and DPPH radicals, but it exhibited weaker scavenging activity for the superoxide anion radical and for SOD. In contrast, the red pepper seed extract exhibited strong SOD activity and high scavenging activity against the superoxide anion radical, but showed weaker ferrous chelating activity, hydroxyl radical scavenging, and DPPH radical scavenging. The reducing power level and ABTS radical scavenging activity of the red pepper seed were higher than those of the red pepper pericarp at the highest tested concentration. Highest total phenolic and flavonoid contents were obtained from the red pepper pericarp extracts.

Márkus et al. (1999) found that a rainy and cool season yielded red paprika (*C. annuum*) fruits with more β -carotene but less diesters of red xanthophylls as compared to those produced in a relatively dry and warm season. The ripening stage at harvest was found to affect the quality of paprika. Harvest at unripe stages (color break or faint red) resulted in a high accumulation of dehydroascorbic acid in the overripe fruits, whereas de novo biosynthesis of carotenoids and tocopherols was partially retarded. Application of pre-drying centrifugation resulted in a marked loss of ascorbic acid, and as a consequence, carotenoid stability was impaired during the storage

of ground paprika. Sugar caramelization caused dry pods and ground paprika to retain more pigments and tocopherol as compared to those from control or centrifuged red pepper samples. During the storage of ground paprika, color stability was improved by grinding the seeds with the pericarp.

The first stage of maturation (small green) of hot pepper fruits (*Capsicum annuum* var. *acuminatum*) showed the highest radical-scavenging activity (IC_{50} of 129 $\mu\text{g/mL}$) (Conforti et al. 2007). The methanolic extract of green pepper (second stage) showed significant antioxidant activity (IC_{50} of 522 $\mu\text{g/mL}$). Addition of methanolic extract of red and green pepper inhibited oxidation of linoleic acid. Methanolic extract of red pepper (third stage) showed greater antioxidative potency than the others (IC_{50} of 3 $\mu\text{g/mL}$). The different composition of lipophilic compounds and the various amount of phenolics, in the three stage of ripening of *C. annuum* var. *acuminatum* fruits, influenced the antioxidant activity.

Total ascorbic acid was higher in bell pepper than in tomato fruit grown in controlled hydroponic conditions (Yahia et al. 2001). In bell pepper fruit, the level increased rapidly during its development, reaching a maximum of 136.1 mg/100 g at 51 days from fruit set and then decreased suddenly, reaching a minimum of 65.5 mg/100 g at 64 days. Bell pepper had more putrescine than tomatot. No major changes were observed in spermine and spermidine in bell pepper and in spermidine in tomato fruits. However, putrescine in bell pepper fruit and spermine in tomato fruit increased very early until about 30–38 days and then decreased.

A study of five different coloured bell pepper genotypes grown as hydroponics system showed that concentration of antioxidant components and taste-related properties varied among the pepper cultivars at both the mature and whole coloured ripened stages (Ghasemnezhad et al. 2011). With advanced maturation, total antioxidant activity increased, however some antioxidant components such as ascorbic acid, total phenols decreased. Further, total soluble solid and titratable acidity increased with advanced fruits maturation. The concentration of flavonoids such as quercetin and catechin varied greatly among the pepper

cultivars at the two maturity stages. The richest cultivar in quercetin and catechin content was Zorro with dark violet fruits.

Organic cultivation of sweet bell pepper was found to significantly increase dry matter, vitamin C, total carotenoids, β -carotene, α -carotene, *cis*- β -carotene, total phenolic acids (as well as individual gallic and chlorogenic acids) and flavonoids (quercetin D-glucoside, quercetin and kaempferol) compared with conventionally grown fruits (Hallmann and Rembiałkowska 2012). The bell pepper variety also affected the level of antioxidant compounds in fruits.

Capsinoids analogues of capsaicin, namely capsiate, dihydrocapsiate, and their analogues were found to be devoid of pro-oxidant activity but showed highly significant antioxidant activity in all systems investigated (Rosa et al. 2003). They could protect linoleic acid against free radical attack in simple in-vitro systems, inhibiting both its autoxidation and its iron- or EDTA-mediated oxidation.

Peroxisomes from green and red pepper fruits (*Capsicum annuum* cv. Lamuyo) contained crystalline cores which varied in shape and size, and the presence of chloroplasts and chromoplasts in green and red pepper fruits, respectively (Mateos et al. 2003). Most ROS-related enzymes catalase, superoxide dismutase, xanthine oxidase, glutathione reductase and NADP(+)-dehydrogenases studied had higher specific activity and protein content in green than in red fruits. The total ascorbate content (200–220 mg/100 g FW) was similar in crude extracts from the two types of fruits, but higher in peroxisomes from red peppers. The glutathione concentration was 2-fold greater in green pepper crude extracts than in red fruits, whereas peroxisomes from both tissues showed similar values. The presence in pepper peroxisomes of different antioxidative enzymes and their corresponding metabolites implied that these organelles might be an important pool of antioxidants in fruit cells.

Capsanthin from paprika as well as β -carotene, lutein, and zeaxanthin suppressed hydroperoxide formation (Matsufuji et al. 1998). Capsanthin decomposed more slowly than the other carotenoids, and the radical scavenging effect of capsanthin

was found to last longer. Also, the capsanthin esterified partially and/or totally with fatty acids (mono- and/or diesterified capsanthin), isolated from paprika colour, suppressed oxidation of methyl linoleate in a similar manner as nonesterified capsanthin. Icariside E(5), from ripe fruits of *Capsicum annuum* var. *acuminatum*, neither induced an increase in the intracellular levels of reactive oxygen species nor affected the mitochondria permeability transition, and it did not signal through the vanilloid receptor type 1 (Iorizzi et al. 2001). This compound protected Jurkat cells from apoptosis induced by the oxidative stress mediated by serum withdrawal. These results suggested that icariside E(5) may have antioxidant properties. The ethanol extract of *C. annuum* var. *acuminatum* small, characterized by the major content of total polyphenols, flavonoids, carotenoids and capsaicinoids, showed the highest radical scavenging activity (IC_{50} of 152.9 $\mu\text{g/mL}$) (Tundis et al. 2011). In contrast, *C. annuum* var. *cerasiferum* showed a significant antioxidant activity evaluated by the β -carotene bleaching test (IC_{50} of 3.1 $\mu\text{g/mL}$). Of *C. annuum* green and red paprika and paprika leaves, red paprika showed the highest contents of capsanthin (58.33 mg/100 g dry weight) and L-ascorbic acid (1987.25 mg/100 g dry weight), and main compounds of paprika leaves were lutein, chlorophyll, and γ -tocopherol (96.91, 2136.71, and 723.49 mg/100 g dry weight, respectively) (Kim et al. 2011). Red paprika showed the strongest antioxidant activity (IC_{50} =55.23 $\mu\text{g/mL}$ in an ABTS assay and 150.40 $\mu\text{g/mL}$ in a DPPH assay), and the antioxidant activity of paprika leaves was higher than β -carotene but lower than red paprika. Paprika leaves with various phytochemicals such as lutein, chlorophyll, and γ -tocopherol, might be used in nutraceuticals and pharmaceuticals for improving human health.

A new lignan glycoside and a known one, icariside E(5) were isolated from *C. annuum* fruits (Lee et al. 2009). The chemical structure was elucidated as (8R)-isodehydrodiconiferyl alcohol-4'-O-(6"-vanilloyl)- β -D-glucopyranoside named vanilloylicariside E(5). Both lignans exhibited

a strong scavenging effect on DPPH with IC_{50} values of 42.1 μM for icariside E(5) and 4.5 μM for vanilloylicariside E(5).

Five carotenoid compounds were identified in the pickled paprika and after 42 days of storage, total carotenoid content was 2.44 mg/100 g fresh weight (fw) and ascorbic acid content was 50.90 mg/100 g dry weight (dw) (Park et al 2011). ABTS radical-scavenging activity of the pickled paprika was maintained above 70% until 28 days of storage, and then decreased to 47% of the initial activity. pH increased from 2.78 to 3.10 at 14th day and was then maintained until 42 days. Soluble solids increased gradually and colour values including L^* , a^* , and b^* decreased during storage. Hardness also decreased from 6.17 to 1.90 kgf during storage. The overall taste of the pickled paprika was deemed to be good until 28 days of storage indicating that pickled paprika showed a possibility as a new pickled product.

The methanol extract, and its ethyl acetate and n-butanol fractions of *Capsicum annuum* leaves showed good DPPH scavenging effect at 100 $\mu\text{g/mL}$ (Choi et al. 2007). Four compounds were isolated and identified as apigenin (1), vanillic acid (2), uracil (3) and apigenin 7-O- β -D-apiofuranosyl(1 $\rightarrow$ 2)- β -D-glucopyranoside (4). IC_{50} value of compound 2 was 14.7 $\mu\text{g/mL}$, while compounds 1, 3 and 4 had no effect on the DPPH radical.

Antitumour Activity

Capsanthin and related carotenoids isolated from red paprika *Capsicum annuum* fruits displayed potent in-vitro anti-tumour-promoting activity with inhibitory effects on Epstein-Barr virus early antigen (EBV-EA) activation induced by the tumour promoter 12-O-tetradecanoylphorbol-13-acetate (TPA) (Maoka et al. 2001c). Among them, capsanthin diester and capsorbin diester showed strong inhibitory effects. In addition, capsanthin, capsanthin 3'-ester and capsanthin 3,3'-diester, major carotenoids in paprika, exhibited potent anti-tumour-promoting activity in an in-vivo mouse skin two-stage carcinogenesis assay using 7, 12-dimethylbenz[a]anthracene as

an initiator and TPA as a promoter. Macho et al (2003) reported that capsiate and its dihydroderivative derivative, nor-dihydrocapsiate, major capsaicnoids of sweet pepper, were found to exhibit potent chemopreventive activity. Capsiate induced apoptosis in tumoral cells that was preceded by an increase in the production of reactive oxygen species and by a subsequent loss of mitochondria transmembrane potential ($\Delta\psi(m)$). They target a variety of pathways involved in cancer development and inflammation, and may have considerable potential for dietary health benefits as well as for pharmaceutical development.

The hexane, acetone, methanol extracts *Capsicum annuum* var. *angulosum*, Anastasia Red showed relatively higher cytotoxic activity against two human oral tumour cell lines (HSC-2, HSG) than against normal human gingival fibroblasts (HGF), suggesting a tumour-specific cytotoxic activity (Motohashi et al. 2003). The cytotoxic activity of these extracts was enhanced by fractionation. Several fractions reversed the multidrug resistance (MDR) phenotype with L5178 mouse lymphoma T cells, more efficiently than (+/-)-verapamil. The extracts and fractions did not show any detectable anti-human immunodeficiency virus (HIV) or anti-*Helicobacter pylori* activity. In further studies, some fractions of hexane and acetone extracts showed higher cytotoxic activity against three human oral tumor cell lines (squamous cell carcinoma HSC-2, HSC-3, submandibular gland carcinoma HSG) than against three normal human oral cells (gingival fibroblast HGF, pulp cell HPC, periodontal ligament fibroblast HPLF), suggesting a tumour-specific cytotoxic activity (Shirataki et al. 2005). No fractions displayed anti-HIV activity, but some hydrophobic fractions showed higher anti-*H. pylori* activity, urease inhibition activity and MDR reversal activity. The higher MDR activity of these fractions against MDR gene-transfected L5178 mouse lymphoma T cells may possibly be due to their higher content of carotene or polyphenol.

Hydrogen donating activity of *C. annuum* leaves was found to increase with increasing concentration of extract (Kim et al. 2003). Reducing power of the ethyl acetate fraction increased as

the amount of extract increased. In the presence of 900 μg of ethyl acetate fraction, reducing power was significantly higher than control with no extract. Among the various solvent fractions, ethyl acetate fraction showed the strongest scavenging effect on hydrogen peroxide. Nitrite scavenging activity was lower at higher pH and at pH 1.2, 90% scavenging activity was obtained at 500 μg concentration. The methanol extract of *Capsicum annuum* leaves showed significantly strong quinone reductase (QR) inductive activity compared to that of broccoli (Ku and Kang 2010). Two major QR inducers were isolated and identified as lutein and β -carotene. The concentration required to double the specific activity of QR (CD) values of lutein and β -carotene were 87.5 and 10.0 μM , respectively. NADP(H): quinone reductase, glutathione S transferase (GST), and UDP-glucuronosyltransferase are regarded as phase 2 detoxifying enzymes and may protect against chemical carcinogenesis (Benson et al. 1980; Talalay et al. 1988, 1995).

The pretreatment of human myeloid ML-1a cells with capsaicin blocked tumour necrosis factor (TNF)-mediated activation of nuclear transcription factor, NF-kappa B in a dose- and time-dependent manner (Singh et al 1996). Resiniferatoxin, capsaicin analogue was at least eight times as potent as capsaicin in inhibiting NF-kappa B activation. Neither agent by itself activated NF-kappa B or affected the DNA-binding ability of NF-kappa B. Capsaicin also suppressed phorbol ester-mediated NF-kappa B activation. Capsaicin treatment of cells also prevented the degradation of I kappa B alpha, and thus the nuclear translocation of the p65 subunit of NF-kappa B, essential for NF-kappa B activation. TNF-dependent promoter activity of I kappa B alpha, containing NF-kappa B binding sites, was also inhibited by capsaicin. The results indicated that capsaicin and its analogue inhibited NF-kappa B activation, and thus could be used as a potential target for drug development. Surh et al. (2000) found that topical application of tetradecanoylphorbol-13-acetate (TPA) onto dorsal skin of female ICR mice resulted in marked activation of epidermal nuclear factor-kappa B (NF-kappaB) and activator protein 1 (AP-1),

but curcumin and capsaicin, when topically applied prior to TPA, significantly attenuated TPA-induced activation of each transcription factor in mouse skin. Likewise, both compounds inhibited NF-kappaB and AP-1 activation in cultured human promyelocytic leukemia (HL-60) cells stimulated with TPA. Based on these findings, it appeared that curcumin and capsaicin could exert anti-tumour promotional effects through suppression of the tumour promoter-induced activation of transcription factors, NF-kappaB and AP-1. Capsaicin, pungent ingredient in *C. annuum* and its synthetic analog capsazepine blocked TNF α -induced NF κ B activation in a dose-dependent manner with 50% inhibitory concentration (IC₅₀) values of 0.68 and 4.2 μ M, respectively transfected 293/NF κ B-Luc human embryonic kidney cells (Luqman et al. 2011). No significant cytotoxicity was observed at the highest concentrations tested (53.1 μ M for capsazepine and 65.5 μ M for capsaicin). Additionally, these vanilloids inhibited aromatase activity with IC₅₀ values of 13.6 and 8.8 μ M, respectively. Computer-aided molecular docking studies showed docking scores indicative of good binding affinity of these vanilloids with aromatase and NF κ B.

Antiinflammatory Activity

Nordihydrocapsiate from sweet pepper was found to have immunosuppressive activity (Sancho et al. 2002). Capsaicin and nordihydrocapsiate inhibited early and late events in T cell activation, including CD69, CD25 and ICAM-1 cell surface expression, progression to the S phase of the cell cycle and proliferation in response to TCR and CD28 co-engagement. Both inhibited NF-kappaB activation in response to different agents including tumour necrosis factor (TNF)-alpha. Intraperitoneal pre-treatment with nordihydrocapsiate prevented mice from lethal septic shock induced by lipopolysaccharide. In a second model of inflammation nordihydrocapsiate pretreatment greatly reduced the extensive damage in the glandular epithelium observed in the bowel of dextran sulfate sodium (DSS)-treated mice. The results suggested that nordihydrocapsiate targeted specific

pathways involved in inflammation, and may have considerable potential for dietary health benefits as well as for pharmaceutical development.

Oral treatment of mouse with a methanolic *C. annuum* extract significantly reduced the pathophysiological signs of allergic airway disease, including increased inflammatory cell recruitment to the airways, airway hyperresponsiveness, and increased levels of T-helper type 2 cytokines (Jang et al. 2011). Reactive oxygen species were also decreased in cells from bronchoalveolar lavage fluid. Additionally, administration of the extract attenuated ovalbumin-induced increases in nuclear factor- κ B (NF- κ B) in lungs. The results suggested that *C. annuum* extract may be an effective oral treatment for allergic airway inflammation by virtue of its antioxidant activity.

Immunomodulatory Activity

Oral administration of capsicum ethanol extracts and capsaicin enhanced interleukin-2 and interferon-gamma production in cultured murine Peyer's patch cells ex vivo in response to concanavalin A stimulation (Takano et al. 2007). The population of CD3(+) cells in the Peyer's patch cells was significantly reduced while CD19(+) cells increased after oral administration of capsicum extract and capsaicin. Orally administered capsicum extract and capsaicin did not change the T cell subset (CD4(+) and CD8(+)), Th1 (IFN-gamma(+)) and T2 (IL-4(+)) ratio. These findings indicated that capsicum extract and capsaicin modulated T cell-immune responses, and their immunomodulatory effects on murine PP cells were partly due to both transient receptor potential vanilloid 1 (TRPV1)-dependent and -independent pathway.

Hot water-soluble crude polysaccharide (HCAP-0) obtained from the fruits of *Capsicum annuum* showed potent anti-complementary activity (Paik et al. 2003). Further fractionation and purification of HCAP-O yielded HCAP-IIa, HCAPIIIa1, and IIIa2 fractions that had high anti-complementary activities. The HCAP-IIIa1 and IIIa2 consisted of homogeneous polysaccharides. The anti-complementary activities were

unaffected by treatment with polymyxin B, indicating that the modes of complement activation were not due to preexisting lipopolysaccharide. The crossed immuno-electrophoresis showed that both classical and alternative pathways were activated by HCAP-IIIa2.

Antimicrobial Activity

The plain and heated aqueous extracts from fresh *Capsicum annuum*, *Capsicum baccatum*, *Capsicum chinense*, *Capsicum frutescens*, and *Capsicum pubescens* varieties were found to exhibit varying degrees of inhibition against *Bacillus cereus*, *Bacillus subtilis*, *Clostridium sporogenes*, *Clostridium tetani*, and *Streptococcus pyogenes* (Cichewicz and Thorpe 1996). Ethyl acetate, acetone and methanol extracts of *Capsicum annuum* fruit exhibited in-vitro antimicrobial activity against *Klebsiella pneumonia*, *Bacillus megaterium*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Escherichia coli*, *Enterobacter cloaca*, *Corynebacterium xerosis*, *Streptococcus faecalis*, *Kluyveromyces marxianus* and *Rhodotorula rubra* with 7–20 mm inhibition zone by the disc diffusion method (Keskin and Toroglu 2011).

The extract of *Capsicum annuum* bell pepper exhibited antibacterial activity against *Salmonella typhimurium* and *Pseudomonas aeruginosa* inoculated in raw beef meat (Careaga et al. 2003). The minimum inhibitory concentration of the extract to prevent the growth of *S. typhimurium* in minced beef was 1.5 ml/100 g of meat; the addition of 1, 2, 3 and 4% w/w of sodium chloride did not have any additional inhibitory effect on *Salmonella*. In the case of *P. aeruginosa*, a concentration of 0.3 ml of the extract/100 g of meat showed a bacteriostatic effect, while a concentration of 3 ml/100 g of meat showed a bactericidal effect. When 1% w/w of sodium chloride was added to the meat together with the extract, the concentration needed to kill *P. aeruginosa* was reduced. Extracts from *C. annuum* habanero, serrano and pimiento morrón peppers, inhibited growth of *Listeria monocytogenes*, *Staphylococcus aureus*, *Salmonella typhimurium* and *Bacillus cereus* with *Listeria* being the most sensitive and

Salmonella the most resistant. (Dorantes et al. 2000). Of the phenylpropanoids identified capsaicin, dihydrocapsaicin, cinnamic acid, *m*-coumaric acid and *o*-coumaric acid, cinnamic and *m*-coumaric acids were found to contribute to the inhibition of the four bacteria via the chilli extracts. *Capsicum annuum* varieties (10) were found to contain phenylpropanoids, seven of which were identified as L-phenylalanine, *t*-cinnamic acid, *o*-coumaric acid, *m*-coumaric acid, ferulic acid, caffeic acid and capsaicin) all intermediates of the capsaicinoids pathway (Acero-Ortega et al. 2005). Three of the ten extracts exhibited inhibitory activity against *Listeria monocytogenes*. No significant difference were found among the compounds in bacteriostatic action but a significant difference was found between these compounds and the bactericidal action of caffeic acid. Some of the active compounds in *Capsicum* extracts responsible for the antibacterial action had been identified as *t*-cinnamic acid and its derivatives, all intermediate compounds in phenylpropanoids pathway (Dorantes et al. 2008). *Capsicum annuum* oleoresins are generally recognized as safe (GRAS) by the FDA, and so their use as natural antimicrobials in food products is safe.

The methanol extract of red chilli could inhibit cholera toxin production in recently emerged *Vibrio cholerae* O1 El Tor variant strains without affecting their viability (Chatterjee et al. 2010). Further, capsaicin, the active component of red chilli, also drastically inhibited cholera toxin production in *V. cholerae* strains belonging to various serogroups including variants. Capsaicin effectively repressed the transcription of *ctxA*, *tcpA* and *toxT* genes, but not of *toxR* and *toxS* genes. In contrast, capsaicin significantly enhanced the transcription of the *hns* gene, the product of which is known to regulate negatively the transcription of *ctxAB*, *tcpA* and *toxT* genes. These results suggested that capsaicin might act as a potent repressor for cholera toxin production possibly by enhancing the transcription of *hns*.

Three peptide enriched fractions, namely F1, F2 and F3, were obtained chili pepper (*Capsicum annuum*) seed proteins (Diz et al. 2006). The F1 fraction, mainly composed of three peptides

ranging from 6 to 10 kDa, and exhibited strong fungicidal activity against *Candida albicans*, *Saccharomyces cerevisiae* and *Schizosaccharomyces pombe* and also promoted several morphological changes to *C. albicans*, including the formation of pseudohyphae, as revealed by scanning electron micrography. F1 fraction also reduced the glucose stimulated acidification of the medium mediated by H(+)-ATPase of *S. cerevisiae* cells in a dose-dependent manner and caused the permeabilization of yeast plasma membrane. In a separate study, a fraction, named F3, enriched with basic proteins of 6–16 kDa, and four subfractions denominated RP1, RP2, RP3 and RP4 were obtained from chilli pepper seeds (*Capsicum annuum*) (Ribeiro et al. 2007). The F3 fraction, rich in peptides, inhibited the growth of yeasts *Saccharomyces cerevisiae*, *Candida albicans*, *Candida parapsilosis*, *Candida tropicalis*, *Pichia membranifaciens*, *Kluyveromyces marxianus* and *Candida guilliermondii*. The RP3 and RP4 subfractions showed high inhibitory activity against the growth of *S. cerevisiae*. The F3 fraction was also able to inhibit glucose-stimulated acidification of the medium by yeast cells of *S. cerevisiae* and to cause several morphological changes in different yeasts, such as cell wall disorganization, bud formation as well as the formation of pseudohyphae. A 6,000 Da peptide, named CaTI, isolated from *Capsicum annuum* seeds showed potent inhibitory activity against trypsin and chymotrypsin (Ribeiro et al. 2012). CaTI inhibited the growth of *Saccharomyces cerevisiae*, *Kluyveromyces marxianus* and *Candida albicans* and induced cellular agglomeration and the release of cytoplasmic content. No effect on growth was observed in *C. tropicalis* but morphological changes were noted. Scanning electron microscopy showed that *S. cerevisiae*, *K. marxianus* and *C. albicans*, in the presence of CaTI, exhibited morphological alterations, such as the formation of pseudohyphae, cellular aggregates and elongated forms. CaTI also induced the production of nitric oxide and interfered in a dose-dependent manner with glucose-stimulated acidification of the medium mediated by H(+)-ATPase of *S. cerevisiae* cells.

Furostanol saponins capsicoside E–G isolated from *C. annuum* seeds showed higher antimicrobial activity against yeasts than against common fungi (Iorizzi et al. 2002). Data indicated that the anti-yeast activity was related to the combination of the oligosaccharide chain (S1, S2, or S3) with an O-methyl group at R(3) and the presence of a hydroxyl group at the C-2 position. Among the various solvent fractions from the methanol extract of *C. annuum* leaves, ethyl acetate and ethanol fraction exhibited the strongest activity against *Staphylococcus aureus*, *Bacillus cereus* and *Streptococcus mutans* (Kim et al. 2003). *Capsicum annuum* extract and synthetic capsaicinoid derivatives exhibited antibacterial activity against *Streptococcus mutans* (Santos et al. 2012). The minimum inhibitory concentration at which the ethyl acetate extract prevented the growth of *S. mutans* was 2.5 mg/mL; those of the isolated compounds capsaicin and dihydrocapsaicin were 1.25 µg/mL, while synthetic capsaicinoid derivative (N-(4-hydroxyphenylethyl)decamide was 5.0 µg/mL, synthetic capsaicinoid derivatives (E)-N-(4-hydroxy-3-methoxybenzyl)-3,7-dimethylocta-2,6-dienamide; 4-hydroxy-3-methoxy-N-((E)-3,7-dimethylocta-2,6-dienyl)benzamide; and N-(4-hydroxy-3-methoxybenzyl)decamide were 2.5 µg/mL respectively.

Two pungent compounds found in *Capsicum* species (capsaicin and dihydrocapsaicin) were also assayed for their antimicrobial effects. Ca-LTP(1), lipid transfer proteins isolated from *C. annuum* seeds, exhibited antifungal activity against *Colletotrichum lindemuthianum*, and especially against *Candida tropicalis*, causing several morphological changes to the cells including the formation of pseudohyphae (Diz et al. 2011). Ca-LTP(1) also inhibit mammalian α -amylase activity in-vitro. The 9 kDa LTP also inhibited the growth of the fungi, *Fusarium oxysporum*, the yeasts, *Saccharomyces cerevisiae*, *Pichia membranifaciens*, *Candida albicans*, and inhibited glucose-stimulated acidification of the medium by yeast cells of *S. cerevisiae* and caused several morphological changes in *P. membranifaciens* (Cruz et al. 2010).

Gastroprotective Activity

Capsaicin was found to specifically inhibit growth of *Helicobacter pylori* dose-dependently at concentrations greater than 10 µg/mL but did not inhibit the growth of a human fecal commensal *Escherichia coli* strain indicating that ingestion of chilli a protective effect against *H. pylori*-associated gastroduodenal disease (Jones et al. 1997). Lee et al (2007a) demonstrated that nontoxic dose of capsaicin inhibited *Helicobacter pylori*-induced interleukin-8 production by gastric epithelial cells through the modulation of IkappaB-, NF-kappaB-, and interleukin-8 pathways. They suggested that capsaicin could be proposed as a potential antiinflammatory drug by inhibition of the production of pro-inflammatory cytokine interleukin-8 in *H. pylori*-infected gastric epithelium.

Chilli Consumption and Gastric Cancer

López-Carrillo et al. (2003) conducted a hospital-based case-control study in three areas of Mexico from 1994 to 1996 to ascertain the association of capsaicin consumption, *Helicobacter pylori* positivity and gastric cancer. Two hundred thirty-four cases of gastric cancer and 468 matched controls were enrolled and their diet and other characteristics were investigated. The risk of gastric cancer was increased among high-level consumers of capsaicin (90–250 mg of capsaicin per day, approximately 9–25 jalapeño peppers per day) as compared to low-level consumers (0–29.9 mg of capsaicin per day, approximately 0 to less than 3 jalapeño peppers per day); this effect was independent of *Helicobacter pylori* status and other potential gastric cancer determinants and was higher among diffuse gastric cancer cases compared to intestinal gastric cancer cases. They found no significant interaction between capsaicin ingestion and *Helicobacter pylori* on gastric cancer risk. Chili pepper consumption might be an independent determinant of gastric cancer in Mexico. The known capsidiol from sweet pepper fruit showed bacteriostatic properties in-vitro against *Helicobacter pylori* with a minimum

inhibitory concentration (MIC) of 200 µg/mL when compared with the commercial drug metronidazole (MIC, 250 µg/mL) (De Marino et al. 2006).

Dömötör et al. (2007) found that capsaicin-sensitive afferent nerves (CSANs) were involved in the protection of gastric mucosa. In a study of 21 *Helicobacter pylori*-positive and 30 *H. Helicobacter pylori*-negative patients with chronic gastritis and 20 patients with functional dyspepsia (as histologically healthy controls). The expression of capsaicin receptor, calcitonin gene-related peptide (CGRP), and substance P (SP) was significantly higher in the mucosa of patients with chronic gastritis than in controls, however, no significant difference was obtained in the immunodistribution in patients with *H. pylori*-negative versus *H. pylori*-positive gastritis. They concluded that CSANs participated in the development of human gastritis, however, their participation did not depend on the presence of *Helicobacter pylori* as a causative factor.

Hypocholesterolemic/Hypolipidemic Activity

Incorporation of carotenoids β-carotene (C1), acyl derivatives of capsanthin (C2), and acyl derivatives of capsorubin (C3) isolated from red paprika (*Capsicum annum*) oleoresin into human plasma low density lipoproteins (LDL)s changed the LDL flotation coefficient distribution for LDL fraction (Medvedeva et al. 2003). Carotenoids C1, C2, and C3 efficiently suppressed the oxidation of LDL, inhibited the formation of conjugated dienes from polyunsaturated fatty acid residues, lowered the content of small dense LDL subfraction, and inhibited the transformation of cholesterol to auto oxidized products (in particular to 5,6-epoxycholesterol, 7-ketocholesterol and 7 β-hydroxycholesterol). The data suggested that the main carotenoids may effectively inhibit LDL oxidation in-vitro with probable lowering the “atherogenic” LDL subfraction production in-vivo.

Administration of purified capsanthin, the main carotenoid in paprika (*Capsicum annum*),

to male Wistar rats for 2 weeks resulted in a significant increase in plasma HDL-cholesterol without detectable differences in plasma total cholesterol and TAG concentrations (Aizawa and Inakuma 2009). A statistically significant correlation was found between dietary capsanthin concentrations and plasma HDL-cholesterol concentrations. Capsanthin administration resulted in up-regulation of mRNA for apoA5 and lecithin cholesterol acyltransferase (LCAT). These results suggested that capsanthin had an HDL-cholesterol-raising effect on plasma, and the potential to increase cholesterol efflux to HDL particles by increasing apoA5 levels and/or enhancement of LCAT activity.

Weight Loss/Antiobesity Activity

Ohnuki et al. (2001) showed that administration of capsaicin or capsiate (from non-pungent CH-19 Sweet pepper) to mice for 2 weeks increased oxygen consumption and serum adrenalin concentration. Both capsaicin and capsiate significantly suppressed body fat accumulation. Masuda et al. (2003) reported that 2-week treatment of capsiate increased metabolic rate and promoted fat oxidation at rest, suggesting that capsiate may prevent obesity. Two-week treatment of capsiate increased the levels of uncoupling protein 1 (UCP1) protein and mRNA in brown adipose tissue and UCP2 mRNA in white adipose tissue. This dose of capsiate did not change serum triiodothyronine or thyroxine levels. These results suggested that UCP1 and UCP2 may contribute to the promotion of energy metabolism by capsiate, but that thyroid hormones did not. Kawabata et al. (2006) found that repeated intake of (*C. annuum*) CH-19 Sweet reduced the body weight and suppressed body fat accumulation. the body weight loss due to the repeated intake of CH-19 Sweet was significantly correlated with the sympathetic nervous response after its ingestion. They proposed that the repeated intake of CH-19 Sweet reduced the body weight and suppressed body fat accumulation by sympathetic nervous activation in humans. In another study they found that capsinoids increased energy

expenditure in wild-type mice, but not in transient receptor potential vanilloid 1 (TRPV1) knockout mice, implying that capsinoids increased energy expenditure and enhanced thermogenesis via gastrointestinal TRPV1 (Kawabata et al. 2009). Although the jejunal administration of capsinoids did not raise the tail skin temperature, an intravenous injection of capsinoids did, indicating that capsinoids could barely pass through the intestinal wall into the blood. In further studies they demonstrated that oxygen consumption was increased in mice administered with capsinoids but not in dietary-restricted mice, although there was a similar suppression of body fat accumulation in both groups (Haramizu et al. 2011a). The weight rebound was more notable in the dietary-restricted mice than in the mice administered with capsinoids. Their results indicated that suppressing body fat accumulation by capsinoids was more beneficial than a restricted diet for maintaining body weight. In another recent study, Haramizu et al. (2011b) found that that 2 weeks treatment of capsiate and exercise increased energy metabolism and suppressed body fat accumulation during four more weeks of ad libitum feeding. The body weight in capsiate and exercise groups was significantly lower than that of control group. The oxygen consumption was significantly enhanced in capsiate and exercise groups than in the control mice. Further, the abdominal adipose tissue weight in capsiate and exercise groups was significantly lower than that of control group. The results indicated that suppressing body fat accumulation by capsiate intake was beneficial for maintaining an ideal body weight as exercise.

In a 12-week, placebo-controlled, double-blind, randomized involving 40 women and 40 men with a mean age of 42 years and body mass index of 30.4, treatment with 6 mg/day capsinoids orally appeared to be safe and was associated with abdominal fat loss (Snitker et al. 2009). Capsinoid ingestion was associated with an increase in fat oxidation that was nearly significant. CH-19 Sweet (*C. annuum*) fruits were found to contain three analogs (capsinoids) namely capsiate, dihydrocapsiate, and nordihydrocapsiate of capsaicin, a major component of pungency of hot peppers

(Sasahara et al. 2010). The three capsinoids bound to transient potential vanilloid 1 (TRPV1) receptors expressed in cultured cells and activated Ca(2+) influx in a concentration-dependent manner with similar magnitudes. In contrast to capsaicin, capsinoids at the same concentration induced virtually no nociceptive responses when applied to the eyes or the oral cavities of mice. Intravenous administration of capsaicin or 20-fold increased doses of each capsinoid to rats induced significant increases in plasma catecholamine levels. Orally administered, each capsinoid enhanced oxygen consumption in mice. Based on the results, capsaicin and these three capsinoids should have similar bio-potency, though capsinoids do not generate pungency or sensory irritation.

In a single-blind, randomized, placebo-controlled, crossover design of 18 healthy men aged 20–32 years, capsinoid ingestion was found to increase energy expenditure through the activation of brown adipose tissue (thermogenesis) in humans (Yoneshiro et al. 2012). Placebo ingestion produced no significant change in energy expenditure. Neither capsinoids nor placebo changed the skin temperature in various regions, including regions close to brown adipose tissue deposits.

Hypoglycaemic/Antidiabetic Activity

The mature, green-stage fruits of hot pepper fruits (*Capsicum annuum* var. *acuminatum*) had the highest in-vitro activity against alpha-amylase and alpha-glucosidase with 50% inhibitory concentration (IC₅₀) values of 55.88 and 76.11 µg/mL, respectively (Loizzo et al. 2008). An aqueous extract combination (1:1:1) of three pepper varieties *Capsicum annuum* var. *grossum*, *C. annuum* var. *abbreviatum*, and *C. annuum* var. *acuminatum* exhibited an additive effect in the inhibition of pancreatic α-amylase activity but was antagonistic in α-glucosidase inhibitory activity (Oboh et al. 2011). *C. annuum* var. *acuminatum* contributed most to the activities of the combined peppers. The pepper combination also showed additive effects in their phenolic content and

displayed antioxidant properties. Strong inhibitory activities of the peppers against key enzymes linked to type 2 diabetes and Fe²⁺-induced lipid peroxidation in rat pancreas in-vitro, coupled with their antioxidant properties, suggested that the peppers could be used in the prevention and management of type 2 diabetes.

The lipophilic fraction of both *C. annuum* var. *acuminatum* and *C. annuum* var. *cerasiferum* exhibited an interesting and selective inhibitory activity against α-amylase (IC₅₀ of 6.9 and 20.1 µg/mL, respectively) (Tundis et al. 2011).

Cercaricidal Activity

Extracts of the leaves and fruits of *C. annuum* showed a profound effect on the cercaria of *Schistosoma mansoni* (Frischkorn et al. 1978). Ninety to ninety-six percent of the cercaria of *Schistosoma mansoni* were killed within 15 min by *C. annuum* oil.

Antimutagenic Activity

In antimutagenicity studies using *Salmonella typhimurium* tester strain YG1024, extracts from five different types of *Capsicum annuum* ('Chilaca', 'Poblano', 'Serrano', 'Jalapeño' and 'Pimiento') exhibited greater inhibition than pure *trans*-β-carotene on 1-nitropyrene (1-NP), 1,6-dinitropyrene (1,6-DNP) and 1,8-dinitropyrene (1,8-DNP) mutagenicity (González de Mejía et al. 1998). Chilaca pepper extract required 0.36 g (34 nmol expressed as *trans*-β-carotene equivalents) of fresh pepper to inhibit 94% on 1-NP mutagenicity, 78% on 1,6-DNP mutagenicity and 84% on 1,8-DNP mutagenicity. Bell pepper ('Pimiento') extract required 1.53 g (50 nmol expressed as *trans*-β-carotene) to obtain 87, 79 and 73% inhibition on 1-NP; 1,6-DNP and 1,8-DNP mutagenicity respectively. Since pure beta-carotene inhibited only approximately 50% the mutagenicity of nitroarenes, the results suggested that each one of the pepper extracts had more than one antimutagenic compound (e.g., β-carotene and xanthophylls) and those functional

nutrients apparently had a synergistic effect. In another study, using the wing Somatic Mutation And Recombination Test (SMART) in *Drosophila melanogaster*, bell pepper was found to be effective in reducing the mutational events induced by the alkylating agent methyl methanesulfonate (MMS) and the promutagen agent ethyl carbamate (EC) (El Hamss et al. 2003). Pre-treatment of 2-day-old larvae with bell pepper for 24 h followed by a treatment with EC and MMS was only effective in reducing mutations induced by EC. Suppression of metabolic activation or interaction with the active groups of mutagens was postulated to be mechanisms by which bell pepper exerted its antimutagenic action.

Miscellaneous Pharmacological Activities

C. annuum var. *acuminatum* in the prematurity green stage exhibited the highest in-vitro acetylcholinesterase inhibition property ($IC_{50} = 84.30 \mu\text{g/mL}$), using the Ellman method (Loizzo et al. 2008).

Ethyl acetate fraction from the methanol extract of *C. annuum* leaves also showed strongest anti-tyrosinase activity (Kim et al. 2003).

Toxicological Studies

In a 4-week feeding study of ground red chilli (*Capsicum annuum*) in male B6C3F1 mice, general health, body weight and food intake were apparently not adversely affected at any level of pepper (0.5–10% by weight) consumption (Jang et al. 1992). Histopathological evaluation revealed slight glycogen depletion and anisocytosis of hepatocytes in the 10% group. The authors concluded that red chilli was relatively non-toxic at the doses tested in male B6C3F1 mice. A 13-week subchronic toxicity study was performed in F344 rats found that paprika color even at 5% in the diet (0.67 g/rat/day or 2948.4 mg/kg bw/day for male rats and 0.43 g/rat/day or 3197.4 mg/kg bw/day for female rats) did not cause marked adverse effects nor deaths in F344 rats (Kanki et al. 2003). Thus, the no-observed-adverse-effect level

(NOAEL) and the maximum dose level for carcinogenicity testing of paprika colour were established to be 5% in the diet. In another 52-week toxicity study cum 104-week carcinogenicity study in F344 rats, based on slight histopathological changes observed in 5% male livers, the NOEL was estimated to be 2.5% in the diet (1,253 mg/kg bw/day) and the NOAEL was determined to be 5% in the diet (2,388 mg/kg bw/day) for male rats, and for females (Inoue et al. 2008). Additionally, paprika colour did not induce specific tumours nor did it exert significant influence on the development of spontaneous tumours in any of the organs examined in the carcinogenicity study indicating it to be not carcinogenic under the experimental conditions.

Capsinoids are found in almost all pungent peppers and are abundant in the sweet pepper cultivar CH-19 Sweet (Watanabe et al. 2011). They have been deemed as the most promising compounds among all known transient receptor potential vanilloid 1 agonists. They share similar physiological activities as capsaicin, the pungent principle of hot red peppers but appear to be much safer to use as a therapeutic compound (Watanabe et al. 2011).

A 26-week daily gavage dosing toxicity study of CH-19 Sweet extract in rats found that the no observed adverse effect level (NOAEL) for CH-19 Sweet extract in the rat liver rat was 2.5 ml/kg/day in males and 5.0 ml/kg/day in females (178.13–182.88 and 356.25–365.75 mg/kg as capsinoids, respectively) (Kodama et al. 2008). No test substance-related changes were detected in clinical signs, body weight, food consumption, water intake, ophthalmology, or urinalysis. No adverse test article-related changes were observed in low- or mid-dose males or in females at any dose.

A single-dose oral toxicity lethal-dose study of capsinoids contained in CH-19 Sweet extract in rats found the toxicity of CH-19 Sweet to be low with only transient salivation or decreased spontaneous movement was observed on the day of administration at $>$ or $=$ 10 ml/kg BW equivalent to 712.5 mg/kg bw capsinoids (Watanabe, et al. 2008). It was concluded that the lethal dose of CH-19 Sweet extract was estimated to be

higher than 20 ml/kg (1,425 mg/kg as capsinoids) for both males and females since no deaths were observed at any dose in this study. Treatment with CH-19 Sweet extract did not increase the number of revertant colonies in *Salmonella typhimurium* and *Escherichia coli* compared with negative controls either in the presence (+S9) or absence (–S9) of metabolic activation. Treatment with CH-19 Sweet extract failed to induce chromosome aberrations in Chinese hamster lung cultured cells. In an in-vivo micronucleus test using BDF(1) male mice, CH-19 Sweet extract failed to increase the incidence of micronucleated polychromatic erythrocytes (MNPCEs) or decrease the ratio of polychromatic erythrocytes (PCEs) in any of the treatment groups. These results suggested the absence of mutagenicity as well as in-vitro and in-vivo clastogenicity of capsinoids contained in CH-19 Sweet extract.

Studies found that the capsinoid, dihydrocapsiate (4-hydroxy-3-methoxybenzyl 8-methylnonanoate) had a low or extremely low likelihood of inducing genotoxicity (Bernard et al. 2008). In-vitro tests (bacterial reverse mutation test and chromosomal aberration test) of the compound produced positive results in the absence of metabolic activation, but negative results in the presence of metabolic activation. The in-vivo gene mutation assay (with transgenic rats) produced negative results, as did the in-vivo mouse micronucleus assay, which failed to induce micronucleated polychromatic erythrocytes.

Bioavailability Studies

The bioavailability of carotenoids from paprika oleoresin, including zeaxanthin, β -cryptoxanthin, β -carotene and the paprika-specific oxocarotenoids capsanthin and capsorubin in humans was investigated by Pérez-Gálvez et al. (2003). After overnight fasting, the volunteers (n 9) ingested a single dose of the paprika oleoresin containing 6.4 mg zeaxanthin, 4.2 mg β -cryptoxanthin, 6.2 mg β -carotene, 35.0 mg capsanthin and 2.0 mg capsorubin. From the major carotenoids present in the paprika oleoresin only zeaxanthin, β -cryptoxanthin and β -carotene were

detectable in considerable amounts. Although the xanthophylls in paprika oleoresin were mainly present as mono- or di-esters, only free zeaxanthin and β -cryptoxanthin were found in human samples. The bioavailability of the pepper-specific carotenoids capsanthin and capsorubin from paprika oleoresin was very low. However, oleoresin appeared to be a suitable source for the provitamin A carotenoids β -carotene and β -cryptoxanthin and the macular pigment zeaxanthin.

Using an in-vitro gastrointestinal model, Hervert-Hernández et al. (2010) found that hot dried peppers at ripe stage had a high content of bioactive compounds that exhibited significant antioxidant properties (26–80 μ mol trolox equivalents/g of dry matter), such as polyphenols (>2,000 mg/100 g of dry matter) and carotenoids (95–437 mg/100 g of dry matter), which were partially bioaccessible. The amount released from the food matrix by the action of digestive enzymes was about 75% for total polyphenols, up to 49% for both β -carotene and zeaxanthin, and up to 41% for β -cryptoxanthin. The results suggested that from 50 to 80% of these carotenoids could reach the colon to be potentially fermented or could remain unavailable.

O'Sullivan et al. (2010) reported that the order of total carotenoid content in peppers and their respective micelles was red>green>yellow. In terms of cellular carotenoid transport as a percentage of original food and micelle content, the order was yellow peppers>green>red; however, the opposite trend was seen for the actual amount of total carotenoids transported by Caco-2 cells. Although lutein was generally the most abundant carotenoid in the micelles (496.3–1565.7 μ g/100 g), cellular uptake and transport of β -carotene were the highest, 8.3–31.6 and 16.8–42.7%, respectively. Hence, the actual amount of carotenoids present in the original food and respective micelles appeared to reflect the amount transported by Caco-2 cells.

Allergy and Drug Bioavailability Problem

A 27-year-old subject who developed rhinitis and asthma symptoms 1 year after starting to prepare

a certain kind of sausage developed a positive immediate skin prick test (SPT) for paprika (dry powder of *Capsicum annuum*), coriander (*Coriandrum sativum*), and mace (shell of nutmeg, *Myristica fragrans*) at a concentration of 10% (w/v) (Sastre et al. 1996). A partial cross-reactivity was found among IgE-binding components from paprika and mace. Specific bronchial inhalation challenges showed an immediate asthmatic reaction to extracts from paprika, coriander, and mace. The tests demonstrate that inhalation of dust from paprika, coriander, and mace can result in an IgE-mediated reaction to botanically unrelated spices. Profilin was detected in bell pepper extracts by an anti-celery profilin antibody. It showed high IgE binding activity in all extracts, which could be inhibited by recombinant birch pollen profiling (Jensen-Jarolim et al. 1998). A homologue of the major birch pollen allergen Bet v 1 was detected in four of eight horticultural strains of bell peppers, and was shown to bind IgE in 1 of the 11 patients. The presence of profilin in all and Bet v 1 in 50% of the tested horticultural bell pepper strains indicated that bell peppers have to be considered potentially dangerous for Bet v 1- and profilin-sensitized patients.

Studies in rats showed that ingestion chilli pepper (*Capsicum annuum*) reduced salicylate bioavailability after oral aspirin administration (Cruz et al. 1999). With a single administration of 300 mg/kg of the *Capsicum annuum* extract, aspirin blood levels were undetectable while salicylic acid bioavailability was reduced in 59%. Chronic administration once daily for 4 weeks of 100 and 300 mg/kg of the extract resulted in undetectable aspirin blood levels, while salicylic acid bioavailability was reduced in 63 and 76%, respectively, compared with controls.

Traditional Medicinal Uses

Various parts of *Capsicum annuum* have been used in traditional medicine (Burkill 1966; Chiej 1984; Bown 1995; Cho et al. 2009). The fruit is regarded to be antihæmorrhoidal, antiseptic, diaphoretic, digestive, irritant, rubefacient, sialagogue, antirheumatic, and tonic. It is ingested

internally for the treatment of the cold stage of fevers, debility during convalescence or old age, for asthma, varicose veins and stomach upsets. Externally, it is used as a therapy for sprains, unbroken chilblains, neuralgia, pleurisy. In Korean traditional medicine, the fruit of the red pepper (namcho) is used to warm body coldness, to activate the stomach function, to smooth blocked internal organs, and is used to treat stomach-aches, emesis, dysentery, chilblain, and scabies. The stem is called nalchogyung and is used to treat rheumatic psychroalgia. The root, called nalchodoo, is used to treat asthenia of the limbs. The leaves are also used to treat emesis, dysentery, and scabies. In Peninsular Malaysia, the root has been recorded as a decoction for treating gonorrhoea.

Other Uses

Some *C. annuum* cultivars are grown as ornamentals especially those displaying fruit in four or five colours on the same plant at the same time and those with unusual fruit shapes or for their dense foliage and bright colourful fruits and for their bright red fruits used as decorations during the festive season such as Christmas. The fruits and shoots with fruits dried or fresh are used as wreaths, house decorations and floral arrangements. In New Mexico, mature bright red chillies are hung in colourful strings (ristras) used as symbol of hospitality.

Paprika and paprika oleoresin besides being used in a wide assortment of foods, drugs, and cosmetics, are also employed for improving the feather colour of flamingos in zoos or koi fish in aquariums. Chilli pepper extracts and oleoresin are used in production of self-defence and less than-lethal (LTL) weaponry.

Chilli pepper extracts have antibacterial property. Growth of the phytopathogenic *Erwinia carotovora* subsp. *carotovora* was inhibited by extracts of *C. annuum* habanero, bell pepper and bell pepper and its bioactive ingredients *meta*-coumaric acid and *trans*-cinnamic acid but capsaicin and dihydrocapsaicin did not (Acero et al. 2003).

Comments

Refer also to notes in *Capsicum baccatum*, *C. chinense* and *C. frutescens*.

Selected References

- Acero C, Dorantes AL, Jaramillo ME, Hernandez-Sanchez H, Lopez-Malo A (2003) Effect of chili (*Capsicum* sp.) extracts on the growth of *Erwinia carotovora*. *Revista Mexicana de Fitopatología* 21:233–237
- Acero-Ortega C, Dorantes-Alvarez L, Hernández-Sánchez H, Gutiérrez-López G, Aparico G, Jaramillo-Flores ME (2005) Evaluation of phenylpropanoids in ten *Capsicum annum* L. varieties and their inhibitory effects on *Listeria monocytogenes* Murray, Webb and Swann Scott A. *Food Sci Technol Int* 11(1):5–10
- Aizawa K, Inakuma T (2009) Dietary capsanthin, the main carotenoid in paprika (*Capsicum annum*), alters plasma high-density lipoprotein-cholesterol levels and hepatic gene expression in rats. *Br J Nutr* 102(12):1760–1766
- Al Othman ZA, Ahmed YB, Habila MA, Ghafar AA (2011) Determination of capsaicin and dihydrocapsaicin in *Capsicum* fruit samples using high performance liquid chromatography. *Molecules* 16(10):8919–8929
- Anonymous (2007) Final report on the safety assessment of *Capsicum annum* extract, *Capsicum annum* fruit extract, *Capsicum annum* resin, *Capsicum annum* fruit powder, *Capsicum frutescens* fruit, *Capsicum frutescens* fruit extract, *Capsicum frutescens* resin, and capsaicin. *Int J Toxicol* 26(Suppl 1):3–106
- Antonious GF, Jarret RL (2006) Screening *Capsicum* accessions for capsaicinoids content. *J Environ Sci Health B* 41(5):717–729
- Antonious GF, Kochhar TS, Jarret RL, Snyder JC (2006) Antioxidants in hot pepper: variation among accessions. *J Environ Sci Health B* 41(7):1237–1243
- Barbero GF, Palma M, Barroso CG (2006) Pressurized liquid extraction of capsaicinoids from peppers. *J Agric Food Chem* 54(9):3231–3236
- Benson AM, Hunkeler MJ, Talalay P (1980) Increase of NAD(P)H: quinone reductase by dietary antioxidants: possible role in protection against carcinogenesis and toxicity. *Proc Natl Acad Sci USA* 77:5216–5220
- Bernard BK, Watanabe E, Kodama T, Tsubuku S, Otabe A, Nakajima M, Masumori S, Shimada S, Tanaka J, Masuyama T (2008) Studies of the toxicological potential of capsinoids: V. Genotoxicity studies of dihydrocapsiate. *Int J Toxicol* 27(Suppl 3):59–72
- Bosland PW (1996) Capsicums: innovative uses of an ancient crop. In: Janick J (ed) *Progress in new crops*. ASHS Press, Arlington, pp 479–487
- Bosland PW, Bailey AL, Iglesias-Olivas J (1988) *Capsicum* pepper varieties and classification. New Mexico State Univ. Ext. Cir. 530, New Mexico State University, Albuquerque
- Bown D (1995) *Encyclopaedia of herbs and their uses*. Dorling Kindersley, London, p 424
- Burkill IH (1966) *A dictionary of the economic products of the Malay Peninsula*, Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Buttery RG, Seifert RM, Guadagni DG, Ling LC (1969) Characterization of some volatile constituents of bell peppers. *J Agric Food Chem* 17:1322–1327
- Careaga M, Fernández E, Dorantes L, Mota L, Jaramillo ME, Hernandez-Sanchez H (2003) Antibacterial activity of *Capsicum* extract against *Salmonella typhimurium* and *Pseudomonas aeruginosa* inoculated in raw beef meat. *Int J Food Microbiol* 83(3):331–335
- Chatterjee S, Asakura M, Chowdhury N, Neogi SB, Sugimoto N, Haldar S, Awasthi SP, Hinenoya A, Aoki S, Yamasaki S (2010) Capsaicin, a potential inhibitor of cholera toxin production in *Vibrio cholerae*. *FEMS Microbiol Lett* 306(1):54–60
- Chen CY, Yeh YT, Yang WL (2011) Amides from the stem of *Capsicum annum*. *Nat Prod Commun* 6(2):227–229
- Chiej R (1984) *Encyclopaedia of medicinal plants*. MacDonald, London, p 447
- Cho JG, Lee DY, Lee JW, Lee DG, Lee YH, Kim SY, Kim SH, Baek NI (2009) Acyclic diterpenoids from the leaves of *Capsicum annum*. *J Korean Soc Appl Biol Chem* 52(2):128–132
- Choi JG, Hur JM, Cho HW, Park JC (2007) Phenolic compounds from *Capsicum annum* leaves showing radical scavenging effect. *Korean J Pharmacogn* 38:258–262
- Cichewicz RH, Thorpe PA (1996) The antimicrobial properties of chile peppers (*Capsicum* species) and their uses in Mayan medicine. *J Ethnopharmacol* 52(2):61–70
- Conforti F, Statti GA, Menichini F (2007) Chemical and biological variability of hot pepper fruits (*Capsicum annum* var. *acuminatum* L.) in relation to maturity. *Food Chem* 102(4):1096–1104
- Cremer DR, Eichner K (2000) Formation of volatile compounds during heating of spice paprika (*Capsicum annum*) powder. *J Agric Food Chem* 48(6):2454–2460
- Cruz L, Castañeda-Hernández G, Navarrete A (1999) Ingestion of chilli pepper (*Capsicum annum*) reduces salicylate bioavailability after oral aspirin administration in the rat. *Can J Physiol Pharmacol* 77(6):441–446
- Cruz LP, Ribeiro SF, Carvalho AO, Vasconcelos IM, Rodrigues R, Da Cunha M, Gomes VM (2010) Isolation and partial characterization of a novel lipid transfer protein (LTP) and antifungal activity of peptides from chilli pepper seeds. *Protein Pept Lett* 17(3):311–318
- de Azevedo-Meleiro CH, Rodriguez-Amaya DB (2009) Qualitative and quantitative differences in the carotenoid composition of yellow and red peppers determined by HPLC-DAD-MS. *J Sep Sci* 32(21):3652–3658
- De Marino S, Borbone N, Gala F, Zollo F, Fico G, Pagiotti R, Iorizzi M (2006) New constituents of sweet *Capsicum annum* L. fruits and evaluation of their biological activity. *J Agric Food Chem* 54(20):7508–7516

- Deli J, Tóth G (1997) Carotenoid composition of the fruits of *Capsicum annuum* Cv. Bovet 4 during ripening. *Z Lebensm Unters Forsch A* 205:388–391
- Deli J, Molnár P, Matus Z, Tóth G (2001a) Carotenoid composition in the fruits of red paprika (*Capsicum annuum* var. *lycopersiciforme rubrum*) during ripening; biosynthesis of carotenoids in red paprika. *J Agric Food Chem* 49(3):1517–1523
- Deli J, Molnár P, Matus Z, Tóth G, Trabe B, Pfander H (2001b) Prenigroxanthin' [(all-E,3R,3'S,6'S)- β , γ -carotene-3,3',6'-triol], a novel carotenoid from red paprika (*Capsicum annuum*). *Tetrahedron Lett* 42(7):1395–1397
- Diz MS, Carvalho AO, Rodrigues R, Neves-Ferreira AG, Da Cunha M, Alves EW, Okorokova-Façanha AL, Oliveira MA, Perales J, Machado OL, Gomes VM (2006) Antimicrobial peptides from chili pepper seeds causes yeast plasma membrane permeabilization and inhibits the acidification of the medium by yeast cells. *Biochim Biophys Acta* 1760(9):1323–1332
- Diz MS, Carvalho AO, Ribeiro SF, Da Cunha M, Beltramini L, Rodrigues R, Nascimento VV, Machado OL, Gomes VM (2011) Characterisation, immunolocalisation and antifungal activity of a lipid transfer protein from chili pepper (*Capsicum annuum*) seeds with novel α -amylase inhibitory properties. *Physiol Plant* 142(3):233–246
- Dömötör A, Kereskay L, Szekeres G, Hunyady B, Szolcsányi J, Mózsik G (2007) Participation of capsaicin-sensitive afferent nerves in the gastric mucosa of patients with *Helicobacter pylori*-positive or-negative chronic gastritis. *Dig Dis Sci* 52(2):411–417
- Dorantes L, Colmenero R, Hernandez H, Mota L, Jaramillo ME, Fernandez E, Solano C (2000) Inhibition of growth of some foodborne pathogenic bacteria by *Capsicum annum* extracts. *Int J Food Microbiol* 57(1–2):125–128
- Dorantes L, Aroujo J, Carmona A, Hernandez-Sanchez H (2008) Effect of capsicum extracts and cinnamic acid on the growth of some bacteria important in dairy products. In: Gutierrez-Lopez GF, Welti-Chanes J, Parada-Arias E (eds) Food engineering integrated approaches. Springer, New York, pp 337–344
- Eggink PM, Maliepaard C, Tikunov Y, Haanstra JPW, Bovy AG, Visser RGF (2012) A taste of sweet pepper: volatile and non-volatile chemical composition of fresh sweet pepper (*Capsicum annuum*) in relation to sensory evaluation of taste. *Food Chem* 132(1):301–310
- El Hamss R, Idaomar M, Alonso-Moraga A, Muñoz Serrano A (2003) Antimutagenic properties of bell and black peppers. *Food Chem Toxicol* 41(1):41–47
- Embaby HE-S, Mokhtar SM (2011) Chemical composition and nutritive value of lantana and sweet pepper seeds and nabak seed kernels. *J Food Sci* 76(5):C736–C741
- Eshbaugh WH (1980) The taxonomy of the genus *Capsicum* (Solanaceae). *Phytologia* 47(3):153–165
- Estrada B, Bernal MA, Díaz J, Pomar F, Merino F (2002) Capsaicinoids in vegetative organs of *Capsicum annuum* L. in relation to fruiting. *J Agric Food Chem* 50(5):1188–1191
- Facciola S (1990) Cornucopia. A source book of edible plants. Kampong Publ., Vista, p 677
- Forero MD, Quijano CE, Pino JA (2009) Volatile compounds of chile pepper (*Capsicum annuum* L. var. *glabriusculum*) at two ripening stages. *Flavour Fragr J* 24:25–30
- Frischkorn CG, Frischkorn HE, Carrazzoni E (1978) Cercaricidal activity of some essential oils of plants from Brazil. *Naturwissenschaften* 65(9):480–483
- Ghasemnezhad M, Sherafati M, Payvas GA (2011) Variation in phenolic compounds, ascorbic acid and antioxidant activity of five coloured bell pepper (*Capsicum annum*) fruits at two different harvest times. *J Func Food* 3(1):44–49
- Gnayfeed MH, Daood HG, Illés V, Biacs PA (2001) Supercritical CO(2) and subcritical propane extraction of pungent paprika and quantification of carotenoids, tocopherols, and capsaicinoids. *J Agric Food Chem* 49(6):2761–2766
- González de Mejía E, Quintanar-Hernández A, Loarca-Piña G (1998) Antimutagenic activity of carotenoids in green peppers against some nitroarenes. *Mutat Res* 416(1–2):11–19
- Gutsu EV, Kintya PK (1989) Steroid glycosides of the roots of *Capsicum annuum*. IV. Structure of capsicosides C2 and C3. *Chem Nat Comp* 25(4):500–501
- Gutsu EV, Kintya PK, Shvets SA, Lazur'evskii GV (1986) Steroid glycosides of the roots of *Capsicum annuum*. I. The structure of capsicosides A1, B1, and C1. *Chem Nat Comp* 22(6):661–664
- Gutsu EV, Kintya PK, Lazur'evskii GV (1987) Steroid glycosides of the roots of *Capsicum annuum*. II. The structure of the capsicosides. *Chem Nat Comp* 23(2):202–205
- Hallmann E, Rembialkowska E (2012) Characterisation of antioxidant compounds in sweet bell pepper (*Capsicum annuum* L.) under organic and conventional growing systems. *J Sci Food Agric*. doi:10.1002/jsfa.5624
- Haramizu S, Kawabata F, Masuda Y, Ohnuki K, Watanabe T, Yazawa S, Fushiki T (2011a) Capsinoids, non-pungent capsaicin analogs, reduce body fat accumulation without weight rebound unlike dietary restriction in mice. *Biosci Biotechnol Biochem* 75(1):95–99
- Haramizu S, Kawabata F, Ohnuki K, Inoue N, Watanabe T, Yazawa S, Fushiki T (2011b) Capsiate, a non-pungent capsaicin analog, reduces body fat without weight rebound like swimming exercise in mice. *Biomed Res* 32(4):279–284
- Hervert-Hernández D, Sáyo-Ayerdi SG, Goñi I (2010) Bioactive compounds of four hot pepper varieties (*Capsicum annuum* L.), antioxidant capacity, and intestinal bioaccessibility. *J Agric Food Chem* 58(6):3399–3406
- Higashiguchi F, Nakamura H, Hayashi H, Kometani T (2006) Purification and structure determination of glucosides of capsaicin and dihydrocapsaicin from various *Capsicum* fruits. *J Agric Food Chem* 54(16):5948–5953
- Hofmann A, Proust J, Dorowski A, Schantz R, Huber R (2000) Annexin 24 from *Capsicum annuum*. X-ray

- structure and biochemical characterization. *J Biol Chem* 275(11):8072–8082
- Hornero-Méndez D, Mínguez-Mosquera MI (2000) Xanthophyll esterification accompanying carotenoid overaccumulation in chromoplast of *Capsicum annum* ripening fruits is a constitutive process and useful for ripeness index. *J Agric Food Chem* 48(5):1617–1622
- Hornero-Méndez D, Gómez-Ladrón De Guevara R, Mínguez-Mosquera MI (2000) Carotenoid biosynthesis changes in five red pepper (*Capsicum annum* L.) cultivars during ripening. Cultivar selection for breeding. *J Agric Food Chem* 48(9):3857–3864
- Howard LR, Talcott ST, Brenes CH, Villalon B (2000) Changes in phytochemical and antioxidant activity of selected pepper cultivars (*Capsicum* species) as influenced by maturity. *J Agric Food Chem* 48(5):1713–1720
- Inoue T, Umemura T, Maeda M, Ishii Y, Okamura T, Tasaki M, Nishikawa A (2008) Safety assessment of dietary administered paprika color in combined chronic toxicity and carcinogenicity studies using F344 rats. *Food Chem Toxicol* 46(8):2689–2693
- Iorizzi M, Lanzotti V, De Marino S, Zollo F, Blanco-Molina M, Macho A, Muñoz E (2001) New glycosides from *Capsicum annum* L. var. *acuminatum*. Isolation, structure determination, and biological activity. *J Agric Food Chem* 49(4):2022–2029
- Iorizzi M, Lanzotti V, Ranalli G, De Marino S, Zollo F (2002) Antimicrobial furostanol saponins from the seeds of *Capsicum annum* L. var. *acuminatum*. *J Agric Food Chem* 50(15):4310–4316
- Itoh T, Jeong TM, Hirano Y, Tamura T, Matsumoto T (1977) Occurrence of lanosterol and lanostenol in seeds of red pepper (*Capsicum annum*). *Steroids* 29(5):569–577
- Jang JJ, Devor DE, Logsdon DL, Ward JM (1992) A 4-week feeding study of ground red chilli (*Capsicum annum*) in male B6C3F1 mice. *Food Chem Toxicol* 30(9):783–787
- Jang HY, Kim SM, Yuk JE, Kwon OK, Oh SR, Lee HK, Jeong H, Ahn KS (2011) *Capsicum annum* L. methanolic extract inhibits ovalbumin-induced airway inflammation and oxidative stress in a mouse model of asthma. *J Med Food* 14(10):1144–1151
- Jarén-Galán M, Nienaber U, Schwartz SJ (1999) Paprika (*Capsicum annum*) oleoresin extraction with supercritical carbon dioxide. *J Agric Food Chem* 47(9):3558–3564
- Jensen-Jarolim E, Santner B, Leitner A, Grimm R, Scheiner O, Ebner C, Breiteneder H (1998) Bell peppers (*Capsicum annum*) express allergens (profilin, pathogenesis-related protein P23 and Bet v 1) depending on the horticultural strain. *Int Arch Allergy Immunol* 116(2):103–9
- Jeong WY, Jin JS, Cho YA, Lee JH, Park S, Jeong SW, Kim YH, Lim CS, Abd El-Aty AM, Kim GS, Lee SJ, Shim JH, Shin SC (2011) Determination of polyphenols in three *Capsicum annum* L. (bell pepper) varieties using high-performance liquid chromatography-tandem mass spectrometry: their contribution to overall antioxidant and anticancer activity. *J Sep Sci* 34(21):2967–2974
- Jones ECS, Pyman FL (1925) Relation between chemical constitution and pungency in acid amides. *J Am Chem Soc* 127:2588–2598
- Jones NL, Shabib S, Sherman PM (1997) Capsaicin as an inhibitor of the growth of the gastric pathogen *Helicobacter pylori*. *FEMS Microbiol Lett* 146(2):223–227
- Kanki K, Nishikawa A, Furukawa F, Kitamura Y, Imazawa T, Umemura T, Hirose M (2003) A 13-week sub-chronic toxicity study of paprika color in F344 rats. *Food Chem Toxicol* 41(10):1337–1343
- Katz G (2008) Paprika (*Capsicum annum* L.). http://www.uni-graz.at/~katzger/engl/Caps_ann.html
- Kawabata F, Inoue N, Yazawa S, Kawada T, Inoue K, Fushiki T (2006) Effects of CH-19 sweet, a non-pungent cultivar of red pepper, in decreasing the body weight and suppressing body fat accumulation by sympathetic nerve activation in humans. *Biosci Biotechnol Biochem* 70(12):2824–2835
- Kawabata F, Inoue N, Masamoto Y, Matsumura S, Kimura W, Kadowaki M, Higashi T, Tominaga M, Inoue K, Fushiki T (2009) Non-pungent capsaicin analogs (capsinoids) increase metabolic rate and enhance thermogenesis via gastrointestinal TRPV1 in mice. *Biosci Biotechnol Biochem* 73(12):2690–2697
- Kawaguchi Y, Ochi T, Takaishi Y, Kawazoe K, Lee KH (2004) New sesquiterpenes from *Capsicum annum*. *J Nat Prod* 67(11):1893–1896
- Keskin D, Toroglu S (2011) Studies on antimicrobial activities of solvent extracts of different spices. *J Environ Biol* 32(2):251–256
- Kim JH, Jeong CH, Shin KH (2003) Biological activities of solvent fractions of *Capsicum annum* leaves. *Korean J Food Preser* 10:540–546
- Kim JS, Ahn J, Lee SJ, Moon B, Ha TY, Kim S (2011) Phytochemicals and antioxidant activity of fruits and leaves of paprika (*Capsicum annum* L., var. special) cultivated in Korea. *J Food Sci* 76(2):C193–C198
- Kobata K, Sutoh K, Todo T, Yazawa S, Iwai K, Watanabe T (1999) Nordihydrocapsiate, a new capsinoid from the fruits of a nonpungent pepper, *Capsicum annum*. *J Nat Prod* 62(2):335–336
- Kodama T, Watanabe E, Masuyama T, Tsubuku S, Otake A, Mochizuki M, Bernard BK (2008) Studies of the toxicological potential of capsinoids: II. A 26-week daily gavage dosing toxicity study of CH-19 Sweet extract in rats. *Int J Toxicol* 27(Suppl 3):11–27
- Kozukue N, Han JS, Kozukue E, Lee SJ, Kim JA, Lee KR, Levin CE, Friedman M (2005) Analysis of eight capsaicinoids in peppers and pepper-containing foods by high-performance liquid chromatography and liquid chromatography-mass spectrometry. *J Agric Food Chem* 53(23):9172–9181
- Ku KM, Kang YH (2010) Quinone reductase inductive activity of *Capsicum annum* leaves and isolation of the active compounds. *J Korean Soc Appl Biol Chem* 53(6):709–715
- Lee Y, Howard LR, Villalón B (1995) Flavonoids and antioxidant activity of fresh pepper (*Capsicum annum*) cultivars. *J Food Sci* 60:473–476

- Lee JH, Kiyota N, Ikeda T, Nohara T (2006) Acyclic diterpene glycosides, capsianosides VIII, IX, X, XIII, XV and XVI from the fruits of paprika *Capsicum annuum* L. var. *grossum* Bailey and Jalapeño *Capsicum annuum* L. var. *annuum*. Chem Pharm Bull(Tokyo) 54(10):1365–1369
- Lee IO, Lee KH, Pyo JH, Kim JH, Choi YJ, Lee YC (2007a) Anti-inflammatory effect of capsaicin in *Helicobacter pylori*-infected gastric epithelial cells. Helicobacter 12(5):510–517
- Lee JH, Kiyota N, Ikeda T, Nohara T (2007b) Acyclic diterpene glycosides, capsianosides C, D, E, F and III, from the fruits of hot red pepper *Capsicum annuum* L. used in Kimchi and their revised structures. Chem Pharm Bull(Tokyo) 55(8):1151–1156
- Lee JH, Kiyota N, Ikeda T, Nohara T (2008) Three new acyclic diterpene glycosides from the aerial parts of paprika and pimiento. Chem Pharm Bull(Tokyo) 56(4):582–584
- Lee DY, Lee DG, Cho JG, Bang MH, Lyu HN, Lee YH, Kim SY, Baek NI (2009) Lignans from the fruits of the red pepper (*Capsicum annuum* L.) and their antioxidant effects. Arch Pharm Res 32(10):1345–1349
- Lightbourn GJ, Griesbach RJ, Novotny JA, Clevidence BA, Rao DD, Stommel JR (2008) Effects of anthocyanin and carotenoid combinations on foliage and immature fruit color of *Capsicum annuum* L. J Hered 99(2):105–111
- Loizzo MR, Tundis R, Menichini F, Statti GA, Menichini F (2008) Influence of ripening stage on health benefits properties of *Capsicum annuum* var. *acuminatum* L.: in vitro studies. J Med Food 11(1):184–189
- López-Carrillo L, López-Cervantes M, Robles-Díaz G, Ramírez-Espitia A, Mohar-Betancourt A, Meneses-García A, López-Vidal Y, Blair A (2003) Capsaicin consumption, *Helicobacter pylori* positivity and gastric cancer in Mexico. Int J Cancer 106(2):277–282
- Luning PA, de Rijk T, Wichers HJ, Roozen JP (1994) Gas chromatography, mass spectrometry, and sniffing port analyses of volatile compounds of fresh bell peppers (*Capsicum annuum*) at different ripening stages. J Agric Food Chem 42:977–983
- Luning PA, Ebbenhörst-Seller T, de Rijk T, Roozen JP (1995a) Effect of hot-air-drying on flavour compounds of bell peppers (*Capsicum annuum*). J Sci Food Agric 68:355–365
- Luning PA, Yuksel D, Van Der Vuurst De Vries R, Roozen JP (1995b) Aroma changes in fresh bell peppers (*Capsicum annuum*) after hot-air drying. J Food Sci 60:1269–1276
- Luo XJ, Peng J, Li YJ (2011) Recent advances in the study on capsaicinoids and capsinoids. Eur J Pharmacol 650(1):1–7
- Luqman S, Meena A, Marler LE, Kondratyuk TP, Pezzuto JM (2011) Suppression of tumor necrosis factor- α -induced nuclear factor κ B activation and aromatase activity by capsaicin and its analog capsazepine. J Med Food 14(11):1344–1351
- Macho A, Lucena C, Sancho R, Daddario N, Minassi A, Munoz E, Appendino G (2003) Non-pungent capsaicinoids from sweet pepper: synthesis and evaluation of the chemopreventive and anticancer potential. Eur J Nutr 42(1):2–9
- Maoka T, Fujiwara Y, Hashimoto K, Akimoto N (2001a) Capsanthone 3,6-epoxide, a new carotenoid from the fruits of the red paprika *Capsicum annuum* L. J Agric Food Chem 49(8):3965–3968
- Maoka T, Fujiwara Y, Hashimoto K, Akimoto N (2001b) Isolation of a series of apocarotenoids from the fruits of the red paprika *Capsicum annuum* L. J Agric Food Chem 49(3):1601–1606
- Maoka T, Mochida K, Kozuka M, Ito Y, Fujiwara Y, Hashimoto K, Enjo F, Ogata M, Nobukuni Y, Tokuda H, Nishino H (2001c) Cancer chemopreventive activity of carotenoids in the fruits of red paprika *Capsicum annuum* L. Cancer Lett 172(2):103–109
- Maoka T, Akimoto N, Fujiwara Y, Hashimoto K (2004) Structure of new carotenoids with the 6-oxo-kappa end group from the fruits of paprika, *Capsicum annuum*. J Nat Prod 67(1):115–117
- Marín A, Ferreres F, Tomás-Barberán FA, Gil MI (2004) Characterization and quantitation of antioxidant constituents of sweet pepper (*Capsicum annuum* L.). J Agric Food Chem 52(12):3861–3869
- Márkus F, Daoud HG, Kapitány J, Biacs PA (1999) Change in the carotenoid and antioxidant content of spice red pepper (paprika) as a function of ripening and some technological factors. J Agric Food Chem 47(1):100–107
- Masuda Y, Haramizu S, Oki K, Ohnuki K, Watanabe T, Yazawa S, Kawada T, Hashizume S, Fushiki T (2003) Upregulation of uncoupling proteins by oral administration of capsate, a nonpungent capsaicin analog. J Appl Physiol 95(6):2408–2415
- Mateos RM, León AM, Sandalio LM, Gómez M, del Río LA, Palma JM (2003) Peroxisomes from pepper fruits (*Capsicum annuum* L.): purification, characterisation and antioxidant activity. J Plant Physiol 160(12):1507–1516
- Materska M, Perucka I (2005) Antioxidant activity of the main phenolic compounds isolated from hot pepper fruit (*Capsicum annuum* L.). J Agric Food Chem 53(5):1750–1756
- Materska M, Perucka I, Stochmal A, Piacente S, Oleszek W (2003a) Quantitative and qualitative determination of flavonoids and phenolic acid derivatives from pericarp of hot pepper fruit cv. Bronowicka Ostra. Pol J Food Nutr Sci 12/53(SI 2):72–76
- Materska M, Piacente S, Stochmal A, Pizzà C, Oleszek W, Perucka I (2003b) Isolation and structure elucidation of flavonoid and phenolic acid glycosides from pericarp of hot pepper fruit *Capsicum annuum* L. Phytochemistry 63(3):893–898
- Matsufuji H, Nakamura H, Chino M, Takeda M (1998) Antioxidant activity of capsanthin and the fatty acid esters in paprika (*Capsicum annuum*). J Agric Food Chem 46(9):3468–3472
- Matsumoto T, Osawa Y, Itoh T (1983) 4 α -Methyl-5 α -cholest-8(14)-en-3 β -ol from the seeds of *Capsicum annuum*. Phytochemistry 22(11):2621–2622

- Mazida MM, Salleh MM, Osman H (2005) Analysis of volatile aroma compounds of fresh chilli (*Capsicum annuum*) during stages of maturity using solid phase microextraction (SPME). *J Food Comp Anal* 18(5):427–437
- Medvedeva NV, Andreenkov VA, Morozkin AD, Sergeeva EA, Prokof'ev II, Misharin AI (2003) Inhibition of oxidation of human blood low density lipoproteins by carotenoids from paprika. *Biomed Khim* 49(2): 191–200 (in Russian)
- Mondal S, Das D, Maiti D, Roy SK, Islam SS (2009) Structural investigation of a heteropolysaccharide isolated from the green fruits of *Capsicum annuum*. *Carbohydr Res* 344(9):1130–1135
- Motohashi N, Wakabayashi H, Kurihara T, Takada Y, Maruyama S, Sakagami H, Nakashima H, Tani S, Shirataki Y, Kawase M, Wolfard K, Molnár J (2003) Cytotoxic and multidrug resistance reversal activity of a vegetable, 'Anastasia Red', a variety of sweet pepper. *Phytother Res* 17(4):348–352
- Naef R, Velluz A, Jaquier A (2008) New volatile sulfur-containing constituents in a simultaneous distillation-extraction extract of red bell peppers (*Capsicum annuum*). *J Agric Food Chem* 56(2):517–527
- Nelson EK (1919) Vanillyl-acyl amides. *J Am Chem Soc* 41:2121–2130
- O'Sullivan L, Jiwan MA, Daly T, O'Brien NM, Aherne SA (2010) Bioaccessibility, uptake, and transport of carotenoids from peppers (*Capsicum* spp.) using the coupled in vitro digestion and human intestinal Caco-2 cell model. *J Agric Food Chem* 58(9):5374–5379
- Oboh G, Ademiluyi AO, Faloye YM (2011) Effect of combination on the antioxidant and inhibitory properties of tropical pepper varieties against α -amylase and α -glucosidase activities in vitro. *J Med Food* 14(10):1152–1158
- Ochi T, Takaishi Y, Kogure K, Yamauti I (2003) Antioxidant activity of a new capsaicin derivative from *Capsicum annuum*. *J Nat Prod* 66(8):1094–1096
- Ohnuki K, Haramizu S, Oki K, Watanabe T, Yazawa S, Fushiki T (2001) Administration of capsaite, a non-pungent capsaicin analog, promotes energy metabolism and suppresses body fat accumulation in mice. *Biosci Biotechnol Biochem* 65(12): 2735–2740
- Oruña-Concha MJ, López-Hernández J, Simal-Lozano JA, Simal-Gándara J, González-Castro MJ, de la Cruz GC (1998) Determination of volatile components in fresh, frozen, and freeze-dried Padrón-type peppers by gas chromatography-mass spectrometry using dynamic headspace sampling and microwave desorption. *J Chromatogr Sci* 36(12):583–588
- Paik SY, Ra KS, Chang IS, Park YC, Park HS, Baik HS, Yun JW, Choi JW (2003) Purification and characterization of complement-activating acidic polysaccharides from the fruits of *Capsicum annuum*. *J Biochem Mol Biol* 36(2):230–236
- Palevitch D, Craker LE (1995) Nutritional and medicinal importance of red pepper (*Capsicum* spp.). *J Herbs Spices Med Plants* 3:55–83
- Park J, Kim S, Moon B (2011) Changes in carotenoids, ascorbic acids, and quality characteristics by the pickling of paprika (*Capsicum annuum* L.) cultivated in Korea. *J Food Sci* 76(7):C1075–C1080
- Pérez-Gálvez A, Martin HD, Sies H, Stahl W (2003) Incorporation of carotenoids from paprika oleoresin into human chylomicrons. *Br J Nutr* 89(6):787–793
- Perucka I, Materska M (2003) Antioxidant activity and contents of capsaicinoids isolated from paprika fruits. *Pol J Food Nutr Sci* 12(53):15–18
- Poulos JM (1994) *Capsicum* L. In: Siemonsma JS, Piluek K (eds) Plant resources of south-east Asia, no. 8. vegetables. Pudoc, Wageningen, pp 136–140
- Reilly CA, Crouch DJ, Yost GS (2001) Quantitative analysis of capsaicinoids in fresh peppers, oleoresin capsaicin and pepper spray products. *J Forensic Sci* 46(3):502–509
- Ribeiro SF, Carvalho AO, Da Cunha M, Rodrigues R, Cruz LP, Melo VM, Vasconcelos IM, Melo EJ, Gomes VM (2007) Isolation and characterization of novel peptides from chilli pepper seeds: antimicrobial activities against pathogenic yeasts. *Toxicon* 50(5):600–611
- Ribeiro SF, Silva MS, Da Cunha M, Carvalho AO, Dias GB, Rabelo G, Mello EO, Santa-Catarina C, Rodrigues R, Gomes VM (2012) *Capsicum annuum* L. trypsin inhibitor as a template scaffold for new drug development against pathogenic yeast. *Antonie Van Leeuwenhoek* 101(3):657–670
- Rodríguez-Burruezo A, Kollmannsberger H, González-Mas MC, Nitz S, Fernando N (2010) HS-SPME comparative analysis of genotypic diversity in the volatile fraction and aroma-contributing compounds of *Capsicum* fruits from the *annuum-chinensenfrutescens* complex. *J Agric Food Chem* 58(7):4388–4400
- Rosa A, Deiana M, Casu V, Paccagnini S, Appendino G, Ballero M, Dessí MA (2003) Antioxidant activity of capsinoids. *J Agric Food Chem* 50(25):7396–7401
- Sancho R, Lucena C, Macho A, Calzado MA, Blanco-Molina M, Minassi A, Appendino G, Muñoz E (2002) Immunosuppressive activity of capsaicinoids: capsaite derived from sweet peppers inhibits NF-kappaB activation and is a potent antiinflammatory compound in vivo. *Eur J Immunol* 32(6):1753–1763
- Santos MM, Vieira-da-Motta O, Vieira IJ, Braz-Filho R, Gonçalves PS, Maria EJ, Terra WS, Rodrigues R, Souza CL (2012) Antibacterial activity of *Capsicum annuum* extract and synthetic capsaicinoid derivatives against *Streptococcus mutans*. *J Nat Med* 66(2):354–356
- Sasahara I, Furuhashi Y, Iwasaki Y, Inoue N, Sato H, Watanabe T, Takahashi M (2010) Assessment of the biological similarity of three capsaicin analogs (Capsinoids) found in non-pungent chili pepper (CH-19 Sweet) fruits. *Biosci Biotechnol Biochem* 74(2):274–278
- Sastre J, Olmo M, Novalvos A, Ibañez D, Lahoz C (1996) Occupational asthma due to different spices. *Allergy* 51(2):117–120
- Shirataki Y, Kawase M, Sakagami H, Nakashima H, Tani S, Tanaka T, Sohara Y, Schelz J, Molnár J, Motohashi N (2005) Bioactivities of anastasia black (Russian sweet pepper). *Anticancer Res* 25(3B):1991–1999

- Sim KH, Sil HY (2008) Antioxidant activities of red pepper (*Capsicum annuum*) pericarp and seed extracts. *Int J Food Sci Technol* 43:1813–1823
- Simian H, Robert F, Blank I (2004) Identification and synthesis of 2-heptanethiol, a new flavor compound found in bell peppers. *J Agric Food Chem* 52:306–310
- Simonne AH, Simonne EH, Eitenmiller RR, Mills HA, Green NR (1997) Ascorbic acid and provitamin A contents in unusually colored bell peppers (*Capsicum annuum* L.). *J Food Comp Anal* 10(4):299–311
- Singh S, Natarajan K, Aggarwal BB (1996) Capsaicin (8-methyl-N-vanillyl-6-nonenamide) is a potent inhibitor of nuclear transcription factor-kappa B activation by diverse agents. *J Immunol* 157(10):4412–4420
- Singh S, Jarret R, Russo V, Majetich G, Shimkus J, Bushway R, Perkins B (2009) Determination of capsinoids by HPLC-DAD in *Capsicum* species. *J Agric Food Chem* 57(9):3452–3457
- Snitker S, Fujishima Y, Shen H, Ott S, Pi-Sunyer X, Furuhashi Y, Sato H, Takahashi M (2009) Effects of novel capsinoid treatment on fatness and energy metabolism in humans: possible pharmacogenetic implications. *Am J Clin Nutr* 89(1):45–50
- Starkenmann C, Niclass Y (2011) New cysteine-S-conjugate precursors of volatile sulfur compounds in bell peppers (*Capsicum annuum* L. cultivar). *J Agric Food Chem* 59(7):3358–3365
- Sun T, Xu Z, Wu CT, Janes M, Prinyawiwatkul W, No HK (2007) Antioxidant activities of different colored sweet bell peppers (*Capsicum annuum* L.). *J Food Sci* 72(2):S98–S102
- Surh YJ, Han SS, Keum YS, Seo HJ, Lee SS (2000) Inhibitory effects of curcumin and capsaicin on phorbol ester-induced activation of eukaryotic transcription factors, NF-kappaB and AP-1. *Biofactors* 12(1–4):107–112
- Takano F, Yamaguchi M, Takada S, Shoda S, Yahagi N, Takahashi T, Ohta T (2007) Capsicum ethanol extracts and capsaicin enhance interleukin-2 and interferon-gamma production in cultured murine Peyer's patch cells ex vivo. *Life Sci* 80(17):1553–1563
- Talalay P, De Long MJ, Prochaska HJ (1988) Identification of a common chemical signal regulating the induction of enzymes that protect against chemical carcinogenesis. *Proc Natl Acad Sci USA* 85:8261–8265
- Talalay P, Fahey JW, Holtzclaw WD, Prestera T, Zhang Y (1995) Chemoprotection against cancer by phase 2 enzyme induction. *Toxicol Lett* 82–83:173–179
- Tanaka Y, Hosokawa M, Otsu K, Watanabe T, Yazawa S (2009) Assessment of capsinoninoid composition, nonpungent capsaicinoid analogues, in capsicum cultivars. *J Agric Food Chem* 57(12):5407–5412
- Tundis R, Loizzo MR, Menichini F, Bonesi M, Conforti F, Statti G, De Luca D, De Cindio B, Menichini F (2011) Comparative study on the chemical composition, antioxidant properties and hypoglycaemic activities of two *Capsicum annuum* L. cultivars (Auminumatum small and Cerasiferum). *Plant Foods Hum Nutr* 66(3):261–269
- U.S. Department of Agriculture, Agricultural Research Service (USDA) (2012) USDA National Nutrient Database for Standard Reference, Release 25 Nutrient Data Laboratory Home Page, <http://www.ars.usda.gov/ba/bhnrc/ndl>
- van Ruth SM, Roozen JP (1995) Gas chromatography/sniffing port analysis and sensory evaluation of commercially dried bell peppers (*Capsicum annuum*) after rehydration. *Food Chem* 54:165–170
- Walpole CS, Wrigglesworth R, Bevan S, Campbell EA, Dray A, James IF, Masdin KJ, Perkins MN, Winter J (1993) Analogues of capsaicin with agonist activity as novel analgesic agents; structure-activity studies. 3. The hydrophobic side-chain “C-region”. *J Med Chem* 36(16):2381–2389
- Watanabe E, Kodama T, Masuyama T, Tsubuku S, Otake A, Mochizuki M, Nakajima M, Masumori S, Bernard BK (2008) Studies of the toxicological potential of capsinoids. I. Single-dose toxicity study and genotoxicity studies of CH-19 Sweet extract. *Int J Toxicol* 27(Suppl 3):1–9
- Watanabe T, Ohnuki K, Kobata K (2011) Studies on the metabolism and toxicology of emerging capsinoids. *Expert Opin Drug Metab Toxicol* 7(5):533–542
- Whitehead IM, Threlfall DR, Ewing DF (1987) *Cis*-9,10-dihydrocapsenone: a possible catabolite of capsidiol from cell suspension cultures of *Capsicum annuum*. *Phytochemistry* 26(5):1367–1369
- Xiao ZB, Zhu JC, Feng T, Tian HX, Yu HY, Niu YW, Zhang XM (2010) Comparison of volatile components in Chinese traditional pickled peppers using HS-SPME-GC-MS, GC-O and multivariate analysis. *Nat Prod Res* 24(20):1939–1953
- Yahara S, Izumitani Y, Nohara T (1988) A novel acyclic diterpene glycoside, capsianside A, from *Capsicum annuum* var. *fasciculatum*. *Tetrahedron Lett* 29:1943–1946
- Yahara S, Kobayashi N, Izumitani Y, Nohara T (1991) Solanaceous plants. XXIII. New acyclic diterpene glycosides, capsianosides VI, G and H from the leaves and stems of *Capsicum annuum* L. *Chem Pharm Bull* 39:3258–3260
- Yahara S, Ura T, Sakamoto C, Nohara T (1994) Steroidal glycosides from *Capsicum annuum*. *Phytochemistry* 37(3):831–835
- Yahia EM, Contreras-Padilla M, Gonzalez-Aguilar G (2001) Ascorbic acid content in relation to ascorbic acid oxidase activity and polyamine content in tomato and bell pepper fruits during development, maturation and senescence. *LWT- Food Sci Technol* 34(7):452–457
- Yamauchi R, Aizawa K, Inakuma T, Kato K (2001) Analysis of molecular species of glycolipids in fruit pastes of red bell pepper (*Capsicum annuum* L.) by high-performance liquid chromatography-mass spectrometry. *J Agric Food Chem* 49(2):622–627
- Yoneshiro T, Aita S, Kawai Y, Iwanaga T, Saito M (2012) Nonpungent capsaicin analogs (capsinoids) increase energy expenditure through the activation of brown adipose tissue in humans. *Am J Clin Nutr*. doi:10.3945/ajcn.111.018606
- Ziino M, Condurso C, Romeo V, TripodiG VA (2009) Volatile compounds and capsaicinoid content of fresh hot peppers (*Capsicum annuum* L.) of different Calabrian varieties. *J Agric Food Chem* 89:774–780
- Zimmermann M, Schieberle P (2000) Important odorants of sweet bell pepper powder (*Capsicum annuum* cv. *annuum*): differences between samples of Hungarian and Moroccan origin. *Eur Food Res Technol* 211:175–180

Capsicum baccatum var. *pendulum*

Scientific Name

Capsicum baccatum L. var. *pendulum* (Willd.)
Eshbaugh.

Synonyms

Capsicum frutescens var. *pendulum* (Willd.)
Besser, *Capsicum indicum* var. *pendulum* (Willd.)
Dierb., *Capsicum pendulum* Willd. (basionym).

Family

Solanaceae

Common/English Names

Aji, Aji Amarillo, Aji Pepper, Amarillio Chillí,
Locoto, Peruvian Hot Pepper, Wild Baccatum.

(Varietal names):

Aji Amarillo, Aji Amarillo Mirasol, Aji Andean, Aji
Ayucullo, Aji Benito, Aji Blanco Cristal, Aji Bolivian
Long, Aji Brazilian Bonanza, Aji Brazilian Starfish,
Aji Caballero, Aji Camba, Aji Chanca, Aji Chivato,
Aji Cito, Aji Cochabamba, Aji Cohincho, Aji
Colarado, Aji Criolla Sella, Aji Cristal, Aji De Mesa,
Aji Escabeche, Aji Exploding Fire, Aji Francos,
Aji Golden, Aji Habanero, Aji Indian, Aji Lemon
Drop, Aji Limon, Aji Little Finger, Aji Mirasol, Aji

Mono, Aji Montesino, Aji Norteno, Aji Omnicolor,
Aji Orange, Aji Orchid (Aji Flor), Aji Oro, Aji Panca,
Aji Peruvian, Aji Picante, Aji Pilange, Aji Pineapple,
Aji Portachuela, Aji Red Olive, Aji Rojo (Aji Red,
Puca Uchu), Aji Russian Yellow, Aji Serranito,
Aji Valentine, Aji Verdi, Aji White Wax, Aji Yellow,
Albero's, Banana Aji, Bubba, Bell Chile, Bishop's
Crown, Bishop's Hat, Campana, Balloon, Christmas
Bell, Nepalese Bell, Peppa Dew, Piquanté.

Vernacular Names

Brazil: Cambuci, Pimenta Cambuci, Pimenta-
Malagueta, Ubtuba Cambuci;

Costa Rica: Cuerno De Oro;

Czech: Paprika Roční;

Danish: Cayennepeber, Peru-peber;

Dutch: Cayenne peper;

East Africa: Peri-Peri;

French: Piment Chien;

German: Glockenpaprika, Hängende Paprika,
Peruanischer Pfeffer;

Peru: Aji, Aji Amarillo, Escabeche, Chinchí
Uchu, Uchu (Quecha);

Portuguese: Peri-Peri, Pimentinha;

Spanish: Aji, Pimiento De Las Indias, Piris.

Origin/Distribution

Archeological, taxonomical, genetical and bio-
chemical evidence suggest that the cultivated ajis
(*Capsicum baccatum* var. *pendulum*) were derived

from the wild *C. baccatum* var. *baccatum*, known as “arivivi” in Bolivia (Eshbaugh 1976; McLeod et al. 1983; Pickersgill et al. 1979). Both the cultivated and the wild forms of *C. baccatum* are native to South America, the distribution of *C. baccatum* var. *baccatum* is reported as being more restrictive, being limited primarily to northern Argentina, Bolivia, south-western Brazil, western Paraguay, and central Peru with a center of diversity/origin in Bolivia/Peru (D’Arcy and Eshbaugh 1974; Eshbaugh 1970; Hunziker 1950). The cultivated *C. baccatum* var. *pendulum* is found from the lowlands to mid-altitudes in Argentina, Bolivia, Peru, Ecuador, Paraguay, Colombia, Chile, and a larger part within Brazil. It has been introduced to Central America, Hawaii, the mainland United States, India, Australia and elsewhere. A third variety *C. baccatum* var. *praetermissum* (Heiser & P.G. Sm.) Hunz. (Hunziker 1971) is believed to have derived from isolated populations of the wild type *C. baccatum* var. *baccatum*. Its distribution appears to be restricted to southern Brazil (McLeod et al. 1983).



Plate 1 Fruit, flower and leaves of Bishop crown

Agroecology

This lowland to mid-elevation species is widespread throughout South America particularly adjacent to the Andes. It is robust and is quite tolerant of mild frost. It requires full sun and thrives on well-drained, fertile sandy-loamy soils. It tolerates a wide pH range from 4.5 to 8.3.

Edible Plant Parts and Uses

Capsicum baccatum aji Amarillo, has been used for millennia in Andean cuisine. It is mainly used as a condiment for flavouring in many dishes and is used fresh, dried or in ground powder form. Common dishes include salsa, the Peruvian stew, *Aji de Gallina*, *Hauncaina* sauce and the Bolivian *Fricase Paceno*. The fruits are used fresh in Peruvian *ceviche* (lime-marinated fish); ceviche is also a popular dish in the coastal regions of Central and South America.

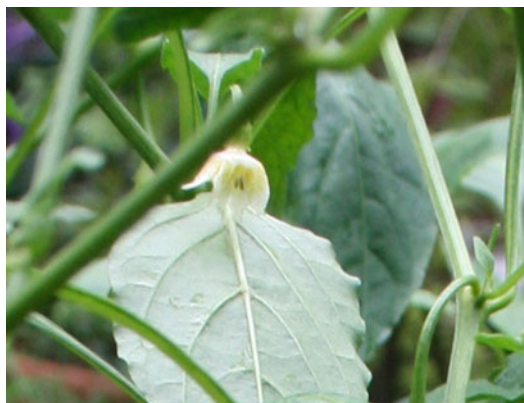


Plate 2 Flower of Bishop crown

Botany

Plant with green branched, erect stem, 60–100 cm high. Leaves large, alternate on long petiole 4–5 cm; lamina rhomboid-ovate, 6–7 cm by 3.5–4.5 cm wide with tapering acuminate tip and

cuneate base and slightly undulating entire margin, medium green, with distinct mid-rib (Plates 1 and 2). Flowers hermaphrodite, solitary at leaf axils; pedicel pendant at anthesis. Calyx campanulate, green with five short teeth. Corolla with 6–8 revolute lobes, off-white with yellowish spots at the lower portion (Plates 1 and 2). Stamens with yellowish anther turning yellowish-brown with maturity, style yellowish-white with capitate stigma. Fruits pendant very rarely erect, 3–5 cm long, 1.5–3 cm wide, persistent, firm-fleshed and variously shaped, elongate, oblong to unusual bell-shaped with 3 (–4) flared lobes resembling a bishop's crown or monk's hat, glossy green turning to glossy red, lemon-yellow, orange, or brown (rarely) when mature (Plate 1). Seeds numerous, straw coloured.

Jarret (2007) reported mean fruit weight of 295 accessions of *Capsicum baccatum* from the USDA/ARS *Capsicum* germplasm collection to be 5.91 g with a range of 0.15–22.8 g. Mean fruit length was 6.01 cm with a range of 0.8–16.0 cm. Mean fruit width was 1.86 cm and a range of 0.5–4.75 cm. Ninety-three percent of accessions were elongate. Mature fruit colours included red (73.6%), orange (19.7%), yellow (3%), green (0.3%), and mixed (3%).

Nutritive/Medicinal Properties

A total of 16 carotenoids were identified in 12 Bolivian accessions of the Andean peppers *Capsicum baccatum* (ají) and *C. pubescens* (rocoto) and 2 California Wonder cultivars (*C. annuum*) controls (Rodríguez-Burruezo et al. 2010). Differences among species were mostly found at the quantitative level. Among red-fruited genotypes, capsanthin was the main carotenoid in the three species (25–50% contribution to carotenoid fraction), although ajíes contained the lowest contribution of this carotenoid. The contribution of capsanthin 5,6-epoxide to total carotenoids in *Capsicum baccatum* was high (11–27%) in comparison to *C. pubescens* and red *C. annuum*. In general, antheraxanthin and violaxanthin were the next most relevant carotenoids in the red Andean peppers (6.1–10.6%). Violaxanthin was

the major carotenoid in yellow-/orange-fruited genotypes of the three species (37–68% total carotenoids), although yellow rocotos were characterized by lower levels (<45%). *Cis-violaxanthin*, *antheraxanthin*, and *lutein* were the next most relevant carotenoids in the yellow/orange Andean peppers (5–14%). In terms of nutritional contribution, both ajíes and rocotos provided a remarkable provitamin A activity, with several accessions showing a content in retinol equivalents higher than *C. annuum* controls. As a whole, rocotos showed the highest contributions of provitamin A carotenoids to the carotenoid fraction. Further, levels of lutein in yellow/orange ajíes and rocotos were clearly higher than California Wonder pepper ($\geq 1,000 \mu\text{g}/100\text{g}$). Additionally, the Andean peppers, particularly red ajíes, can be also considered as a noteworthy source of capsanthin, the most powerful antioxidant compound among pepper carotenoids.

C. baccatum fruits were found to contain coniferyl esters coniferyl (E)-8-methyl-6-nonenoate (capsiconiate) and coniferyl 8-methyl-nonanoate (dihydrocapsiconiate) (Kobata et al. 2008). Kollmannsberger et al. (2011) found ají (*Capsicum baccatum* L. var. *pendulum*) and rocoto (*Capsicum pubescens* R. & P.) to be mildly pungent compared with *C. chinense* (13–352 vs 1,605 mg/kg in total capsaicinoids). The two Andean peppers had more earthy/vegetable/bell pepper-like aromas. Rocotos also exhibited a distinct additional cucumber odour, while the ajíes had a distinctive sweet/fruity note. 2-heptanethiol, 3-isobutyl-2-methoxypyrazine and several phenols (e.g. guaiacol) and terpenoids (e.g. α -pinene, 1,8-cineol, linalool) were found to be the basis of *C. baccatum* aroma, with some 3-methyl-2-butyl esters contributing to fruity notes. A total of 49 compounds, mostly monoterpenes and aldehydes, were identified in the dedode-moça chilli pepper (*Capsicum baccatum* var. *pendulum*) (Junior et al. 2012).

Total phenol content was correlated with ascorbic acid ($R^2=0.97$) and free sugars ($R^2=0.80$) in the *Capsicum* germplasm tested that included four accessions of *Capsicum chinense*; five accessions of *C. baccatum*; six accessions of *C. annuum*; and two of *C. frutescens*

(Antonious et al. 2006a). Concentrations of total phenols (1.4, 1.3, and 1.3 mg/g fruit) and ascorbic acid (1.6, 1.2, and 1.3 mg/g fruit) were significantly greater in PI-633757, PI-387833, and PI-633754, respectively, compared to other accessions analyzed. Total capsaicinoids concentrations were greatest (1.3 mg/g fruit) in PI-438622 and lowest (0.002 mg/g fruit) in Grif-9320. Capsaicin and dihydrocapsaicin were the dominant capsaicinoids detected in methanol extract of fresh fruits of *Capsicum chinense*, *C. frutescens*, *C. baccatum*, *C. annuum*, and *C. pubescens* (Antonious and Jarret 2006); nordihydrocapsaicin was also detected. Capsaicin concentrations were typically greater than dihydrocapsaicin. Concentrations of total capsaicinoids varied from not detectable to 11.2 mg/fruit. Statistical analysis revealed that accession PI-441624 (*C. chinense*) had the highest capsaicin content (2.9 mg/g fresh fruit) and accession PI-497984 (*C. frutescens*) had the highest dihydrocapsaicin content (2.3 mg/g fresh fruit). Accessions PI-439522 (*C. frutescens*) and PI-497984 contained the highest concentrations of total capsaicinoids. Capsaicin (*trans*-methyl-*N*-vanillyl-nonenamide) is the main pungent compound extracted from the red hot pepper fruit (*Capsicum* spp.). *Capsicum chacoense* Hunz., was found to contain similar amounts of capsaicin (13.9 mg/100 g of dry fruit) in comparison with *Capsicum baccatum* L. (12.6 mg/100 g) and *Capsicum annum* L. (10.1 mg/100 g) (López et al. 2011).

Ten cultivars out of 35 cultivars tested: 18 cultivars of *C. annuum*, 7 of *C. baccatum*, 5 of *C. chinense*, 4 of *C. frutescens*, and 1 of *C. pubescens* contained capsaicinoids (Tanaka et al. 2009). Capsaicinoid Baccatum (CCB) (*C. baccatum* var. *praetermissum*) showed the highest capsaicinoid content (3,314 µg/g DW) and Charapita (*C. chinense*) had the second highest content. The other eight cultivars had much lower capsaicinoid content than these two cultivars (<300 µg/g DW). The capsaicinoid content in *C. baccatum* fruits was found to increase until 30 days after flowering (DAF) and to decrease rapidly until 40 DAF. Capsaicinoids had been reported to have agonist activity for transient receptor potential vanilloid type 1 (TRPV1).

Forty-nine samples representing distinct morphotypes of four cultivated species (*C. annuum* var. *annuum*, *C. annuum* var. *glabriusculum*, *C. baccatum*, *C. chinense*, and *C. frutescens*) were found to contain detectable levels (11–369 µg/g) of a capsinoid, E-capsiate (Singh et al. 2009). Nine of the E-capsiate-containing samples also had dihydrocapsiate (18–86 µg/g).

Wahyuni et al. (2011) found that composition and level of metabolites in the fruits of four pepper species, *Capsicum annuum*, *Capsicum frutescens*, *Capsicum chinense* and *Capsicum baccatum* varied greatly between accessions and was independent of species and geographical location. Fruit colour was determined by the accumulation of specific carotenoids leading to salmon, yellow, orange, red and brown colored fruits. Levels of both O-glycosides and C-glycosides of quercetin, luteolin and apigenin varied strongly between accessions. All non-pungent accessions were devoid of capsaicins, whereas capsaicinoid levels ranged from 0.07 up to 80 mg/100 g fruit weight in fruit pericarp. In general, pungent accessions accumulated the highest capsaicinoid levels in placenta plus seed tissue compared to pericarp. The non-pungent capsaicinoid analogs, capsates, could be detected at low levels in some pungent accessions. All accessions accumulated high levels of vitamin C, up to 200 mg/100 g fruit weight. The highest vitamin E concentration found was 16 mg/100 g fruit weight.

Antiinflammatory Activity

Studies showed that pretreatment of rats with *C. baccatum* fruit juice (0.25–2.0 g/kg) significantly decreased leucocyte and neutrophil migration, exudate volume and protein and LDH concentration in pleural exudates of a pleurisy model (Spiller et al. 2008). *C. baccatum* juice also suppressed neutrophil migration and decreased the vascular permeability on carrageenan-induced peritonitis in mice. This juice also reduced neutrophil recruitment and exudate levels of pro-inflammatory cytokines TNF- α and IL-1 β in mouse inflammatory immune peritonitis. The major active ingredient was

capsaicin which was able to inhibit the neutrophil migration towards the inflammatory focus. Dichloromethane and ethanol extract of *C. baccatum* (1 mg/ear) elicited a 52 and 35% inhibition of the arachidonic acid-ear edema respectively (López et al. 2011). However, the oral administration (300 mg/kg) of all tested extracts showed no antiinflammatory activity in the carrageenan-induced paw edema. The antiinflammatory activity of *C. baccatum* fruit extracts was confirmed through the carrageenan-induced pleurisy model in mice (Zimmer et al. 2012). Transient receptor potential vanilloid 1 (TRPV1) had been reported to be involved in the reduction of ear edema and TNF- α levels in an animal model of contact dermatitis (Alawi and Keeble 2010; Banvolgyi et al. 2005).

Antinociceptive/Analgesic Activity

Two coniferyl esters: coniferyl (E)-8-methyl-6-nonenoate (capsiconiate) and coniferyl 8-methylnonanoate (dihydrocapsiconiate) isolated from *C. baccatum* fruit exhibited agonist activity for transient receptor potential vanilloid 1 (TRPV1) in HEK293 cells (Kobata et al. 2008). The EC₅₀ values of capsiconiate and dihydrocapsiconiate were 3.2 and 4.2 μ M, respectively. Knotkova et al. (2008) elucidated the molecular basis for pain relief by capsaicin and other transient receptor potential vanilloid subfamily, member 1 (TRPV1) agonists. They reported capsaicin receptor TRPV1 to be a polymodal nociceptor, exhibiting a dynamic threshold of activation that could be lowered under inflammatory conditions. TRPV1 desensitization of primary sensory neurons is a powerful approach to relieve symptoms of nociceptive behavior in animal models of chronic pain. TRPV1 desensitization of primary sensory neurons had been proven to be a powerful approach to relieve symptoms of nociceptive behavior in animal models of chronic pain. However, over-the-counter capsaicin creams had shown moderate to poor analgesic efficacy which in part could be related to low dose, poor skin absorption, and compliance factors. They predicted a “revival” for capsaicin and other TRPV1 agonists in the clinical management of pain associated with inflammation, metabolic imbalances

(e.g., diabetes), infections (HIV), and cancer, despite the current focus of the pharmaceutical industry on TRPV1 antagonists. The topical application of capsaicin had been reported to have a therapeutic value in a variety of neuropathic pain conditions such as rheumatoid arthritis (Deal et al. 1991; McCarthy and McCarthy 1992), painful knee osteoarthritis (Kosuwon et al. 2010), painful diabetic peripheral neuropathy (Tsfaye et al. 2011), postherpetic neuralgia (Bernstein et al. 1987, 1989; Backonja et al. 2010; Wallace and Pappagallo 2011) and painful human immunodeficiency virus-associated distal sensory polyneuropathy (HIV-DSP) (Simpson et al. 2010).

Antioxidant and Antimicrobial Activities

The antioxidant activity was positively correlated with the amount of phenolics found in extracts of different parts of *Capsicum baccatum* (Kappel et al. 2008). The ex-vivo antioxidant potential was also confirmed using the rat liver slice model. The extracts exhibited weak antimicrobial activity against Gram-positive and Gram-negative bacteria and fungi. The antioxidant activity of *C. baccatum* fruit extracts was also shown by Zimmer et al. (2012) using DPPH scavenging assay and the contents of active ingredients of phenolics and flavonoids determined.

The plain and heated aqueous extracts from fresh *Capsicum annum*, *Capsicum baccatum*, *Capsicum chinense*, *Capsicum frutescens*, and *Capsicum pubescens* varieties were found to exhibit varying degrees of inhibition against *Bacillus cereus*, *Bacillus subtilis*, *Clostridium sporogenes*, *Clostridium tetani*, and *Streptococcus pyogenes* (Cichewicz and Thorpe 1996). Two pungent compounds found in *Capsicum* species (capsaicin and dihydrocapsaicin) were also assayed for their antimicrobial effects.

Traditional Medicinal Uses

The hot and pungent fruit is regarded as antihemorrhoidal, antirheumatic, antiseptic, diaphoretic, digestive, irritant, rubefacient, sialagogue

and tonic (Bown 1995). It is administered internally to treat cold stage of fevers, debility in convalescence or old age, varicose veins, asthma and digestive problems. Externally it is used in the topical application of sprains, unbroken chilblains, neuralgia, pleurisy etc.

Other Uses

C. baccatum cultivars can be used in chilli breeding for genetic improvement purposes. Chilli Pepper extracts and oleoresin containing capsaicin are used in production of self-defence and less than-lethal (LTL) weaponry e.g. in pepper sprays. Fruit extracts of *C. baccatum* have been found to exhibit toxic and repellent effects against spider mites (Antonious et al. 2006b). Capsaicin is also employed in a gel-based product as a feral pigeon deterrent from specific roosting and loafing areas.

Comments

Capsicum baccatum L. has been conventionally classified into two different species, *C. pendulum* Willd. and *C. microcarpum* Cav. Hunziker (1961) suggested uniting these two species into a single species, *C. baccatum*. Based on crossability and quantitative morphological analysis, however, Eshbaugh (1970) suggested that these two species form a complex of cultivated and wild types. *C. pendulum* represents the cultivated and *C. microcarpum* the wild type. Eshbaugh (1968, 1970) designated *C. pendulum* as *C. baccatum* var. *pendulum* (Willd.) Eshbaugh and *C. microcarpum* as *C. baccatum* L., var. *baccatum*. Some authors have observed that *C. baccatum* var. *baccatum* intergrades into domesticated *C. baccatum* (Eshbaugh 1980; Pickersgill et al. 1979), while others have observed the ease with which these two varieties can be separated from another based on morphologic characteristics (Eshbaugh 1970; Jensen et al 1979). Eshbaugh taxonomical treatment was supported by the study of Egawa and Tanaka (1984). Studies using biochemical/molecular methods to differentiate

var. *baccatum* from var. *pendulum* have met with limited success. For instance, Ballard et al. (1970) observed that the flavonoid profiles of both varieties were identical. Jensen et al. (1979) reported that *C. baccatum* var. *pendulum* and *C. baccatum* var. *baccatum* could not be differentiated from each other based on isozymes (23 loci, 63 alleles), but *C. baccatum* var. *praetermissum* was distinctly different from both. Walsh and Hoot (2001) differentiated the two varieties from one another using sequence data obtained from waxy introns and atpBrbcL noncoding spacer regions. However, because only a single accession of each variety was included in the study, the possibility that those differences reflected only intraspecific variability cannot be discounted (Jarret 2007).

Selected References

- Alawi K, Keeble J (2010) The paradoxical role of the transient receptor potential vanilloid 1 receptor in inflammation. *Pharmacol Ther* 125:181–195
- Antonious GF, Jarret RL (2006) Screening *Capsicum* accessions for capsaicinoids content. *J Environ Sci Health B* 41(5):717–729
- Antonious GF, Kochhar TS, Jarret RL, Snyder JC (2006a) Antioxidants in hot pepper: variation among accessions. *J Environ Sci Health B* 41(7):1237–1243
- Antonious GF, Meyer JE, Snyder JC (2006b) Toxicity and repellency of hot pepper extracts to spider mite, *Tetranychus urticae* Koch. *J Environ Sci Health B* 41(8):1383–1391
- Backonja MM, Malan TP, Vanhove GF, Tobias JK, C102/106 Study Group (2010) NGX-4010, a high-concentration capsaicin patch, for the treatment of postherpetic neuralgia: a randomized, double-blind, controlled study with an open-label extension. *Pain Med* 11(4):600–608
- Ballard RE, McClure JW, Eshbaugh WH, Wilson KG (1970) A chemosystematic study of selected taxa of *Capsicum*. *Am J Bot* 57:225–233
- Banvolgyi A, Palinkas L, Berki R, Clark N, Grant A D, Helyes Z (2005) Evidence for a novel protective role of the vanilloid TRPV1 receptor in a cutaneous contact allergic dermatitis model. *J Neuroimmunol* 169:86–96
- Bernstein JE, Bickers DR, Dahl MV, Roshal JY (1987) Treatment of chronic postherpetic neuralgia with topical capsaicin. A preliminary study. *J Am Acad Dermatol* 17(1):93–96
- Bernstein JE, Korman NJ, Bickers DR, Dahl MV, Millikan LE (1989) Topical capsaicin treatment of chronic postherpetic neuralgia. *J Am Acad Dermatol* 21(2 Pt 1):265–270

- Bown D (1995) Encyclopaedia of herbs and their uses. Dorling Kindersley, London, 424 pp
- Chile Head (2011) Varieties database. <http://www.g6csy.net/chile/database.html>
- Cichewicz RH, Thorpe PA (1996) The antimicrobial properties of chile peppers (*Capsicum* species) and their uses in Mayan medicine. *J Ethnopharmacol* 52(2): 61–70
- D'Arcy WG, Eshbaugh WH (1974) New World peppers [*Capsicum*-Solanaceae] north of Colombia: A resume. *Baileya* 19:93–105
- DeWitt D, Bosland PW (1996) Peppers of the world: an identification guide. Ten Speed Press, Berkeley, 219 pp
- Egawa Y, Tanaka M (1984) Cytogenetical relationships among the three species of chilli peppers, *Capsicum chinense*, *C. frutescens* and *C. baccatum*. *Jpn J Breed* 34:50–56
- Eshbaugh WH (1968) A nomenclatural note on the genus *Capsicum*. *Taxon* 17:51–52
- Eshbaugh WH (1970) A biosystematic and evolutionary study of *Capsicum baccatum* (Solanaceae). *Brittonia* 22:31–43
- Eshbaugh WH (1976) XII. Genetic and biochemical systematic studies of chili peppers (*Capsicum*-Solanaceae). *Bull Torrey Bot Club* 102:396–403
- Eshbaugh WH (1980) The taxonomy of the genus *Capsicum* (Solanaceae). *Phytologia* 47(3):153–165
- Eshbaugh WH, Guttman SI, McLeod MJ (1983) The origin and evolution of domesticated *Capsicum* species. *J Ethnobiol* 3:49–54
- Hunziker AT (1950) Estudios sobre Solanaceae. I. Sinopsis de las especies silvestres de Capsicum de Argentina y Paraguay. *Darwiniana* (Buenos Aires) 9:225–247 (In Spanish)
- Hunziker AT (1961) Noticia sobre el cultivo de *Capsicum baccatum* L. (Solanaceae) en Argentina. *Kurtziana* (Cordoba) 1:303 (In Spanish)
- Hunziker AT (1971) Estudios sobre Solanaceae. VII. Contribucion al conocimiento de *Capsicum* generos afines (*Witheringia*, *Achnistus*, *Athenaea*, etc.), Tercera Parte. *Kurtziana* 6:241–259 (In Spanish)
- Jarret RL (2007) Morphologic variation for fruit characteristics in the USDA/ARS *Capsicum baccatum* L. germplasm collection. *HortSci* 42(5):1303–1305
- Jensen RJ, McLeod MJ, Eshbaugh WH, Guttman SI (1979) Numerical taxonomic analyses of allozymic variation in *Capsicum* - (Solanaceae). *Taxon* 28: 315–327
- Junior SB, Tavares AM, Filho JT, Zini CI, Godoy HT (2012) Analysis of the volatile compounds of Brazilian chilli peppers (*Capsicum* spp.) at two stages of maturity by solid phase micro-extraction and gas chromatography-mass spectrometry. *Food Res Int* 48(1):96–107
- Kappel VD, Costa GM, Scola G, Silva FA, Landell MF, Valente P, Souza DG, Vanz DC, Reginatto FH, Moreira JC (2008) Phenolic content and antioxidant and antimicrobial properties of fruits of *Capsicum baccatum* L. var. *pendulum* at different maturity stages. *J Med Food* 11(2):267–274
- Katzer G (2012) Chile (*Capsicum frutescens* L. and others). http://www.uni-graz.at/~katzer/engl/Caps_fru.html
- Knotkova H, Pappagallo M, Szallasi A (2008) Capsaicin (TRPV1 agonist) therapy for pain relief: farewell or revival? *Clin J Pain* 24(2):142–154
- Kobata K, Tate H, Iwasaki Y, Tanaka Y, Ohtsu K, Yazawa S, Watanabe T (2008) Isolation of coniferyl esters from *Capsicum baccatum* L., and their enzymatic preparation and agonist activity for TRPV1. *Phytochemistry* 95(5):1179–1184
- Kollmannsberger H, Rodríguez-Burruezo A, Nitz S, Nuez F (2011) Volatile and capsaicinoid composition of ají (*Capsicum baccatum*) and rocoto (*Capsicum pubescens*), two Andean species of chile peppers. *J Sci Food Agric* 91(9):1598–1611
- Kosuwon W, Sirichatiwapee W, Wisanuyotin T, Jeeravipoolvarn P, Laupattarakasem W (2010) Efficacy of symptomatic control of knee osteoarthritis with 0.0125% of capsaicin versus placebo. *J Med Assoc Thai* 93(10):1188–1195
- López P, Gorzalczy S, Acevedo C, Alonso R, Ferraro G (2011) Chemical study and anti-inflammatory activity of *Capsicum chacoense* and *C. baccatum*. *Rev Bras Farmacogn* 22(2):455–458
- McCarthy GM, McCarthy DJ (1992) Effect of topical capsaicin in the therapy of painful osteoarthritis of the hands. *J Rheumatol* 19(4):604–607
- McLeod MJ, Guttman SI, Eshbaugh WH, Rayle RE (1983) An electrophoretic study of evolution in *Capsicum* (Solanaceae). *Evolution* 37:562–574
- National Research Council (1989) Lost crops of the Incas: little-known plants of the Andes with promise for worldwide cultivation. BOSTID, National Research Council. National Academy Press, Washington, DC, 428 pp
- Pickersgill B, Heiser CB, McNeil J (1979) Numerical taxonomic studies on variation and domestication in some species of *Capsicum*. In: Hawkes JG, Lester RN, Skelding AD (eds) The biology and taxonomy of the Solanaceae. Academic, New York, pp 678–700
- Rodríguez JM, Berke T, Engle L, Nienhuis J (1999) Variation among and within *Capsicum* species revealed by RAPD markers. *Theor Appl Genet* 99:147–156
- Rodríguez-Burruezo A, Prohens J, Raigón MD, Nuez F (2009) Variation for bioactive compounds in ají (*Capsicum baccatum* L.) and rocoto (*C. pubescens* R. & P.) and implications for breeding. *Euphytica* 170(1–2):169–181
- Rodríguez-Burruezo A, González-Mas Mdel C, Nuez F (2010) Carotenoid composition and vitamin A value in ají (*Capsicum baccatum* L.) and rocoto (*C. pubescens* R. & P.), 2 pepper species from the Andean region. *J Food Sci* 75(8):S446–S453
- Simpson DM, Gazda S, Brown S, Webster LR, Lu SP, Tobias JK, Vanhove GF, NGX-4010 C118 Study Group (2010) Long-term safety of NGX-4010, a high-concentration capsaicin patch, in patients with peripheral neuropathic pain. *J Pain Symptom Manage* 39(6):1053–1064

- Singh S, Jarret R, Russo V, Majetich G, Shimkus J, Bushway R, Perkins B (2009) Determination of capsinoids by HPLC-DAD in *Capsicum* species. *J Agric Food Chem* 57(9):3452–3457
- Spiller F, Alves MK, Vieira SM, Carvalho TA, Leite CE, Lunardelli A, Poloni JA, Cunha FQ, de Oliveira JR (2008) Anti-inflammatory effects of red pepper (*Capsicum baccatum*) on carrageenan- and antigen-induced inflammation. *J Pharm Pharmacol* 60(4):473–478
- Tanaka Y, Hosokawa M, Otsu K, Watanabe T, Yazawa S (2009) Assessment of capsinoninoid composition, nonpungent capsaicinoid analogues, in capsicumcultivars. *J Agric Food Chem* 57(12):5407–5412
- Tesfaye S, Vileikyte L, Rayman G, Sindrup S, Perkins B, Baconja M, Vinik A, Boulton A, Toronto Expert Panel on Diabetic Neuropathy (2011) Painful diabetic peripheral neuropathy: consensus recommendations on diagnosis, assessment and management. *Diabetes Metab Res Rev* 27:629–638
- Wahyuni Y, Ballester AR, Sudarmonowati E, Bino RJ, Bovy AG (2011) Metabolite biodiversity in pepper (*Capsicum*) fruits of thirty-two diverse accessions: variation in health-related compounds and implications for breeding. *Phytochemistry* 72(11–12): 1358–1370
- Wallace M, Pappagallo M (2011) Qutenza®: a capsaicin 8% patch for the management of postherpetic neuralgia. *Expert Rev Neurother* 11(1):15–27
- Walsh BM, Hoot SB (2001) Phylogenetic relationships of *Capsicum* (Solanaceae) using DNA sequences from two noncoding regions: the chloroplast ATPB-RBCL spacer region and nuclear *waxy* introns. *Int J Plant Sci* 162:1409–1418
- Zimmer AR, Leonardi B, Miron D, Schapoval E, Oliveira JR, Gosmann G (2012) Antioxidant and anti-inflammatory properties of *Capsicum baccatum*: from traditional use to scientific approach. *J Ethnopharmacol* 139(1):228–233

Capsicum chinense

Scientific Name

Capsicum chinense Jacquin.

Synonyms

Capsicum sinense Murray, *Capsicum toxicarium* Poepp. ex Fingerh.

Family

Solanaceae

Common/English Names

Habaneros, Habanero Chilli, Habanero Pepper, Satan Chili, Scotch Bonnet, Yellow Lantern.

Common names for the different varieties are based on their source of origin or production:

Adjuma (Suriname), Ají Limo or Naucho (Peru), Ají Dulce (Venezuela), Datil (Florida), Fatalii (South Central Africa), Habanero Chile (Cuba and Yucatán), Habanero Cultivar Red Savina Pepper (Costa Rica and California), Madame Jeanette (Haiti), Naga Morich (Bangladesh), Dorset Naga Pepper, Naga Jolokia Pepper or Bhut Jolokia Chili Pepper (India), African Pili-Pili (Burundi), Scotch Bonnet (Jamaica).

Vernacular Names

Bolivia: Común Uchu;

French: Piment Enragé De La Jamaïque, Piment Chien;

Nigeria: Yoruba Ata Rodo (Isawumi);

Portuguese: Pimento De Cheiro;

Quechuan: Chinchu Uchu (Fresh), Chaki Uchu (Dried);

India: Bhut Jôlôkia (Assamese), Naga Morich (Bengali), Umorok (Manipuri).

Origin/Distribution

Capsicum chinense originated from the Amazonas and introduced into Central America, the Yucatan region and the Caribbean islands where it was cultivated many centuries ago. It was misnamed *Capsicum chinense* (from China) by Niko-lauss von Jacquin, a Dutch physician, who collected the plants in the Caribbean in 1777.

Agroecology

Similar agroecological requirements as for *Capsicum annum* and *Capsicum frutescens* – warm tropical to subtropical climate in frost free areas, a range of 7–29°C with annual rainfall of 300–4,300 mm in full sun on fertile well-drained soil rich in organic matter.

Edible Plant Parts and Uses

Eaten fresh or pulverised and made into hot sauces and pastes which are available as commercial products. Beside the hot sauces other processed products include: dried pods which should be rehydrated for about a half hour in hot water before using; smoked pods which should also be rehydrated; powders, pickles whole or chopped pieces in vinegar and crushed or pureed Habaneros.

Habaneros hot sauces are not only well known in the Caribbean and mainland USA but world-wide such as *piquante* and *chien* from Martinique and *ti-malice* from Haiti which consists of shallots, lime juice, garlic, and the hottest habaneros available. Puerto Rico boasts of two hot sauces *pique* – habaneros combined with acidic Seville oranges and *sofrito*, which comprises small piquins (“bird peppers”) with annatto seeds, cilantro, onions, garlic, and tomatoes. In Jamaica, Scotch bonnets are combined with the pulp and juices of mangoes, papayas, and tamarinds. The Virgin Islands have a concoction called “*Asher*,” which combines habaneros with limes, cloves, allspice, salt, vinegar, and garlic.

Botany

Small, much-branched, mostly erect, annual or perennial sub-shrub, 30–120 cm high. The leaves are pale to medium green, usually ovate in shape, and are usually crinkled, which is a distinguishing trait. Flowers and fruits occurs in clusters of 2–3 or more per node and this trait distinguishes it from the other *Capsicum* species which bears one per node. The flowers have white, slightly greenish corollas and purple anthers without diffuse spots at base of lobes; corolla lobes are usually straight. Pedicels erect or declining at anthesis. The pods vary greatly in size and shape, ranging from chiltepin-sized berries 0.5 cm diameter, globose to cylindrical, 2–5 × 1.5–3 cm, to elongated pods up to 10 cm long, wrinkled, usually pendant, red to orange to yellow or white when mature (Plates 1–4). The familiar habaneros



Plate 1 Fruits of a yellow scotch bonnet variety



Plate 2 Fruits of a red scotch bonnet variety



Plate 3 Ripe and green fruits of habanero variety



Plate 4 Harvested fruits of habanero variety

are pendant, lantern-shaped or campanulate (a flattened bell shape), and some are pointed at the end. Caribbean *chinenses* are often flattened at the end and resemble a tam, or bonnet. Often the blossom ends of these pods are inverted.

Nutritive/Medicinal Properties

Concentrations (mg/100 g fresh weight (FW) of whole fruit) of sucrose, glucose, and fructose in *Capsicum chinense* fruit ranged from 0.0 to 150, 68 to 701, and 101 to 823, respectively (Jarret et al. 2009). The total sugars (sucrose+glucose+fructose) ranged from 198 to 1,543 mg/100 g FW. Concentrations of organic acids ranged from 0.0 (not detected) to 818, 430, 340, and 232 mg/100 g FW for citric, malic, fumaric, and succinic acids, respectively. However, the relative ranking in the concentrations of the individual acids was genotype-dependent. Total ascorbic-acid values ranged from 30 to 1,466 mg/100 g FW. In another study, fruits of *C. chinense* accessions PI-152452 (Brazil) and PI-360726 (Ecuador) contained the greatest concentrations of ascorbic acid (1.2 and 1.1 mg/g fresh fruit, respectively), while PI-438648 (Mexico) contained the greatest concentration of total phenols content (349 µg/g fresh fruit) among the other 63 accessions tested (Antonious et al. 2009b). Accession PI-355817 from Ecuador contained the greatest concentrations of β-carotene (8 mg/g fresh fruit).

The Habanero chili (*Capsicum chinense*) had significantly higher total phenolic content (5.92 mg/g GAE) than the Chiltepin chili (*Capsicum annuum* var. *glabriusculum*) (4.85 mg/g GAE) (Rodríguez-Maturino et al. 2012). In contrast, Chiltepin chili showed higher total antioxidant activity (11.10 mg of GAE/g of dry weight) than Habanero chili. Habanero chilli had lower content (14 mg/g dry weight) of carotenoids that includes the yellow isochromic fraction (provitamin A carotenoids, b-carotene and b-crip-toxanthin) and while the Chiltepin chilli had higher levels of yellow isochromic fraction (36 mg/g dry weight). Chiltepin chilli had higher levels of red isochromic fraction (capsanthin and capsorubin) than the Habanero. Also the Chiltepin showed the higher value of extractable colour (80 ASTA units) than Habanero (40 ASTA units).

Capsaicinoid namely capsaicin, dihydrocapsaicin, nordihydrocapsaicin, homocapsaicin, homodihydrocapsaicin, and nonivamide were found in fresh peppers (*C. annuum* – Anaheim, Red Chilli, Green chilli, green bell pepper, yellow bell pepper; *C. chinense*- Habañero), oleoresin capsicum, and pepper spray products (Reilly et al. 2001). Fresh Habañero (Utah) pepper was found to have 510 µg/g total capsaicinoid, 3.6% nordihydrocapsaicin, 1.4% nonivamide, 61% capsaicin, 32% dihydrocapsaicin, 0.9% homocapsaicin and 1.1% homodihydrocapsaicin. The total capsaicinoid concentration in extracts of the fresh peppers was reflective of the relative “hotness” of the pepper (habañero>anaheim=red-chili>green-chili>green bell>yellow bell) (Reilly et al. 2001). The sum of the concentrations of capsaicin and dihydrocapsaicin in the extracts of fresh pepper paralleled the relative pungency of the pepper type and appeared to dictate the pungency of the fruit. For example, extracts of habañero peppers (the “hottest” pepper) contained approximately 90% capsaicin and dihydrocapsaicin while extracts of the milder green-chili pepper contained about 65% capsaicin and dihydrocapsaicin.

The Habanero chilli peppers and the Scotch Bonnet varieties of *Capsicum chinense* are

renowned to be very aromatic and the hottest pepper in the world (Kurian and Starks 2002). The hot, pungent taste was reported due to the presence of non-volatile capsaicinoids, particularly capsaicin {N-[(4-hydroxy-3-methoxyphenyl)methyl]-8-methyl-non-6-enamide} and dihydrocapsaicin {N-[(4-hydroxy-3-methoxyphenyl)methyl]-8-methyl-nonanamide} accounting for approximately 80–90% of the spiciness (Higashiguchi et al. 2006; Davis et al. 2007). *Capsicum chinense* (orange habañero) peppers, both undried and dried, contained average values of 1,250 ppm capsaicin and 540 ppm dihydrocapsaicin relative to undried weight (Kurian and Starks 2002). Relative to dry weight, the orange habañero peppers contained 8,840 ppm capsaicin and 3,940 ppm dihydrocapsaicin. In another study, The content of capsaicinoids of ten Habanero chilli pepper, responsible for the pungency of chilli peppers, varied between 41.8 and 65.9 mg/g dry fruit (Pino et al. 2007). Mean concentration of orange Habanero cultivars was 55.0 mg/g, while red cultivars had 45.0 mg/g dry fruit, indicating that the former were more pungent. In general, orange and brown Habanero cultivars had higher amounts of esters, with their fruity odour notes, than red cultivars. These differences were reflected in the amount of total volatiles, which is higher in orange and brown cultivars in comparison with red cultivars.

Capsiconinoid, a group of nonpungent capsaicinoid analogues with agonist activity for transient receptor potential vanilloid type 1 (TRPV1), be a receptor for capsaicin, was found in ten cultivars of *Capsicum annuum*, *C. baccatum*, *C. chinense*, *C. frutescens*, and *C. pubescens*. (Tanaka et al. 2009). Capsiconinoid Baccatum (CCB) (*C. baccatum* var. *praetermissum*) showed the highest capsiconinoid content (3,314 µg/g DW) and Charapita (*C. chinense*) had the second highest content. The other eight cultivars had much lower capsiconinoid content than these two cultivars (<300 µg/g DW). Time-course analysis during fruit development revealed that capsiconinoid content in CCB fruits increased until 30 days after flowering (DAF) and then decreased rapidly until 40 DAF.

Total phenol content was correlated with ascorbic acid ($R^2=0.97$) and free sugars

($R^2=0.80$) in the *Capsicum* germplasm tested that included four accessions of *Capsicum chinense*; five accessions of *C. baccatum*; six accessions of *C. annuum*; and two of *C. frutescens* (Antonious et al. 2006a). Concentrations of total phenols (1.4, 1.3, and 1.3 mg/g fruit) and ascorbic acid (1.6, 1.2, and 1.3 mg/g fruit) were significantly greater in PI-633757, PI-387833, and PI-633754, respectively, compared to other accessions analyzed. Total capsaicinoids concentrations were greatest (1.3 mg/g fruit) in PI-438622 and lowest (0.002 mg/g fruit) in Grif-9320. Capsaicin and dihydrocapsaicin were the dominant capsaicinoids detected in methanol extract of fresh fruits of *Capsicum chinense*, *C. frutescens*, *C. baccatum*, *C. annuum*, and *C. pubescens* (Antonious and Jarret 2006); nordihydrocapsaicin was also detected. Capsaicin concentrations were typically greater than dihydrocapsaicin. Concentrations of total capsaicinoids varied from not detectable to 11.2 mg/fruit. Statistical analysis revealed that accession PI-441624 (*C. chinense*) had the highest capsaicin content (2.9 mg/g fresh fruit) and accession PI-497984 (*C. frutescens*) had the highest dihydrocapsaicin content (2.3 mg/g fresh fruit). Accessions PI-439522 (*C. frutescens*) and PI-497984 contained the highest concentrations of total capsaicinoids.

Capsaicin concentrations in fruits of *Capsicum chinense* accessions were generally greater than dihydrocapsaicin (Antonious et al. 2009a). Concentrations of capsaicin varied among accessions from 1.52 mg/g fruit in PI640900 to 0.01 mg/g fruit in PI257050. Concentrations of dihydrocapsaicin varied among accessions from 1.16 mg/g in PI640900 to 0.003 mg/g in PI257050. Concentrations of total capsaicinoids (capsaicin and dihydrocapsaicin) varied among accessions from 2.68 mg/g 1 in PI640900 to 0.01 mg/g in PI-257050. Nordihydrocapsaicin was present at very low concentrations when compared to capsaicin and dihydrocapsaicin. Concentrations of nordihydrocapsaicin in fruits of *C. chinense* averaged 0.26 µg/g fresh fruit. Fruits of *C. chinense* accession PI640900 (USA) contained the greatest concentration of capsaicin (1.52 mg/g fruit) and dihydrocapsaicin (1.16 mg/g fruit), while total major capsaicinoids in the fruits of PI438648

(Mexico) averaged 2 mg/g fruit. These two accessions were identified as potential candidates for mass production of major capsaicinoids that have health-promoting properties and for use as a source of pest control agents in agricultural fields. In another paper they reported that mature fruits of *C. chinense* accessions PI-152452 (Brazil) and PI-360726 (Ecuador) contained the greatest concentrations of ascorbic acid (1.2 and 1.1 mg/g fresh fruit, respectively), while PI-438648 (Mexico) contained the greatest concentration of total phenols content (349 µg/g fresh fruit) among the other 63 accessions tested (Antonious et al. 2009b). Accession PI-355817 from Ecuador contained the greatest concentrations of β-carotene (8 mg/g fresh fruit). These accessions were identified as potential candidates for mass production of antioxidants with health-promoting properties.

Kollmannsberger et al. (2011) found that *C. chinense* were more pungent than ají (*Capsicum baccatum* L. var. *pendulum*) and rocoto (*Capsicum pubescens* R. & P.) (1,650 vs 13–352 mg/kg in total capsaicinoids). The powerful fruity/exotic aroma of the *C. chinense* control was attributed to esters such as ethyl 4-methylpentanoate, norcarotenoids such as β-ionone and the hydrocarbon ectocarpene.

Forty-nine samples representing distinct morphotypes of four cultivated species (*C. annuum* var. *annuum*, *C. annuum* var. *glabriusculum*, *C. baccatum*, *C. chinense*, and *C. frutescens*) were found to contain detectable levels (11–369 µg/g) of a capsinoid, E-capsiate (Singh et al. 2009). Nine of the E-capsiate-containing samples also had dihydrocapsiate (18–86 µg/g). Tanaka et al. (2010) showed that three mildly pungent cultivars of *Capsicum chinense* (Zavory Hot, Aji Dulce strain 2, and Belize Sweet) contained high levels of capsinoid. It was shown that these cultivars had novel p-amt alleles, which contained mutations that differed from those of *C. annuum*. Capsinoids have similar bioactivities to capsaicinoids such as suppression of fat accumulation and antioxidant activity.

One hundred and two volatile compounds were identified from Yucatan Habanero chili pepper (Pino et al. 2006). (E)-2-hexenal, hexyl

3-methylbutanoate, (Z)-3-hexenyl 3-methylbutanoate, hexyl pentanoate, 3,3-dimethylcyclohexanol, and hexadecanoic acid were found to be the major constituents. During Habanero chili pepper maturation, the majority of volatile compounds decreased or even disappeared, some of them with green odour notes while esters, which have fruity odour notes, increased at the same time. In another study, the content of volatile compounds, responsible for the flavour of Cachucha peppers (*Capsicum chinense*), varied between 110.71 and 302.53 mg/kg (Pino et al. 2011). One hundred and thirty-six compounds were identified, from which hexyl isopentanoate, hexyl pentanoate, hexyl 2-methylbutanoate, 3,3-dimethylcyclohexanol, γ-himachalene and germacrene D were the major ones. More than 300 volatile constituents were detected in the ripe fruits of 16 *Capsicum* accessions from the *annuum-chinense-frutescens* complex (Rodríguez-Burruezo et al. 2010). Esters and terpenoids were the main groups, although other minor compounds, such as nitrogen and sulfur compounds, phenol derivatives, norcarotenoids, lipoxygenase derivatives, carbonyls, alcohols, and other hydrocarbons, were also identified. The sniffing test revealed that the diversity of aromas found among the studied cultivars was due to qualitative and quantitative differences of, at least, 23 odour-contributing volatiles (OCVs). *C. chinense*, and *C. frutescens* accessions, with fruity/exotic aromas, were characterized by a high contribution of several esters and ionones and a low or nil contribution of green/vegetable OCVs. Different combinations of fruity/exotic and green/vegetable OCVs would explain the range of aroma impressions found among *C. annuum* accessions. A total of 77 compounds, mostly esters and sesquiterpenes, were identified in the murupi chilli pepper (*Capsicum chinense*) (Junior et al. 2012).

Capsicum chinense scotch bonnet cv fruit was found to have 47.632 mg/g of capsaicin, 23.096 mg/g and a Scoville heat value of 142931 indicating it to be high hot chilli pepper according to the Scoville scale (Gahungu et al. 2011). Seventy volatile compounds were identified, comprising 25 aliphatic esters (34.16%), 9 alcohols (19.68%), 15 terpenoids (15.63), 10 acids (15.87%), 2 ketones

(5.92%), 4 hydrocarbons (4.4%), 3 aldehydes (2.17%) and 1 other compound dihydroactinidolide were detected. Hexyl isopentanoate (9.17%), hexyl pentanoate (5.62%), pentyl 3-methylbutanoate (4.21%), octyl-2-methylbutanoate (3.37%), (Z)-3-hexenyl isopentanoate (2.47%) were the major esters; 10-undecenol (9.20%), 3,3-dimethylcyclohexanol (4.61%), 2,3-dimethylcyclohexanol (2.59%) the major alcohols; β -chamigrene (5.64%) the major terpene; dihydrocarvone (3.85%), oxacycloheptadecan-2-one (2.96%) the important ketones; hexadecanoic acid (4.69%), (E)-9-tetradecenoic acid (3.86%) and pentadecanoic acid (2.67%) the important acids. Among aldehydes, pentadecanal (1.20%) was quantitatively important and pentadecane (1.61%), 2-methyl-1-tetradecene (1.35%) were the major compounds in hydrocarbons.

Wahyuni et al. (2011) found that composition and level of metabolites in fruits of four pepper species, *Capsicum annuum*, *Capsicum frutescens*, *Capsicum chinense* and *Capsicum baccatum* varied greatly between accessions and was independent of species and geographical location. Fruit colour was determined by the accumulation of specific carotenoids leading to salmon, yellow, orange, red and brown colored fruits. Levels of both O-glycosides and C-glycosides of quercetin, luteolin and apigenin varied strongly between accessions. All non-pungent accessions were devoid of capsaicins, whereas capsaicinoid levels ranged from 0.07 up to 80 mg/100 g fruit weight in fruit pericarp. In general, pungent accessions accumulated the highest capsaicinoid levels in placenta plus seed tissue compared to pericarp. The non-pungent capsaicinoid analogs, capsates, could be detected at low levels in some pungent accessions. All accessions accumulated high levels of vitamin C, up to 200 mg/100 g fruit weight. The highest vitamin E concentration found was 16 mg/100 g fruit weight.

Two new glucosides, capsaicin- β -D-glucopyranoside (1) and dihydrocapsaicin- β -D-glucopyranoside (2), were discovered in the fruit of the *Capsicum annuum* cultivar 'High Heat' (Higashiguchi et al. 2006). The glucosides were also detected in various pungent cultivars of *C. annuum*, *Capsicum frutescens*, and *Capsicum chinense*. However, they were not detected in

non-pungent cultivars of *C. annuum*. Additionally, a positive correlation was observed between the quantity of the capsaicinoids, capsaicin, and dihydrocapsaicin and their glucosides.

A novel lipid transfer protein designated CcLTP was isolated from ripening fruit of *Capsicum chinense* cv Habanero but not from fruit of any *C. annuum* or *C. frutescens* varieties (Liu et al. 2006). However, CcLTP was consistently expressed in seedlings from the three *Capsicum* species and may have possible role in pepper fruit ripening and maturation.

Antioxidant and Antiinflammatory Activities

Capsicum annuum, *Capsicum frutescens*, and *Capsicum chinense* peppers were found to contain high levels of L-ascorbic acid and carotenoids at maturity, contributing 124–338% of the RDA for vitamin C and 0.33–336 RE/100 g of provitamin A activity, respectively (Howard et al. 2000). Levels of phenolic acids, capxanthin, and zeaxanthin generally increased during maturation, whereas the level of lutein declined. Flavonoid concentrations varied greatly among the pepper types analyzed and were negatively correlated to antioxidant activity under the conditions of the beta-carotene-linoleic assay. Significant increases in antioxidant activity were observed in pepper juice models in response to increasing dilution factors and the presence of EDTA, indicating a pro-oxidant effect due to metal ions in the system. In-vitro models demonstrated that increasing levels of flavonoids in combination with constant levels of caffeic and ascorbic acid gave a resultant antioxidant activity that was either additive of the two compounds or competitive in their ability to scavenge peroxy radicals.

The concentration of capsaicin and dihydrocapsaicin in Bhut Jolokia was found to be 5.36%, which was about 338 and 18 times greater than in Scotch Bonnet and Jalapeno, respectively (Liu and Nair 2010). The isolated capsaicin and dihydrocapsaicin were found to inhibit lipid peroxidation and cyclooxygenase (COX-1 and COX-2) enzymes activities.

Antimicrobial Activity

The plain and heated aqueous extracts from *fresh Capsicum annuum*, *Capsicum baccatum*, *Capsicum chinense*, *Capsicum frutescens*, and *Capsicum pubescens* varieties were found to exhibit varying degrees of inhibition against *Bacillus cereus*, *Bacillus subtilis*, *Clostridium sporogenes*, *Clostridium tetani*, and *Streptococcus pyogenes* (Cichewicz and Thorpe 1996). Two pungent compounds found in *Capsicum* species (capsaicin and dihydrocapsaicin) were also assayed for their antimicrobial effects.

Refer also to notes under *Capsicum annuum*, *Capsicum baccatum* and *Capsicum frutescens*.

Other Uses

Bhut Jolokia and other *C. chinense* cultivars can be used in chilli breeding for genetic improvement purposes. In northeastern India, the Bhut Jolopia peppers are smeared on fences or incorporated in smoke bombs as a safety precaution to keep wild elephants at a distance. Chilli Pepper extracts and oleoresin containing capsaicin are used in production of self-defence and less than-lethal (LTL) weaponry such as pepper sprays. Capsaicin is also employed in a gel-based product as a feral pigeon deterrent from specific roosting and loafing areas. Hot pepper extracts has been found to repel to exhibit toxic and repellent effects against spider mites (Antonious et al. 2006b).

Comments

In replicated trials at Las Cruces, New Mexico, 'Bhut Jolokia', a chilli pepper from Assam, India, was found to attain 1,001,304 SHUs (Scoville heat units) by HPLC (Bosland and Baral 2007). Morphologic characters and DNA studies revealed 'Bhut Jolokia' to be a *Capsicum chinense* Jacq. cultivar with genetic introgression from *Capsicum frutescens*. Chilli hotness (pungency) is measured in Scoville Heat Units (SHU) which is originally a subjective organoleptic measure but today, chilli hotness is more frequently determined by HPLC

(high performance liquid chromatography), whose results can be correlated to traditional Scoville ratings: the conversion generally accepted is that 15 Scoville heat units is equal to 1 ppm capsaicin plus capsaicinoids. Mathur et al. (2000) reported the *C. frutescens* variety 'Tezpur' to be the hottest chilli in India with 4.28% capsaicin, 1.42% dihydrocapsaicin, 15% oleoresin and with a pungency of 855,000 SHU. Previously, the hottest chilli tested was 'Red Savina' Habanero (*C. chinense*), with over 577,000 SHU; the extremely fiery Thai chillies (*C. frutescens*) barely reach 100,000 SHU; more common varieties like the 'jalapeno' or the Italian 'peperoncino' (*C. annuum*) generally lie below 5,000 SHU.

Among six economically import Manipuri chilli cultivars belonging to three species of *Capsicum*: *Capsicum annuum* L. (cvs 'Meiteimorok' and 'Haomorok'), *Capsicum frutescens* L. (cvs 'Uchithi' and 'Mashingkha') and *Capsicum chinense* Jacq. (cvs 'Umorok' and 'Chiengpi') studied, the cultivar 'Umorok' was found to have the highest capsaicin content (2.06% w/w), and was also the most pungent with 329,100 SHU (Sanatombi and Sharma 2008). The cv 'Chiengpi' had a capsaicin content of 7.9% and a pungency of 126,000 SHU. The cv 'Uchithi' had 0.88% capsaicin and pungency of 141,200 SHU while 'Mashingkha' had 0.65% capsaicin and pungency of 104,300 SHU. The cultivar 'Haomorok' had the least capsaicin content (0.17%) with a corresponding pungency of 26,000 SHU.

Selected References

- Antonious GF, Jarret RL (2006) Screening *Capsicum* accessions for capsaicinoids content. *J Environ Sci Health B* 41(5):717–729
- Antonious GF, Kochhar TS, Jarret RL, Snyder JC (2006a) Antioxidants in hot pepper: variation among accessions. *J Environ Sci Health B* 41(7):1237–1243
- Antonious GF, Berke T, Jarret RL (2009a) Pungency in *Capsicum chinense*: variation among countries of origin. *J Environ Sci Health B* 44(2):179–184
- Antonious GF, Meyer JE, Snyder JC (2006b) Toxicity and repellency of hot pepper extracts to spider mite, *Tetranychus urticae* Koch. *J Environ Sci Health B* 41(8):1383–1391

- Antonious GF, Lobel L, Kochhar T, Berke T, Jarret RL (2009b) Antioxidants in *Capsicum chinense*: variation among countries of origin. *J Environ Sci Health B* 44(6):621–626
- Bosland PW (1996) Capsicums: innovative uses of an ancient crop. In: Janick J (ed) *Progress in new crops*. ASHS Press, Arlington, pp 479–487
- Bosland PW, Baral JB (2007) Bhut Jolokia — the world's hottest known chile pepper is a putative naturally occurring interspecific hybrid. *Hort Sci* 42(2):222–224
- Chile Head (2011) Varieties database. <http://www.g6csy.net/chile/database.html>
- Cichewicz RH, Thorpe PA (1996) The antimicrobial properties of chile peppers (*Capsicum* species) and their uses in Mayan medicine. *J Ethnopharmacol* 52(2):61–70
- D'Arcy WG, Eshbaugh WH (1974) New world peppers (*Capsicum* – Solanaceae) north of Colombia: a résumé. *Baileya* 19:93–105
- Davis CB, Carolyn EM, Marianna AB, Kenneth WB (2007) Determination of capsaicinoids in Habanero peppers by Chemometric analysis of UV spectral data. *J Agric Food Chem* 55:5925–5933
- Eshbaugh WH (1980) The taxonomy of the genus *Capsicum* (Solanaceae). *Phytologia* 47(3):153–165
- Gahungu A, Ruganintwali E, Karangwa E, Zhang X, Mukunzi D (2011) Volatile compounds and capsaicinoid content of fresh hot peppers (*Capsicum chinense*) scotch bonnet variety at red stage. *Adv J Food Sci Technol* 3(3):211–218
- Higashiguchi F, Nakamura H, Hayashi H, Kometani T (2006) Purification and structure determination of glucosides of capsaicin and dihydrocapsaicin from various *Capsicum* fruits. *J Agric Food Chem* 54(16):5948–5953
- Howard LR, Talcott ST, Brenes CH, Villalon B (2000) Changes in phytochemical and antioxidant activity of selected pepper cultivars (*Capsicum* species) as influenced by maturity. *J Agric Food Chem* 48(5):1713–1720
- Hussain W (2007) World's hottest chile used as elephant repellent. *National Geographic News*. <http://news.nationalgeographic.com/news/2007/11/071120-AP-india-elephants.html>. Retrieved 21 Nov 2007
- Jarret RL, Berke T, Baldwin EA, Antonious GF (2009) Variability for free sugars and organic acids in *Capsicum chinense*. *Chem Biodivers* 6(2):138–145
- Junior SB, Tavares AM, Filho JT, Zini CI, Godoy HT (2012) Analysis of the volatile compounds of Brazilian chilli peppers (*Capsicum* spp.) at two stages of maturity by solid phase micro-extraction and gas chromatography-mass spectrometry. *Food Res Int* 48(1):96–107
- Katzer G (2012) Chile (*Capsicum frutescens* L. and others). http://www.uni-graz.at/~katzer/engl/Caps_fru.html
- Kollmannsberger H, Rodríguez-Burruezo A, Nitz S, Nuez F (2011) Volatile and capsaicinoid composition of aji (*Capsicum baccatum*) and rocoto (*Capsicum pubescens*), two Andean species of chile peppers. *J Sci Food Agric* 91(9):1598–1611
- Kurian AL, Starks AN (2002) HPLC analysis of capsaicinoids extracted from whole orange habanero chili peppers. *J Food Sci* 67(3):956–962
- Liu Y, Nair MG (2010) Capsaicinoids in the hottest pepper Bhut Jolokia and its antioxidant and antiinflammatory activities. *Nat Prod Commun* 5(1):91–94
- Liu K, Jiang H, Moore SL, Watkins CB, Jahn MM (2006) Isolation and characterization of a lipid transfer protein expressed in ripening fruit of *Capsicum chinense*. *Planta* 223(4):672–683
- Mathur R, Sangi RS, Dass SC, Malhotra RC (2000) The hottest chili variety in India. *Curr Sci* 79(3):287–288
- Pino J, Sauri-Duch E, Mabot R (2006) Change in volatile compounds of Habanero chile pepper (*Capsicum chinense* Jack. Cv. Habanero) at two ripening stages. *J Food Chem* 94:394–396
- Pino J, González M, Ceballos L, Centurión-Yah AR, Trujillo-Aguirre J, Latournerie-Moreno L, Sauri-Duch E (2007) Characterization of total capsaicinoids, colour and volatile compounds of Habanero chilli pepper (*Capsicum chinense* Jack.) cultivars grown in Yucatan. *Food Chem* 104(4):1682–1686
- Pino J, Fuentes V, Barrios O (2011) Volatile constituents of Cachucha peppers (*Capsicum chinense* Jacq.) grown in Cuba. *Food Chem* 125(3):860–864
- Poulos JM (1994) *Capsicum* L. In: Siemonsma JS, Piluek K (eds) *Plant resources of south-east Asia*, no. 8. Vegetables. Pudoc, Wageningen, pp 136–140
- Reilly CA, Crouch DJ, Yost GS (2001) Quantitative analysis of capsaicinoids in fresh peppers, oleoresin capsaicin and pepper spray products. *J Forensic Sci* 46(3):502–509
- Rodríguez-Burruezo A, Kollmannsberger H, González-Mas MC, Nitz S, Fernando N (2010) HS-SPME comparative analysis of genotypic diversity in the volatile fraction and aroma-contributing compounds of *Capsicum* fruits from the *annuum-chinense-frutescens* complex. *J Agric Food Chem* 58(7):4388–4400
- Rodríguez-Maturino A, Valenzuela-Solorio A, Troncoso-Rojas R, González-Mendoza D, Grimaldo-Juarez O, Aviles-Marin M, Cervantes-Diaz L (2012) Antioxidant activity and bioactive compounds of Chiltepin (*Capsicum annum* var. *glabriusculum*) and Habanero (*Capsicum chinense*): a comparative study. *J Med Plant Res* 6(9):1758–1763
- Sanatombi K, Sharma GJ (2008) Capsaicin content and pungency of different *Capsicum* spp. cultivars. *Not Bot Hort Agrobot Cluj* 36(2):89–90
- Singh S, Jarret R, Russo V, Majetich G, Shimkus J, Bushway R, Perkins B (2009) Determination of capsaicinoids by HPLC-DAD in *Capsicum* species. *J Agric Food Chem* 57(9):3452–3457
- Tanaka Y, Hosokawa M, Otsu K, Watanabe T, Yazawa S (2009) Assessment of capsaicinoid composition, nonpungent capsaicinoid analogues, in *Capsicum* cultivars. *J Agric Food Chem* 57(12):5407–5412
- Tanaka Y, Hosokawa M, Miwa T, Watanabe T, Yazawa S (2010) Novel loss-of-function putative aminotransferase alleles cause biosynthesis of capsaicinoids, nonpungent capsaicinoid analogues, in mildly pungent chili peppers (*Capsicum chinense*). *J Agric Food Chem* 58(2):11762–11767
- Wahyuni Y, Ballester AR, Sudarmonowati E, Bino RJ, Bovy AG (2011) Metabolite biodiversity in pepper (*Capsicum*) fruits of thirty-two diverse accessions: variation in health-related compounds and implications for breeding. *Phytochemistry* 72(11–12):1358–1370

Capsicum frutescens

Scientific Name

Capsicum frutescens L.

Synonyms

Capsicum annuum L. var. *frutescens* (L.) Kuntze, *Capsicum fastigiatum* Blume, *Capsicum minimum* Roxb., *Capsicum minimum* Blanco, nom.illeg.

Family

Solanaceae

Common/English Names

African Chillies, African Pepper, Bird-Eye Chilli, Bird's-Eye Chili, Bird's-Eye Pepper, Bird Pepper, Cayenne, Chile De Cera, Chili Pepper, Chilli, Fruit Pointing Upwards, Cockspur Pepper, Goat Pepper, Goat's Pod, Guinea Pepper, Hot Chili, Hot Pepper, Mexican Chillies, Paprika, Pungent Pepper, Red Pepper, Sakay, Spur Pepper, Tabasco, Tabasco Pepper, Tabasco Sauce Pepper, Wild Pepper, Zanzibar Pepper.

Vernacular Names

Afrikaans: Brand Rissie;
Amharic: Berber, Mitmita;
Arabic: Dar Feller, Dâr Fulful, Felfel, Filfil Har, Filfilianhar, Filfull Harr, Fulaifilah, Har Fulful Alahmar, Fulful Haar, Shatta;
Armenian: Gdzoo Bghbegh, Kcu Pghpegh;
Aymara: Huayca;
Basque: Chili, Kaiena, Pipermina;
Belarusian: Chyrvony Perec, Kajenski Perac;
Bhutan: Aema, Ema (**Dzongkha**);
Brazil: Malagueta, Pimenta Malagueta, Pimenta-Cumarim, Pimenta-Da-Terra, Pimentão;
Breton: Pimant Brout;
Bulgarian: Chile;
Burmese: Nga Yut Thee, Nil Thee;
Chamorro: Doni, Doni-Halomtano, Doni Halum Tano, Doni-Sali, Donné Sali, Dont Sali;
Chinese: Fan Jiang, La Jiao, Laaht Jiu, Mi Jiao, Ye Jiao Zi, Ye La Zi,;
Chukese: Amwiik, Lonni Mmwiik Yammwiik, Moek, Muik, Mwi, Mwi, Mwi, Mwiik, Mwik, Yammwiik;
Cook Islands: 'Ōporo, Oporo (**Maori**);
Croatian: Čili, Feferon, Kajenska Paprika, Paprika Ljuta;
Czech: Pálivá Paprika, Paprika Křovitá, Pepř Cayenský;

Danish: Cayennepeber, Chili, Spanskpeber;

Dutch: Spaanse Peper;

Esperanto: Duonligneca Kapsiko, Kajena Pipro;

Eastonian: Cayenne'i Pipar, Kibe Paprika, Punapipar, Tšili;

Egypt: Felfel, Filfilianhar;

Farsi: Dar Felfel, Felfel, Pilpil, Philphil;

Fijian: Mboro, Mboro Nganga, Mboro Ni Vavalangi, Rokete;

Finnish: Chilippipuri;

French: Piment Enragé, Piment Fort, Piment Des Oiseaux, Piment-Oiseau, Poivre De Cayenne, Poivre Rouge;

Gaelic: Guindilla;

Galician: Guindilla;

Georgian: Cicaka, Ts'its'ak'a, Ts'iteli Ts'its'aka, Tsitsaka;

German: Beißbeere, Cayenne-Pfeffer, Chili-Pfeffer, Halbstrauchige Paprika, Roter Pfeffer, Tabasco, Vogelpfeffer, Ziegenpfeffer;

Greek: Kavterés Piperiés, Piperi Kagien, Tsili;

Hausa: Barkono, Tatashe, Tattasai, Tugande;

Hawaiian: Nīoi, Nīoi Pepa;

Hebrew: Adom, Paprika Harifa, Paprika Charifa, Pilpel Adom, Pilpel Harif, Tsili;

Hungarian: Aranybors, Cayenne Bors, Cayenni Bors, Chilipaprika, Csilipaprika, Igen Erős Apró, Macskapöcs Paprika, Ördögbors;

I-Kiribati: Te Beneka;

Icelandic: Cayennepipar, Chilipipar;

India: Tero (Apatani), Bhojolak, Bhojonthela, Jolokia, Jolokiya, Moris (Assamese), Kancha Lanka, Lal Marich Lanka, Lanka Marich, Morich (Bengali), fanlu (Bodo), Kancha-lanka, Kancha-morich, Sobuj Marich (Green, Fresh Chiles), Sukano lanka, Sukana morich (Red, Dried Chiles) (Bengali), Mirch (Dogri), Jalik (Garo), Lal marchum (Red Chile), Lila marchum (Green Chile), Lal Marchum, Lila Marchum, Marchum, Mirch, Mirchi (Gujarati), Mirch, Hari mirch (Green), Lal Mirch, Lalmirchi, Lankamirchi (Red) (Hindu), Hmarcha (Hmar), Menasina Kayi, Menasina Kai, Menashina Kayi, Menshinkai, Molaku (Kannada), Martsa-Wangan (Kashmiri), Soh Mynken (Khasi), Chuvanna-Mulagu, Kanthari, Kappalmelaka, Kapu Mologu, Mologu, Mulagu, Paccha-Mulagu, Unakka-

mulagu (Malayalam), Mirchai (Maithili), Morok (manipuri), Hirvya mirchya, Lal mirchya (Marathi), Hmarcha, Marcha (Mizo), Chüsi (Naga-Angami), Mersü (Naga-Ao), Machi, Thise (Naga-Chakhesang-Chokri), Tsüche (Naga-Khezha), Machi (Naga-Lotha), Kosiisii (Naga-Mao), Ihansu (Naga-Rongmei), Kasâthei (Naga-Tangkhu), Kancha lanka, Lanka, Lankamaricha, Sukila lanka (Oriya), Hari Mirch, LalMircha (Punjabi), Marichiphala, Marichiphala Ujjvala (Sanskrit), Kayimunchi, Munchi (Tulu), Sigappu milagai, Vattal (Tamil), Merapu Kai, Mirapakaya, Mirapakayalu (Telugu), Gach Mirch, Hari Mirch, Lal Mirch, Lalmarach, Mirch (Urdu);

Indonesia: Cabé, Cabe, Cabai Merah, Cabai Rawit, Lombok, Lombok Cabai;

Iraq: Filfil Har;

Irish: Cili;

Italian: Diavoleto, Pepe Di Caienne, Pepe D'ucello, Pepe Rosso Piccante, Peperone Acre, Peperone D'india, Peperone Rabbioso, Pepperoncini, Peperoncino, Peperone;

Japanese: Chiri, Kaïenneppa, Kidachi-Tō-Garashi, Tōgarashi, Togarashi;

Khmer: Ma-Tek;

Korean: Gochu, Kaïen Gochu, Kochu;

Laotian: Khi Mu, Mak Pet, Mak Phet Kungsi, Phik, Prik Khi Nu;

Latvian: Čili Pipari, Kajēnas Pipari;

Lebanese: Filfull Harr;

Lithuanian: Čili, Kajeno Pipirai;

Malaysia: Padas (Bisaya, Sarawak), Kacang Penguji (Iban, Sarawak), Cabai Padi, Cili Padi, Lada Merah, Lada Mira (Malay);

Maldives Islands: Mirus (Dhivehi);

Maltese: Bżar Aħmar, Felfel;

Marquesan: Hupo'O, 'Upo'O;

Marshallese: Pepa;

Mongolian: Chinzhüü, Ulaan Chinzhüü, Ulaan Pjer'ts;

Marquesan: Hupo'O, 'Upo'O;

Nauruan: Epeba;

Nepal: Khorsani, Rato Khursani (Nepali) Malta (Nepalbhasa);

Niuean: Polo Magiho, Polo Mangiho, Polo Misi, Polo Miti;

Norwegian: Chilipper, Kajenne, Kayenne, Kayennepepper, Spansk Pepper;

Ossetian: Tsyvzy;

Palauan: Meringel;

Pashto: Murgh;

Philippines: Lada, Rimorimo (Bikol), Katumbal, Kitikot (Bisaya), Siling Kolikot (Cebu Bisaya), Paktiu (Ifugao), Silit-Diablo (Iloko), Kasira (Maguindanao), Lada (Sulu), Chileng-Bundok, Pasiti, Pasitis, Sili Pula, Siling Labyo, Siling Labuyo, Siling-Palai, Siling-Palay (Tagalog);

Pohnpeian: Chilee, Mwik, Sele;

Polish: Papryka Owocowa, Pieprzowiec Owocowy;

Portuguese: Pimenta De Caiena, Pimenta-Malagueta, Pimentão, Piripíri;

Provençal: Pebrino, Pebroun;

Rakahanga-Manihiki: Oporo, Oporo;

Romanian: Ardei Iute;

Russian: Chili, Kajenskij Perets, Krasnij Perets, Perets Kustarnikovyj, Struchkovy Pyerets;

Samoan: Polo, Polo, Polo Feć, Polo Feć, Polo Pālangi, Polo Pālangi, Polo Papalagi, Polo Vao, Polo Vao, Polo Vao, Polo Vao, Polu Uli;

Satawalese: Amuek;

Serbian: Čili, Feferon, Kajena-Biber;

Slovak: Čili Paprika, Čili Paprička, Dederón, Feferónka, Kajenská Paprika;

Slovenian: Čili, Feferoni, Kajenski Poper, Ostra Paprika;

Spanish: Ají, Cayena, Cayena Inglesa, Chile, Guindilla, Pimienta De Cayena, Pimienta Picante;

Sri Lanka: Gas Miris, Rathu Miris (Sinhala);

Swahili: Peri Peri, Pilipili, Pilipili Hoho, Piri Piri;

Swedish: Chilipeppar, Kajenn, Spansk Peppar, Tabascopeppar;

Tahitian: Oporo, 'Ōporo;

Thai: Pisi hui, Phrik Chee Faa, Prik chifa, Prik daeng, Prik haeng pallek, Phrik Kee Fa, Prik Kee Fah, Prik khée nu, Phrik Kheenuu;

Tibetan: Si Pan Dmar Po, Si Pan Sngon Po, Sipeñ Marpo, Sipeñ Ngonpo;

Tigrinya: Berbera;

Tokelauan: Polo Feć;

Tongan: Polo, Polo Fifisi;

Tongarevan: 'Ōpolo, 'Ōporo;

Turkish: Acı Biber, Acı Kırmızı Biber, Cin Biber, Dar Biber, Silis, Tibbi Biber, Toz Biber;

Tuvaluan: Polo Feć, Polo Feuu, Tili;

Ulithian: Much;

Uganda: Rura (Acholi), Kamulali (Luganda), Eshenda (Runyankore);

Uzbek: Garmdori;

Vietnamese: Ót,

Wallisian: Polo;

Yemen: Dar Feller, Dâr Fulful;

Yapese: Mwech Mwig, T'Ebil Tebil;

Yiddish: Shorf Feferl, Terkish Feferl.

Origin/Distribution

The species is endemic to southern USA, Mexico (Vera Cruz) to northern and eastern South America. Naturalised in Africa, India, SE Asia, Australia and Pacific Islands Probably originating in Central and South America but early widespread throughout the New World and subsequently into all tropical and subtropical areas (Smith 1991).

Agroecology

Red chilli pepper grows in a range of 7–29°C with annual rainfall of 300–4,300 mm at elevations from near sea level to more than 2,000 m. It prefers well-drained, sandy or silty-loamy soil and a soil pH of 4.3–8.7. Hot and dry weather is desirable for fruit ripening. The species is intolerant of shade and is frost sensitive, does not grow in temperatures below 7°C.

Edible Plant Parts and Uses

The fruit of this species is smaller but more pungent than *C. annuum* and the uses are similar. It is employed as a spice flavouring in many foods, such as curry powder and tabasco sauce. It is extensively used in Mexican, Italian, Indian, Thai, Malaysian and Indonesian cuisine.



Plate 1 Fruits, flower and leaves of chilli padi



Plate 3 Fruits of unidentified bird-eye chilli



Plate 2 Fruits of chilli padi



Plate 4 Fruits, leaves of another unidentified bird eye chilli

Botany

Small, branched, mostly erect, annual or short-lived perennial sub-shrub, 30–100 cm tall with a short or deep tap root and sparsely pubescent to glabrescent stem. Leaves simple, alternate, ovate to broadly lanceolate, 2.5–7 cm long, 1.5–3 cm wide, margins entire, apex acute to acuminate, base subcuneate, oblique (Plates 1–4), petioles narrowly winged above, 0.8–2 cm long. Flowers more commonly 2–4 per axil, pedicels 1–2.5 cm long, stout in fruit, erect; calyx cupular, truncate, 3–4 mm long, the lobes minute; corolla greenish white or greenish yellow, waxy, divided ca. 1/2 to base, the lobes triangular, ca. 1.5 cm in diameter; stamens 5, inserted toward base of corolla tube;

filaments ca. 1–2 mm long; anthers bluish, oblong. Berry, pungent, ellipsoid-conical to lanceoloid or fusiform, 10–20 mm long, 3–7 mm in diameter, much smaller and narrower than *C. annuum*, pericarp fleshy and firm, hollow, green when young to mostly red or orange when mature and 5 by 1 cm and erect (pointing upwards) (Plates 1–4). Seeds yellowish, flattened-lenticular, 3–5 mm long.

Nutritive/Medicinal Properties

The proximate nutrient value per 100 g edible portion of *C. frutescens* (Chilli padi) fruit was reported by Tee et al. (1997) as follows: water 81.5, energy 47 kcal, protein 3.9 g, fat 0.7 g, ash

6.04 g, carbohydrate 6.2 g, dietary fibre 7.0 g, ash 1.2 10.34 g, Ca 39 mg, P 118 mg, Fe 1.2 mg, K 544 mg, Na 35 mg, Mg 42 mg, Cu 0.13 mg, Zn 0.5 mg, carotenes 1,336 µg, retinol equivalent 228 µg, vitamin B1 0.30 mg, vitamin B2 0.20 mg, niacin 2.0 mg and vitamin C 54.8 mg.

Proximate nutrient composition of hot chilli pepper per 100 g edible portion was reported by USDA (2012) as: water 88.02 g, energy 40 kcal (166 kJ), protein 1.87 g, total lipid 0.44 g, ash 0.87 g, carbohydrate 8.81 g, total dietary fibre 1.5 g, total sugars 5.30 g, Ca 14 mg, Fe 1.03 mg, Mg 23 mg, P 43 mg, K 322 mg, Na 9 mg, Zn 0.26 mg, Cu 0.129 mg, Mn 0.187 mg, Se 0.5 µg, vitamin C 143.7 mg, thiamin 0.072 mg, niacin 1.244 mg, riboflavin 0.086 mg, pantothenic acid 0.201 mg, vitamin B-6 0.506 mg, total folate 23 µg, total choline 10.9 mg, vitamin A 48 µg RAE, vitamin A 952 IU, β -carotene 534 µg, α -carotene 36 µg, β -cryptoxanthin 40 µg, lutein + zeaxanthin 709 µg, vitamin E (α -tocopherol) 0.69 mg, vitamin K (phyloquinone) 14.0 µg, 14:0 (myristic acid) 0.002 g, 16:0 (palmitic acid) 0.033 g, 18:0 (stearic acid) 0.007 g, total mono-unsaturated fatty acids 0.024 g, 18:1 undifferentiated (oleic acid) 0.024 g, total polyunsaturated fatty acids 0.239 g, 18:2 undifferentiated (linoleic acid) 0.228 g, 18:3 undifferentiated (linolenic acid) 0.011 g, tryptophan 0.026 g, threonine 0.074 g, isoleucine 0.065 g, leucine 0.105 g, lysine 0.089 g, methionine 0.024 g, cystine 0.038 g, phenylalanine 0.062 g, tyrosine 0.042 g, valine 0.084 g, arginine 0.096 g, histidine 0.041 g, alanine 0.082 g, aspartic acid 0.286 g, glutamic acid 0.264 g, glycine 0.074 g, proline 0.087 g and serine 0.080 g.

Fatty acids and hydrocarbons were the main chemical components of the volatile oil from *Capsicum frutescens* var. *conoides* from Guizhou, Guangxi, Sichuan and Hubei; other components included esters, ketones, acylamines and aldehydes (Qin et al. 2004). The oils also contained 48–74.52% capsaicin, 2.83–2.87% vitamin E.

The volatile organic compounds found in the cayenne fruit of *C. frutescens* included sesquiterpenes (δ -elemene, α -humelene, γ -himachalene, β -bisabolene) different monoterpenes /monoterpenoids and members of different

classes of metabolites (Cardeal et al. 2006). Eighty-five volatile organic components were identified and quantified in a native Chinese chilli pepper (*Capsicum frutescens*) variety (Liu et al. 2009). Forty compounds were found at the green stage, fifty-three at the breaking stage and sixty-five at the red colour stage. The amount of alkenes and aldehydes increased from 2.762 and 0.120% in green stage to 11.137 and 14.485% in the coloured stage. The content of alcohols decreased from 30.169 to 23.698%. The aromatic compound disappeared during maturity. Ketones were enhanced from 0.983 to 2.693% while esters declined during maturity. One-hundred-seventy-two volatile compounds were identified in three Colombian cultivars of *Capsicum frutescens* representing 30.26, 22.36 and 68.26 mg/kg for Cesari amarillo, Cesari morado and Pajarito cultivars, respectively (Quijano and Pino 2010). Isohexyl isohexanoate, isohexyl isovalerate and isohexyl 2-methylbutyrate were the major compounds in Cesari amarillo and Cesari morado; while in the Pajarito cultivar the majors were isohexyl isovalerate and hexyl isovalerate. More than 300 volatile constituents were detected in the ripe fruits of 16 *Capsicum* accessions from the *annuum-chinense-frutescens* complex (Rodríguez-Burruezo et al. 2010). Esters and terpenoids were the main groups, although other minor compounds, such as nitrogen and sulfur compounds, phenol derivatives, norcarotenoids, lipoxygenase derivatives, carbonyls, alcohols, and other hydrocarbons, were also identified. The sniffing test revealed that the diversity of aromas found among the studied cultivars was due to qualitative and quantitative differences of, at least, 23 odour-contributing volatiles (OCVs). *C. chinense*, and *C. frutescens* accessions, with fruity/exotic aromas, were characterized by a high contribution of several esters and ionones and a low or nil contribution of green/vegetable OCVs. Different combinations of fruity/exotic and green/vegetable OCVs would explain the range of aroma impressions found among *C. annum* accessions. A total of 83 compounds, mostly esters and alcohols, were identified in the malagueta chilli pepper (*Capsicum frutescens*) (Junior et al. 2012).

The following capsaicinoids having a common structure composed of a vanillyl amide moiety and C9–C11 branched fatty acids were extracted from *Capsicum* spp fruits: 440 µg/g capsaicin, 81 µg/g dihydrocapsaicin, and 11 µg/g nordihydrocapsaicin (Manizakiza et al. 1999). The “heat” of chili peppers is directly related to the concentration of capsaicinoids, and it is evaluated by means of the organoleptical “Scoville Scale”. Pure capsaicin tops this scale with a rating of 16,000,000.

Eight capsaicinoids, pungent secondary metabolites were found in various parts of the pepper fruit (pericarp, placenta, seeds, and in the top, middle, and base parts of whole peppers) in 17 species of *Capsicum* peppers and in 23 pepper-containing foods (Kozukue et al. 2005). The compounds were: capsaicin, dihydrocapsaicin, homocapsaicin-I, homocapsaicin-II, homodihydrocapsaicin-I, homodihydrocapsaicin-II, nonivamide, and nordihydrocapsaicin. The concentration found ranged from 0.5 to 3,600 µg of capsaicin equivalent/g of product.

Total phenol content was correlated with ascorbic acid ($R^2=0.97$) and free sugars ($R^2=0.80$) in the *Capsicum* germplasm tested that included four accessions of *Capsicum chinense*; five accessions of *C. baccatum*; six accessions of *C. annuum*; and two of *C. frutescens* (Antonious et al. 2006a). Concentrations of total phenols (1.4, 1.3, and 1.3 mg/g fruit) and ascorbic acid (1.6, 1.2, and 1.3 mg/g fruit) were significantly greater in PI-633757, PI-387833, and PI-633754, respectively, compared to other accessions analyzed. Total capsaicinoids concentrations were greatest (1.3 mg/g fruit) in PI-438622 and lowest (0.002 mg/g fruit) in Grif-9320. Capsaicin and dihydrocapsaicin were the dominant capsaicinoids detected in methanol extract of fresh fruits of *Capsicum chinense*, *C. frutescens*, *C. baccatum*, *C. annuum*, and *C. pubescens* (Antonious and Jarret 2006); nordihydrocapsaicin was also detected. Capsaicin concentrations were typically greater than dihydrocapsaicin. Concentrations of total capsaicinoids varied from not detectable to 11.2 mg/fruit. Statistical analysis revealed that

accession PI-441624 (*C. chinense*) had the highest capsaicin content (2.9 mg/g fresh fruit) and accession PI-497984 (*C. frutescens*) had the highest dihydrocapsaicin content (2.3 mg/g fresh fruit). Accessions PI-439522 (*C. frutescens*) and PI-497984 contained the highest concentrations of total capsaicinoids. Ten cultivars out of 35 cultivars tested: 18 cultivars of *C. annuum*, 7 of *C. baccatum*, 5 of *C. chinense*, 4 of *C. frutescens*, and 1 of *C. pubescens* contained capsiconinoids (Tanaka et al. 2009). Capsiconinoid Baccatum (CCB) (*C. baccatum* var. *praetermissum*) showed the highest capsiconinoid content (3,314 µg/g DW) and Charapita (*C. chinense*) had the second highest content. The other eight cultivars had much lower capsiconinoid content than these two cultivars (<300 µg/g DW). Capsiconinoids had been reported to have agonist activity for transient receptor potential vanilloid type 1 (TRPV1). Forty-nine samples representing distinct morphotypes of four cultivated species (*C. annuum* var. *annuum*, *C. annuum* var. *glabriusculum*, *C. baccatum*, *C. chinense*, and *C. frutescens*) were found to contain detectable levels (11–369 µg/g) of a capsinoid, E-capsiate (Singh et al. 2009). Nine of the E-capsiate-containing samples also had dihydrocapsiate (18–86 µg/g).

Two new glucosides, capsaicin-β-D-glucopyranoside (1) and dihydrocapsaicin-β-D-glucopyranoside (2), were discovered in the fruit of the *Capsicum annuum* cultivar ‘High Heat’ (Higashiguchi et al. 2006). The glucosides were also detected in various pungent cultivars of *C. annuum*, *Capsicum frutescens*, and *Capsicum chinense*. However, they were not detected in non-pungent cultivars of *C. annuum*. Additionally, a positive correlation was observed between the quantity of the capsaicinoids, capsaicin, and dihydrocapsaicin and their glucosides.

C. frutescens leaf was found to contain 95.4 mg/kg of α-tocopherol (Ching and Mohamed 2001).

Capsaicinoids such as dihydrocapsaicin, nordihydrocapsaicin, homodihydrocapsaicin, and homocapsaicin, etc. found in chilli peppers, had been reported to exert multiple pharmacological and physiological effects that impart analgesic, anticancer, antiinflammatory, antioxi-

dant, anti-obesity (Luo et al. 2011), antidiabetic, and hypolipidemic/antihypercholesterolemic activities. Capsaicinoids may have benefits on cardiovascular and gastrointestinal system and may also have potential value in clinic for pain relief, cancer prevention and weight loss. They had been shown to be potential agonists of capsaicin receptor or transient receptor potential vanilloid subfamily member 1 (TRPV1). They could exert effects through the receptor-dependent and receptor-independent pathways.

Antioxidant Activity

Capsicum annuum, *Capsicum frutescens*, and *Capsicum chinense* peppers were found to contain high levels of L-ascorbic acid and carotenoids at maturity, contributing 124–338% of the RDA (Recommended Daily Allowance) for vitamin C and 0.33–336 RE/100 g of provitamin A activity, respectively (Howard et al. 2000). Levels of phenolic acids, capxanthin, and zeaxanthin generally increased during maturation, whereas the level of lutein declined. Flavonoid concentrations varied greatly among the pepper types analyzed and were negatively correlated to antioxidant activity under the conditions of the β -carotene-linoleic assay. Significant increases in antioxidant activity were observed in pepper juice models in response to increasing dilution factors and the presence of EDTA, indicating a pro-oxidant effect due to metal ions in the system. In-vitro models demonstrated that increasing levels of flavonoids in combination with constant levels of caffeic and ascorbic acid gave a resultant antioxidant activity that was either additive of the two compounds or competitive in their ability to scavenge peroxy radicals.

Studies showed that dietary hot short pepper (*Capsicum frutescens* L. var. *abbreviatum*) could prevent cyclophosphamide-induced oxidative stress in brain; although the pericarp (flesh) being a better protectant than the seeds (Obboh and Ogunraku 2010). The higher inhibition of oxidative stress in brain (decrease in malondialdehyde level) and serum enzymes serum glutamate

oxaloacetate transaminase (SGOT), glutamate pyruvate transaminase (SGPT), alkaline phosphatase and metabolites (total bilirubin) by the flesh could be attributable to its significantly higher total phenol content, reducing power and free-radical scavenging ability.

Dietary curcumin and capsaicin separately significantly inhibited the in-vivo iron-induced low-density lipoprotein (LDL) oxidation, as well as copper-induced oxidation of LDL in-vitro (Manjunatha and Srinivasan 2006). The protective effect of the combination of curcumin and capsaicin on LDL oxidation was greater than that of individual compounds. This protective influence of spice principles was also indicated by the relative anodic electrophoretic mobility of oxidized LDL on agarose gel. They also reported that rats injected with iron showed hepatic toxicity as measured by an increase in lipid peroxides and elevated serum enzymes, alanine aminotransferase, aspartate aminotransferase and lactate dehydrogenase. The activities of these enzymes, and the liver lipid peroxide level were reduced by dietary curcumin, capsaicin and their combination, indicating amelioration of the severity of iron-induced hepatotoxicity.

Antimicrobial Activity

The plain and heated extracts of *Capsicum* species including *C. frutescens* were found to exhibit varying degrees of inhibition against *Bacillus cereus*, *Bacillus subtilis*, *Clostridium sporogenes*, *Clostridium tetani*, and *Streptococcus pyogenes* (Cichewicz and Thorpe 1996).

A monomeric mannose/glucose-binding lectin isolated from the seeds of red cluster pepper *Capsicum frutescens* var. *fasciculatum* inhibited the germination of *Aspergillus flavus* and *Fusarium moniliforme* spores and hyphal growth in the two fungi (Ngai and Ng 2001). A steroidal saponin, CAY-1, with a molecular weight of 1243.35 Da, was isolated from dry, ground fruit of *Capsicum frutescens* (De Lucca et al. 2002). CAY-1 was shown to be a potent fungicide for the germinating conidia of *Aspergillus flavus*,

A. fumigatus, *A. parasiticus* and *A. niger* with species-dependent LD₉₀ values between 3 and 20 µM. In vitro assays, CAY-1 was effective against *Pneumocystis carinii* (IC₅₀: 9.5 µM) and *Candida albicans* (IC₉₀: 6.2 µM). It had no effect on the viability of the non-germinating conidia of the two filamentous fungi, *P. carinii* and *C. albicans*, nor on the conidial type of *Fusarium oxysporum*. It was ineffective against the bacteria *Enterobacter agglomerans*, *Bacillus subtilis*, *Escherichia coli* and *Staphylococcus aureus*. CAY-1 was active against 16 different fungal strains, including *Candida* spp. and *Aspergillus fumigatus* [minimum inhibitory concentrations (MIC) ranging from 4 to 16 µg/mL], and was especially active against *Cryptococcus neoformans* (90% inhibition at 1 µg/mL) (Renault et al. 2003). Synergistic activity was also observed between CAY-1 and amphotericin B against *Candida albicans* and *A. fumigatus*. CAY-1 appeared to act by disrupting the membrane integrity of fungal cells. CAY-1 exhibited predominantly additive-synergistic interaction with amphotericin B or itraconazole against the nongerminated and germinating conidia of three *Aspergillus* species and *Candida albicans* (De Lucca et al. 2006a). The results suggested CAY-1 enhanced amphotericin B and itraconazole efficacy. They also found that CAY-1 exhibited antifungal activity against non-germinating conidia and hyphae of clinical isolates of the dermatophytes *Trichophyton mentagrophytes*, *T. rubrum*, *T. tonsurans* and *Microsporum canis* (Stergiopoulou et al. 2008). The minimal inhibitory concentrations (complete visual growth inhibition) of CAY-1 against non-germinating conidia ranged from 10 to 20 µg/mL for all dermatophyte isolates. It exhibited found >90% inhibition of hyphal metabolic activity of these same isolates at 10–20 µg/mL. In another paper, De Lucca et al. (2006b).

Reported on the purification of two antifungal steroidal saponins with same steroidal moiety but differ in the number of glucose moieties from cayenne pepper (*Capsicum frutescens*). The first saponin had four glucose moieties (molecular mass 1,081 Da) and the second contained three glucose moieties (molecular mass 919 Da). The

larger saponin was slightly fungicidal against the nongerminated and germinating conidia of *Aspergillus flavus*, *A. niger*, *A. parasiticus*, *A. fumigatus*, *Fusarium oxysporum*, *F. moniliforme*, and *F. graminearum*, whereas, the second smaller saponin was inactive against these fungi.

The methanolic leaf extract of *Capsicum frutescens* var. *longum* showed dose dependent antibacterial and anthelmintic activity (Vinayaka et al. 2010). Among the bacteria studied, *Staphylococcus aureus* was found to be more susceptible to the methanolic extract followed by *Klebsiella pneumoniae* and *Pseudomonas aeruginosa*. The anthelmintic effect of all concentrations was lesser when compared to the standard.

Antidiabetic Activity

Studies found that capsaicin caused a decrease in blood glucose levels of 4.91 (n=6) mmol/dl versus 6.40 mmol/dl (n=6) for the control at the 2.5 h time interval when the oral glucose tolerance test (OGTT) was performed on dogs treated with capsaicin and compared with the control (Tolan et al. 2001). Also there was an increase in plasma insulin levels of 5.78 µIU/mL (n=6) for the capsaicin treated dogs versus 3.70 µIU/mL (n=10) for the control. Insulin receptor studies on monocytes showed that there was a decrease in the percentage receptor binding for the capsaicin treated dogs when compared with the control. Insulin receptor calculations showed a decrease in number, $2.63 \times 10(8) \times 10(7)$, compared with $8.77 \times 10(8) \times 10(8)$ for the control. The data showed insulin to be responsible for the hypoglycaemic episodes seen in the dogs and that it also caused an increase in insulin secretion which led to a reduction of insulin binding on the insulin receptors. The hypoglycaemic principle, capsaicin in *C. frutescens* was isolated and purified. Purified capsaicin caused a decrease in blood glucose levels at 2.5 h in an OGTT in dogs with a concomitant elevation in plasma insulin levels (Tolan et al. 2004). Studies in healthy Thai women found that within 30 min after consumption of 5 g of fresh *Capsicum frutescens*, plasma glucose level during the absorption period was

significantly inhibited. The metabolic rate was also immediately increased after ingestion and this thermogenic effect was sustained up to 30 min (Chaiyata et al. 2003). In a separate cross-over study of 12 healthy volunteers, consumption of 5 g *Capsicum frutescens*, decreased plasma glucose levels as revealed by OGTT and maintained the insulin levels (Chaiyasit et al. 2009). The results suggested the potential clinical implications of *C. frutescens* in the management of type 2 diabetes.

Studies in streptozotocin induced type 2 diabetic male Sprague Dawley rats showed that after 4 weeks of feeding red chilli (*C. frutescens*) low (RCL, 0.5%) and red chilli high (RCH, 2.0%) the fasting blood glucose concentrations in both RC fed groups were not significantly different (Islam and Choi 2008). The serum insulin concentration was significantly increased in the RCH group compared with the diabetic control and RCL groups. Blood HbA1c, liver weight, liver glycogen and serum lipids were not influenced by the feeding of RC-containing diets. The data suggested that 2% dietary RC was insulinotropic rather than hypoglycemic at least in the experimental condition.

Rau et al. (2006) reported that several herbal extracts including *C. frutescens* were found to be most active in a concentration dependent manner in the activation of peroxisome proliferator-activated receptors (PPAR) that play a pivotal role in lipid and glucose homeostasis. Synthetic activators of PPAR α (fibrates) and PPAR γ (glitazones) are widely used for treatment of dyslipidemia and diabetes, respectively.

Immunological and Anticancer Activities

Studies had reported phenolic substances derived from spices such as curcumin, a yellow colouring agent, contained in turmeric (*Curcuma longa*), [6]-gingerol, a pungent ingredient present in ginger (*Zingiber officinale*) and capsaicin, a principal pungent principle of hot chili pepper (*Capsicum annum*) to possess potent antimutagenic and anticarcinogenic activities (Surh 2002). The chemopreventive effects exerted by these

phytochemicals are often associated with their antioxidative and antiinflammatory activities mediated by intracellular signaling cascades, particularly those involving NF-kappaB and mitogen-activated protein kinases.

Lee et al. (2004) found that capsaicin induced apoptotic MBT-2 murine bladder tumour cell death in a time- and dose-dependent manner. In addition to the caspase-3 activation, capsaicin also induced cytochrome C release and decrease in Bcl-2 protein expression with no changes in the level of Bax. Further, capsaicin at the concentration of inducing apoptosis also markedly reduced the level of reactive oxygen species and lipid peroxidation, implying that capsaicin may enhance the antitumour effect of bacillus Calmette-Guerin (BCG), the most effective intravesical bladder cancer treatment.

Mori et al. (2006) reported capsaicin to have a profound antiproliferative effect on prostate cancer cells, inducing the apoptosis of both androgen receptor (AR)-positive (LNCaP) and androgen receptor-negative (PC-3, DU-145) prostate cancer cell lines associated with an increase of p53, p21, and Bax. Capsaicin down-regulated the expression of not only prostate-specific antigen (PSA) but also AR. Capsaicin, when given orally, significantly slowed the growth of PC-3 prostate cancer xenografts as measured by size and weight compared to vehicle treated mice. Malagarie-Cazenave et al. (2011) reported that capsaicin increased production of cytokine interleukin (IL)-6 in prostate PC-3 cancer cells mediated partly by tumour necrosis factor (TNF)- α secretion and signalling pathway involving Akt, ERK and PKC- α activation.

Huang et al. (2009) found that capsaicin induced apoptosis in human hepatoma HepG2 cells. The results indicated that the capsaicin-induced apoptosis in HepG2 cells may result from the elevation of intracellular Ca²⁺ production, ROS, disruption of alpha psi(m), regulation of Bcl-2 family protein expression and caspase-3 activity.

Capsaicin exhibited anti-proliferative activity against four human small cell lung cancer SCLC cell lines in-vitro and potently suppressed the growth of H69 human SCLC tumours in-vivo as

ascertained by chick chorioallantoic membrane (CAM) assays and nude mice models (Brown et al. 2010). The antiproliferative activity of capsaicin was mediated through the transcription factor E2F4 pathway. In another study, treatment with capsaicin (10 mg/kg body weight) to the lung carcinoma mice restored back the activities of phase I biotransformation enzymes (NADPH-cytochrome P450 reductase, NADH-cytochrome b5 reductase and epoxide hydrolase), phase II enzymes (glutathione-S-transferase, UDP-glucuronyl transferase and DT-diaphorase), and the levels of tumour markers to near normalcy (Anandakumar et al. 2009). The study revealed that capsaicin could effectively detoxify the carcinogens during benzo(a)pyrene-induced lung cancer.

Wu et al. (2006) showed that capsaicin induced G0-G1 cell cycle arrest and apoptosis in a time-dependent manner in human esophagus epidermoid carcinoma CE 81 T/VGH cells through activation of caspase-3 and intracellular Ca(2+) release pathway, and may have potential for the treatment of esophagus epidermoid carcinoma cells. Ip et al. (2012) found that capsaicin-induced cytotoxic effects (cell death) through G0/G1 phase arrest and induction of apoptosis of human nasopharyngeal carcinoma NPC-TW 039 cells in a dose-dependent fashion. Capsaicin treatment induced endoplasmic reticulum (ER) stress by promoting the production of reactive oxygen species (ROS), increasing levels of inositol-requiring 1 enzyme (IRE1), growth arrest and DNA-damage-inducible 153 (GADD153) and glucose-regulated protein 78 (GRP78). Capsaicin elicited an increase in cytosolic Ca(2+), loss of the mitochondrial transmembrane potential ($\Delta\Psi$ (m)), releases of cytochrome c and apoptosis-inducing factor (AIF), and activation of caspase-9 and -3. These results suggested that ER stress- and mitochondria-mediated cell death is involved in capsaicin-induced apoptosis in NPC-TW 039 cells.

Studies showed that capsaicin induced cytotoxic effects cells in a time- and dose-dependent manner and increased reactive oxygen species (ROS) and Ca(2+) but decreased the level of mitochondrial membrane potential ($\Delta\Psi$ (m)) in human colon cancer colo 205 cells (Lu et al.

2010). Levels of Fas, cytochrome c, and caspases were increased, leading to cell apoptosis. Capsaicin decreased the levels of anti-apoptotic proteins such as Bcl-2 and increased the levels of pro-apoptotic proteins such as Bax. Capsaicin-induced apoptosis in colo 205 cells was also done through the activations of caspase-8, -9 and -3. In-vivo studies in immunodeficient nu/nu mice bearing colo 205 tumour xenografts showed that capsaicin effectively inhibited tumour growth. Huh et al. (2011) reported that the combined treatment of capsaicin and cisplatin elicited higher apoptotic cell death of cisplatin-resistant Korean human gastric cancer cell line SNU-668 than that of treatment with either capsaicin or cisplatin alone. The combined treatment induced G1/S arrest and inhibited I κ B phosphorylation in a dose-dependent manner.

Capsaicin potently inhibited growth of ER-positive (MCF-7, T47D, BT-474) and ER-negative (SKBR-3, MDA-MB231) breast cancer cell lines, which was associated with G(0)/G(1) cell-cycle arrest, increased levels of apoptosis and reduced protein expression of human epidermal growth factor receptor (EGFR), HER-2, activated extracellular-regulated kinase (ERK) and cyclin D1 (Thoenissen et al. 2010). Capsaicin blocked breast cancer cell migration in-vitro and decreased by 50% the size of MDA-MB231 breast cancer tumours growing orthotopically in immunodeficient mice without noticeable drug side effects. In-vivo activation of ERK was clearly decreased, as well as expression of HER-2 and cyclin D1, whereas caspase activity and PARP cleavage products were increased in tumours of capsaicin-treated mice. Besides, capsaicin potently inhibited the development of pre-neoplastic breast lesions by up to 80% without evidence of toxicity. Their data indicated capsaicin to be a novel modulator of the EGFR/HER-2 pathway in both ER-positive and -negative breast cancer cells with a potential role in the treatment and prevention of human breast cancer.

Kim et al. (2010) demonstrated that subtoxic doses of capsaicin effectively sensitized multiple malignant glioma (brain and spinal chord tumour) cell lines to tumour necrosis factor-related apoptosis-inducing ligand (TRAIL)-induced

apoptosis. Treatment of various gliomas with capsaicin significantly stimulated DR5, a death receptor of TRAIL, and suppressed the caspase inhibitor survivin. The results indicated that the activity of capsaicin toward DR5 and survivin contributed to the amplification of caspase cascades, thereby restoring TRAIL sensitivity in malignant glioma cells.

Capsaicin and resveratrol, alone or in combination, inhibited cell growth and promoted apoptosis by the elevation of NO• in A375 human melanoma cells (Kim 2012). The data suggested that capsaicin and resveratrol activated the mitochondrial and death receptor pathways, working together to induce apoptosis in A375 cells, and indicated that NO• could be considered a potential target for improvement of the effectiveness of melanoma treatment.

Basu and Srivastava (2005) demonstrated that dendritic cells, a key cell type in vertebrate immune responses, possessed vanilloid receptor 1 (VR1), receptor for capsaicin, (8-methyl-N-vanillyl-6-nonenamide) the principal pungent ingredient of red chili pepper (*Capsicum frutescens*). Engagement of this receptor with capsaicin elicits powerful immune consequences. Capsaicin had been reported to cause neurogenic inflammation and to have analgesic and antiinflammatory activities. Beltran et al. (2007) further demonstrated that intratumoral administration of capsaicin into a preexisting tumour resulted in retarded progression of the injected tumour regardless of the stage of the tumour. Further, capsaicin significantly inhibited growth of other, uninjected tumours in the same animal. Capsaicin-elicited immunity was shown to be T cell-mediated and tumour-specific. The results reflected the immunological potency of a neurological ligand in modulating immune response against an established tumour.

Hypolipidemic/Antihypercholesterolemic Activities

Inclusion of capsaicin (0.015%) in the cholesterol-enriched diet of rats produced significant hypcholesterolemic effect (Kempaiah et al. 2005).

Results suggested capsaicin was protective to low-density lipoprotein oxidation both in-vivo and in-vitro under normal situation, while in hypercholesterolemic situation where the extent of low-density lipoprotein oxidation was already lowered, capsaicin did not offer any further reduction. Dietary curcumin (0.2%), capsaicin (0.015%) or their combination significantly countered the hypercholesterolemia brought about by high cholesterol feeding (Manjunatha and Srinivasan 2007b). Hepatic cholesterol was lowered in normal rats by both but hepatic triglyceride levels were lowered in both normal and hypercholesterolemic rats by capsaicin. Curcumin and capsaicin lowered hepatic and blood lipid peroxides in hypercholesterolemic rats, while the effect in blood was additive with their combination. Hepatic ascorbic acid was enhanced by dietary spice principles in normal rats; glutathione was enhanced by their combination only in hypercholesterolemic rats. Activities of serum glutathione reductase, glutathione transferase and catalase and hepatic glutathione reductase in normal rats and serum glutathione peroxidase in hypercholesterolemic rats were enhanced by both curcumin and capsaicin. While dietary curcumin and capsaicin normalized the changes in the levels of antioxidant molecules and activities of antioxidant enzymes to a significant extent, this effect was not generally additive when given in combination. Dietary high-fat (30%)-induced hypertriglyceridemia in rats was countered by dietary curcumin, capsaicin, or their combination by 12–20% (Manjunatha and Srinivasan 2007a). Curcumin, capsaicin, and their combination decreased serum total cholesterol and lipid peroxide levels in these animals. Serum alphatocopherol, hepatic glutathione, glutathione peroxidase and glutathione transferase contents were increased by dietary curcumin, capsaicin, and their combination in high-fat-fed rats. Hepatic glutathione reductase and glutathione peroxidase were significantly elevated by dietary spice principles in high-fat-fed animals. The additive effect of the two bioactive compounds was generally not evident with respect to hypolipidemic or antioxidant potential. However, the effectiveness of the combination was higher in a few instances.

The lithogenic diet that contained capsaicin, curcumin, or their combination reduced the incidence of cholesterol gallstones by 50, 66, and 56%, respectively, compared with lithogenic control mice (Shubha et al. 2011). This was accompanied by reduced biliary cholesterol and a marginal increase in phospholipid in these spice-fed rats. Increased cholesterol saturation index and cholesterol: phospholipid ratio in the bile caused by the lithogenic diet was countered by the dietary spice compounds. Combination of both species countered the decreased activities of hepatic glutathione reductase and glutathione-S-transferase caused by the lithogenic diet. The increased lipid peroxidation and the decreased concentration of ascorbic acid in the liver caused by the lithogenic diet was also countered by the dietary spice compounds, individually or in combination. Though the capsaicin and curcumin combination did not have an additive influence in reducing the incidence of cholesterol gallstones in mice, their combination nevertheless was more beneficial in enhancing the activity of hepatic antioxidant enzyme — glutathione reductase in the lithogenic situation.

Antiinflammatory Activity

On acute treatment, capsaicin (extracted from *Capsicum frutescens* and standard capsaicin from Sigma Chemicals) produced a dose-related inflammatory response in rat paw as measured by the volume displacement method (De and Ghosh 1988). This response was found to be synergistic when injected with carrageenan. In contrast, chronically capsaicin treated rats (for 10 days) showed a significant inhibition of paw oedema when treated with either carrageenan or a single high dose of capsaicin. Both the extracted and the standard capsaicin showed a similar type of response in all experiments.

A comparison of the extent of carrageenan-induced paw inflammation showed that both dietary curcumin and capsaicin moderately lowered inflammation, while their combination were more effective (Manjunatha and Srinivasan

2006). Dietary curcumin and capsaicin significantly decreased the activity of 5'-lipoxygenase activity in the polymorphonuclear lymphocytes in carrageenan-injected rats, the decrease being even higher in the case of combination of these two spice principles. Kim et al. (2003) found that capsaicin exhibited antiinflammatory activity by inhibiting I κ B- α degradation in lipopolysaccharide-stimulated murine peritoneal macrophages. Significant inhibition of the production of LPS-induced PGE₂ by capsaicin was observed in a dose-dependent manner. Capsaicin inhibited the enzyme activity of COX-2 and the expression of the iNOS protein. Capsaicin completely blocked LPS-induced disappearance of I κ B- α and therefore inactivated NF- κ B. A high expression level of the VR-1 like protein (VRL-1) was observed in peritoneal macrophages, while the expression of VR-1 was not detected. These findings suggested that the antiinflammatory action of capsaicin may occur through a novel mechanism, not by a VR-1 receptor-mediated one.

In the endotoxin lipopolysaccharide-treated rats, hepatic reduced glutathione (GSH) and malondialdehyde MDA increased significantly after capsaicin administration (Abdel-Salam et al. 2012). In lung tissue, both MDA and GSH were decreased by capsaicin administration but in the brain GSH increased significantly. Increase in serum ALT and ALP and nitric oxide after lipopolysaccharide treatment was decreased by capsaicin serum glucose increased markedly after the administration of lipopolysaccharide, and was normalized by capsaicin treatment. The findings suggested that in the presence of mild systemic inflammation, acute capsaicin administration might alter oxidative status in some tissues and exert an antiinflammatory effect. Capsaicin exerted protective effects in the liver and lung against the lipopolysaccharide-induced tissue damage. Choi et al. (2011) found that capsaicin attenuated palmitate-induced expression of macrophage inflammatory protein 1 and interleukin 8 by increasing palmitate oxidation and reducing c-Jun activation in THP-1 (human acute monocytic leukemia) cells.

Capsaicin and Dyspepsia

Functional dyspepsia (FD) is a common and distressing chronic, recurrent, digestive disorder in the upper gastrointestinal tract of unknown cause (Nyren et al. 1992). Functional dyspepsia impacts negatively on work productivity by lowering productivity and increasing production cost through absenteeism, lower work out put and higher medical treatment cost (Brook et al. 2010). Studies by Rodriguez-Stanley et al. (2000) found that consumption of meal plus 5 mg capsaicin gelatine capsule enhanced noxious postprandial heartburn, presumably by direct effects on sensory neurons. Capsaicin did not alter dyspepsia score, oesophageal and gastric pH profiles and gastric emptying. In a randomised double blind study of 15 patients with FD, administration of red pepper powder containing 0.7 mg capsaicin, for 5 weeks was found more effective than placebo in decreasing the intensity of dyspeptic symptoms namely epigastric pain, epigastric fullness, and nausea, probably through a capsaicin-induced desensitization of gastric nociceptive C fibers (Bortolotti et al. 2002). The capsaicin test requiring patients to swallow a capsule containing 0.75 mg capsaicin was found to be a simple and non-invasive method to detect a subgroup of functional dyspepsia with chemical hypersensitivity (Hammer et al. 2008). Führer and Hammer (2009) found that 4 weeks ingestion of capsaicin desensitized both chemonociceptive and mechanonociceptive pathways in healthy volunteers. Symptom reduction after prolonged treatment with capsaicin in dyspeptic patients might be attributed to a dual desensitizing effect of capsaicin on chemonociceptors and mechanonociceptors. In a double-blind, placebo-controlled trial of involving a total of 116 outpatients with upper gastrointestinal (GI) symptoms, 73 patients were diagnosed with functional dyspepsia after swallowing a capsule containing 0.75 mg (Führer et al. 2011). Half of functional dyspepsia patients had chemical hypersensitivity, determined with an oral capsaicin load. Placebo response was negligible. The results suggested that visceral hypersensitivity may play a key role in the pathophysiology of functional dyspepsia.

Capsaicin and Neuralgia, Post-Herpetic Neuralgia, Diabetic Peripheral Neuropathy, Rheumatoid Arthritis, Osteoarthritis

Exposure to significantly high levels of capsaicin (*trans*-8-methyl-N-vanillyl-6-nonenamide), a component of hot red-peppers (*Capsicum annum*, *C. frutescens*, *C. chinense*) powder, and had been reported to permanently impair the nociceptive C fibers carrying pain sensations to the central nervous system in rats and had been shown to relieve pain of cutaneous and mucosal origin and gave promising results in post-herpetic neuralgia (Lynn 1990). Capsaicin as a pure white crystalline material, acts specifically by depleting stores of substance P from sensory neurons, and has been successful in the treatment of several painful conditions (e.g., rheumatoid arthritis, osteoarthritis, peripheral neuropathies) (Cordell and Araujo 1993). However, the crude, dark oleoresin extract of *Capsicum* contains over 100 distinct volatile compounds and therefore may function in many ways dissimilar to capsaicin, the oleoresin continues to be marketed in products with a high degree of variability in efficacy.

Of the 12 patients with post herpetic neuralgia, who applied capsaicin to painful areas of skin for 4 weeks, 9 (75%) experienced substantial relief of their pain in a preliminary study (Bernstein et al. 1987). The only adverse reaction was an intermittent, localized burning sensation experienced by one patient with application of capsaicin. Capsaicin was reported to deplete substance P, an important chemomediator of nociceptive impulses from the periphery to the central nervous system and had been demonstrated in high levels in sensory nerves supplying sites of chronic inflammation. Postherpetic neuralgia occurred after herpes zoster in about one third of patients ≥ 60 years old and could persist for months or even years. In a study on the consequences of long-term topical capsaicin application on the hind paws of rats, McMahon et al. (1991) found that after 10 weeks of capsaicin application, the ability of C fibres to produce neurogenic extravasation was markedly reduced. After 4 weeks of recovery this ability returned to

normal in 0.075% capsaicin-treated animals, but remained impaired in the 0.75% group which exhibited partial recovery 12 weeks after the end of treatment. The levels of substance P and calcitonin-gene-related peptide in the sural nerve supplying the treated skin area were unchanged after both the 0.075 and 0.75% capsaicin treatments. The results suggested that the topical application of capsaicin at low concentration produced a reversible impairment of the terminals of C fibres in the skin without greatly exciting those fibres and without affecting the properties of cell soma. Topical capsaicin treatment did not produce any cell death in the adult animal. In another double-blind study of 32 elderly patients with chronic postherpetic neuralgia, after 6 weeks almost 80% of capsaicin-treated patients experienced some relief from their pain compared with vehicle (Bernstein et al. 1989). Results of un-controlled studies by Frucht-Pery et al. (1997) suggested that capsaicin may be a useful therapy for the alleviation of neuralgia in some individuals with herpes zoster ophthalmicus. Significantly greater relief in the capsaicin-treated group compared with vehicle was observed for all efficacy variables.

In a double-blind randomized study, 70 patients with osteoarthritis (OA) and 31 with rheumatoid arthritis (RA), significantly more relief of pain was reported by the capsaicin-treated patients than the placebo patients throughout the study; after 4 weeks of capsaicin treatment, RA and OA patients demonstrated mean reductions in pain of 57 and 33%, respectively (Deal et al. 1991). These reductions in pain were statistically significant compared with those reported with placebo. They concluded capsaicin cream to be a safe and effective treatment for arthritis. The findings of a 4 week double blind, placebo controlled randomized trial of 21 patients comprising 7 with rheumatoid arthritis and 14 with osteoarthritis suggested topical capsaicin to be a safe and potentially useful drug for the treatment of painful osteoarthritis of the hands (McCarthy and McCarthy 1992). Capsaicin reduced tenderness and pain associated with osteoarthritis but not rheumatoid arthritis as compared with placebo. In a cross-over, double

blinded, randomized, controlled trial of 100 patients averaged 61 years age with mild to moderate knee osteoarthritis, 0.0125% capsaicin gel was found to be an effective treatment (Kosuwon et al. 2010). The burning sensation reported by patients in the capsaicin group was less disturbing than in previous studies and none of the present patients withdrew for this reason.

In a double-blind, randomised parallel-group involving 154 patients with non-specific back pain, the use of capsicum plaster for 3 weeks elicited marked improvement over placebo (Keitel et al. 2001). The sum of the three separate pain scales decreased more markedly in the capsicum group than in the placebo group (38.5% compared to 28.0%). Relatively slight improvements of the impaired mobility and the functional status were explained by the characteristics of the disorder treated. The efficacy ratings by observers and patients was definitely in favour of capsicum. Their results confirmed the findings of other double-blind clinical studies that showed local capsicum preparations to be very suitable for the treatment of neuropathic pain, musculoskeletal disorders, osteoarthritis, or fibromyalgia with or without inflammatory components. Topically applied capsaicin induces the release of substance P, a neurotransmitter, from sensory C-fibres. In another double-blind, randomised, placebo-controlled multicentre parallel group study of 320 patients comprising 160 subjects treated by capsicum plaster and 160 subjects treated by placebo plaster, they confirmed the statistically significant superiority of the capsicum plaster treatment for chronic non-specific low back pain compared to placebo (Frerick et al. 2003). Park et al. (2004) found that capsicum plaster applied at the K-A20 acupuncture point on hands was effective in preventing postoperative sore throat in 150 patients scheduled to undergo abdominal hysterectomy. The prevalence of moderate to severe sore throat at 24 h was lower for the plaster group (0%) than for sham (16%) and placebo controls (19%). Gagnier et al. (2007) in their systemic review of randomised trials on the effects of herbal medicine for chronic low back pain, found three low-quality trials using *Capsicum frutescens* (Cayenne) in various topical

preparations provided moderate evidence for favorable results against placebo and one trial found equivalence to a homeopathic ointment.

In a multicentre, double-blind, parallel-group trial, of 402 patients aged 18–90 years, who had postherpetic neuralgia for at least 6 months, patients who were randomly assigned to NGX-4010 (n=206) had a significantly greater reduction in pain during weeks two to eight than did patients who had the control patch (n=196) (Backonja et al. 2008). The patients who had NGX-4010 had significant improvements in pain during weeks 2 to 12 (mean change in numeric pain rating scale (NPRS) score –29.9% vs –20.4%, difference –9.5, –15.39 to –3.61). Transient blood pressure changes associated with changes in pain level were recorded on the day of treatment, and short-lasting erythema and pain at the site of application were common, self-limited, and generally mild to moderate in the NGX-4010 group and less frequent and severe in the controls. The study showed that one 60-min application of NGX-4010 provided rapid and sustained pain relief in patients with postherpetic neuralgia. No adverse events were associated with treatment except for local reactions at the site of application and those related to treatment-associated pain. Further studies by Backonja et al. (2010) found NGX-4010 (high concentration capsaicin patch) to be a promising topical treatment for postherpetic neuralgia patients and to be tolerable, generally safe, and effective. During days 8–28 after the double-blind treatment, NGX-4010 patients had a mean change in numerical pain rating scale (NPRS) scores from baseline of –32.7% compared with –4.4% for control patients. A similar decrease in NPRS scores from baseline was maintained with subsequent NGX-4010 treatments, regardless of the number of treatments received. Transient increases in application site pain were adequately managed with analgesics. No increases in application site reactions or adverse events were observed with repeated treatments. An open label study of 106 patients with moderate to severe postherpetic neuralgia (PHN) and painful human immunodeficiency virus-associated distal sensory polyneuropathy (HIV-DSP) showed that that repeated treatments

with NGX-4010, a high-concentration capsaicin patch (capsaicin 8%), was found to be generally safe and well tolerated (Simpson et al. 2010). The most frequently reported treatment-emergent adverse events were transient, mild-to-moderate application site erythema, pain, edema, and papules. Small, transient pain-related increases in blood pressure during and immediately after NGX-4010 application were observed. There was no evidence of an increased incidence of adverse events, dermal irritation, intolerability, or impaired neurological function with repeated treatments. Peppin et al. (2011) found that transient patch application-related pain with NGX-4010 (a capsaicin 8% dermal patch) could be managed with local cooling and/or oral analgesics in nearly all cases. Patient adherence to the full intended treatment duration indicated that patch application-related pain was not a barrier to NGX-4010 use.

In pivotal, randomized, double-blind, multicentre trials in adults with non-diabetic peripheral neuropathic pain, a single 60-min application of capsaicin dermal patch (8% capsaicin) reduced the mean numeric pain rating scale (NPRS) scores from baseline to a significantly greater extent than a low-concentration (0.04% w/w capsaicin) control patch during weeks 2–8 (McCormack 2010). In randomized, double-blind, multicentre trials in patients with HIV-associated neuropathy, capsaicin dermal patch reduced the mean NPRS scores from baseline significantly more than control in one study for the 30- and 90-min, but not the 60-min, application during weeks 2–12. In another study, the differences between capsaicin (30- and 60-min applications) and control did not reach statistical significance. An integrated analysis of both studies showed that the 30-min application of capsaicin dermal patch was significantly better than control for the reduction from baseline in mean NPRS scores during weeks 2–12. The efficacy of capsaicin dermal patch was maintained for up to 1 year in extension studies in which patients could receive up to three or four repeat treatments. Capsaicin dermal patch was generally well tolerated in clinical trials. The most common adverse events were transient, mostly mild to

moderate, application-site reactions. Capsaicin had also been reported to have proven efficacy as a topical treatment for painful diabetic peripheral neuropathy (Tesfaye et al. 2011).

Capsaicin is not generally recognized as safe and effective by the U.S. Food and Drug Administration for fever blister and cold sore treatment, but is considered to be safe and effective as an external analgesic counterirritant (Anonymous 2007). A patch containing 8% capsaicin (research code NGX-4010 and marketed under the trade name Qutenza®), approved both in the EU and USA, provides a localized therapy with effects for neuralgia lasting up to 12 weeks after a single 60-min application based clinical trial evidence on the safety, efficacy and unique attributes of this capsaicin 8% patch. (Wallace and Pappagallo 2011). The FDA has approved a topical 8% patch formulation of capsaicin (Qutenza-NeurogesX), available only by prescription, for local treatment of postherpetic neuralgia (Anonymous 2011).

Antiobesity/Weight Loss Activity

Tools for obesity management, including caffeine, ephedrine, capsaicin, and green tea have been proposed as strategies for weight loss and weight maintenance, since they may increase energy expenditure (4–5%), fat oxidation (10–16%) and have been proposed to counteract the decrease in metabolic rate that is present during weight loss (Diepvens et al. 2007; Hursel and Westerterp-Plantenga 2010). Consumption of red chilli pepper had been reported to increase metabolic rate (Henry and Emery 1986) and such an increase in metabolic rate is now widely referred to as the thermic effect (TE) of food or diet-induced thermogenesis (DIT) (Rothwell and Stock 1981). Daily increases in thermogenesis of approximately 300–400 kJ can eventually lead to substantial weight loss (Hursel and Westerterp-Plantenga 2010). Thermogenic ingredients may be considered as functional agents that could help in preventing a positive energy balance and obesity.

Cameron-Smith et al. (1990) reported the capsaicinoid spice principles capsaicin and

dihydrocapsaicin to be thermogenic in the isolated rat hindlimb perfused with constant flow. Both principles elicited similar maximal increases in oxygen consumption (VO₂) and perfusion pressure. Their findings suggested that capsaicin and dihydrocapsaicin could be thermogenic in the rat and that the mechanism of action directly involved vasoconstriction in some manner. Studies by Lim et al. (1979) suggested that hot red pepper ingestion stimulated carbohydrate oxidation at rest and during exercise in long distance male runners 18–23 year of age. The meal with hot red pepper significantly elevated respiratory quotient and blood lactate levels at rest and during exercise. Oxygen consumption at rest was slightly but non-significantly higher in the hot red pepper meal at 30 min after the meal. Plasma epinephrine and norepinephrine levels were significantly higher in those who had only hot red pepper at 30 min after the meal.

In a 3-way crossover, randomised, placebo-controlled, double-blinded intervention study of 19 overweight to obese, a diet supplement containing bioactive food ingredients (a combination of capsaicin, green tea extract (catechins and caffeine), tyrosine, and calcium) increased daily energy expenditure by approximately 200 kJ or 2%, without raising the heart rate or any observed adverse effects (Belza and Jessen 2005). The lack of effect of the enterocoated preparation suggested that a local action of capsaicin in the gastric mucosa was a prerequisite for exerting the thermogenic effect. In a placebo-controlled, double-blind 8-week intervention study of 80 obese subjects, ingestion of a supplement containing a combination of tyrosine, capsaicin, catechines and caffeine was found to stimulate the sympathetic nervous system and promote satiety, lipolysis and thermogenesis (Belza et al. 2007). The bioactive supplement increased 4-hour thermogenesis by 90 kJ more than placebo, and the effect was maintained after 8 weeks and accompanied by a slight reduction in fat mass. The bioactive supplement had no effect on faecal fat excretion, blood pressure or heart rate. The scientists concluded that these bioactive components may support weight maintenance after a hypocaloric diet.

Antihemostatic and Antithrombotic Activities

Capsaicin was found to dose-dependently prolong the tail bleeding time in the conscious mice after the oral administration (Wang et al. 1985). Capsaicin was effective in preventing death caused by adenosine diphosphate-induced acute pulmonary thromboembolism in mice at dose of 25 mg/kg, while aspirin and indomethacin had no effect at 200 mg/kg. Capsaicin also reduced the mortality in collagen- and sodium arachidonate-induced thromboembolic death at dose of 25 and 50 mg/kg, respectively, and aspirin and indomethacin were also effective in these models but only when the dose was higher than 200 mg/kg. Capsaicin also suppressed platelet aggregation significantly, but did not affect blood coagulation. The scientists concluded that capsaicin was proven to be more effective than aspirin and indomethacin in preventing the death of acute pulmonary thromboembolism, and this effect could be due to its inhibition on platelet aggregation.

Cardiovascular studies of on blood vessels showed that both capsaicinoids and capsaicin (extracted from *C. frutescens* fruit) could inhibit vasoconstriction induced by norepinephrine and the vasodilatation effect of capsaicinoids might be due to the action of capsaicin (Jaiarj et al. 1998). Both capsaicinoids and capsaicin were found to cause significant decrease in platelet aggregation induced by adenosine diphosphate and collagen. Comparison of capsaicin with capsaicinoid extract having the same amount of capsaicin revealed that capsaicin had higher antiplatelet aggregating activity than capsaicinoids. This indicated that there might be other substances in the mixture which could decrease the antiplatelet aggregating effect.

Anti-Venom Activity

The macerated ripe fruits of *Capsicum frutescens* exhibited moderate neutralizing ability against the haemorrhagic effect of *Bothrops atrox* venom (Otero et al. 2000).

Anti-Psoriasis Activity

Capsicum frutescens was reported to be an effective treatment for psoriasis (Reuter et al. 2010).

Gastroprotective Activity

Capsaicin (0.1 and 0.5 mg/kg, p.o.) inhibited absolute ethanol-induced gastric lesion formation in rats in a dose-dependent manner (Uchida et al. 1991). The protective effect of capsaicin was attenuated by indomethacin-pretreatment and disappeared in capsaicin-sensitive nerve degenerated rats. Capsaicin did not induce the distension of gastric mucosal folds. Their results suggested that stimulation of capsaicin-sensitive afferent nerves by capsaicin would enhance the prostaglandin formation, leading to an inhibition of gastric lesions. Treatment with small doses of topical capsaicin was found to protect the gastric mucosa from the damage by strong irritants but functional ablation of sensory nerves by pretreatment with larger dose of parenteral capsaicin augmented the formation of gastric lesions (Brzozowski et al. 1996). The scientists found that pretreatment with i.g.(intragastric) capsaicin (0.12–1.0 mg/kg) in rats with intact sensory nerves (series A) reduced dose-dependently the mucosal damage caused by absolute ethanol, acidified aspirin (ASA) or water immersion and restraint stress (WRS). This protection was accompanied by a significant rise in gastric mucosal blood flow (GBF). Parenteral application of capsaicin (1.2–10 mg/kg s.c.) in intact rats dose-dependently increased GBF, and also dose-dependently reduced gastric damage induced by ASA or WRS (but not by ethanol) but this effect was reversed by indomethacin at a dose that suppressed endogenous prostaglandins biosynthesis by about 90%, indicating that prostaglandins were involved in the protective activities of topical capsaicin. Capsaicin deactivation of sensory nerves aggravated mucosal lesions induced by all three ulcerogens and this effect was accompanied by a marked decrease in GBF. In such capsaicin-deactivated rats, topical capsaicin also reduced ethanol-, ASA- or WRS-induced

lesions, while parenteral capsaicin was effective only in the protection against the damage induced by acidified ASA and WRS but not by ethanol. They concluded that capsaicin was capable of protecting gastric mucosa in rats with both intact and capsaicin-deactivated rats and that this protective activity depended, at least in part, upon its hyperemic and antisecretory effects that may be mediated, at least in part, by endogenous release of prostaglandins.

Abdel-Salam et al. (1997) stated in their review that experimental data provided clear evidence indicating capsaicin-sensitive (CS) sensory nerves to be involved in a local defense mechanism against gastric ulcer in the rat abdomen. Stimulation of CS sensory nerves with low intragastric concentrations of capsaicin protected the rat gastric mucosa against injury produced by different ulcerogenic agents. In contrast, high local desensitizing concentrations of capsaicin or systemic neurotoxic doses of the agent markedly enhanced the susceptibility of the rat gastric mucosa to later noxious challenge. Resiniferatoxin, a potent analogue of capsaicin also possessed an acute gastroprotective effect similar to that of capsaicin in the stomach. The gastroprotective effect of capsaicin-type agents involved an enhancement of the microcirculation effected through the release of mediator peptides from the sensory nerve terminals with calcitonin gene-related peptide being the most likely candidate implicated. They stated that capsaicin-sensitive fibres were involved in the repair mechanisms of the gastric mucosa. A protective role for CS sensory nerves had also been demonstrated in the colon. In most studies, capsaicin introduced into the stomach of rats or cats inhibited gastric acid secretion. In humans, recent studies also provided evidence in favour of a beneficial effect of capsaicin on the gastric mucosa but an exact concentration-related assessment of the effect of the agent was still lacking. In another study they found that introduction of capsaicin into the rat stomach in very low concentrations of ng- μ g/mL range protected the gastric mucosa against damage produced by topical acidified aspirin, indomethacin, ethanol or 0.6 N HCl. Resiniferatoxin exhibited acute gastroprotective effect similar to that of

capsaicin (Abdel-Salam et al. 1999). Capsaicin given into the stomach in higher desensitizing concentrations of 6.5 mM markedly enhanced the susceptibility of the gastric mucosa and invariably aggravated gastric mucosal damage evoked by later noxious challenge. Such high desensitizing concentrations of capsaicin, however, did not reduce the cytoprotective effect of prostacyclin (PGI₂) or beta-carotene. Capsaicin or resiniferatoxin had an additive protective effect to that of atropine or cimetidine. They concluded that the gastroprotective effect of capsaicin-type agents involved primarily an enhancement of the microcirculation effected through local release of mediator peptides from the sensory nerve terminals. A reduction in gastric acidity may contribute to some degree in the gastric protective action of capsaicin-type agents. The vasodilator and gastroprotective effects of capsaicin-type agents were not dependent on vagal efferents or sympathetic neurons, but involved prostanoids, histaminergic or cholinergic pathways.

In another review, Szolcsányi and Barthó (2001) stated that capsaicin-sensitive peptidergic afferents plays a pivotal role in the maintenance of gastric mucosal integrity against injurious interventions. They stated that recent evidence indicated that the gastroprotective effect of capsaicin in the human stomach involved additional mechanisms to those already revealed in the rat such as (1) the existence of capsaicin-sensitive afferents with both sensory and mediator releasing functions in the rat stomach; (2) VR-1 agonists (capsaicin, resiniferatoxin, piperine) protected against gastric ulcer of the rat parallel with their sensory stimulating potencies; (3) antidromic stimulation of capsaicin-sensitive vagal and somatic afferents resulted in the release of CGRP (calcitonin gene-related peptide), tachykinins, NO and somatostatin. Mózsik et al. (2001) reported on four response stages of capsaicin-sensitive primary afferents to capsaicin: excitation, a sensory-blocking effect, long-term selective neurotoxic impairment and irreversible cell destruction. These responses were dependent on the dosage and timing of capsaicin. Capsaicin and its analog inhibited the development of different chemically induced gastric mucosal damage in various experimental

models if they were given intragastric doses ($\mu\text{g}/\text{kg}$). Mózsik et al. (2005) reported on the gastro-protective effect of low concentration of capsaicin against the ethanol- and indomethacin (IND)-induced gastric mucosal damage in healthy human subjects. Intragastric application of capsaicin decreased gastric acid secretion basal acid output and enhanced “non-parietal” component, gastric transmucosal potential difference (GTPD) in a dose-dependent manner. The decrease of GTPD evoked by ethanol was inhibited by the capsaicin application, which was reproducible. The gastro-protective effect of capsaicin was attributed to stimulation of the sensory nerve endings.

Gastric Secretion Stimulation Activity

A mixture of red pepper suspension (*Capsicum frutescens*) and α -alanine (an amino-acid) mixture caused an increase of gastric acid in 33 duodenal ulcer and 18 non-duodenal ulcer patients (Solanke et al. 1976). The administration of α -alanine in red pepper suspension produced less gastric acid than the fresh red pepper suspension alone.

Aqueous extracts of *Capsicum annum* or *Capsicum frutescens* induced gastric acid secretion dose-dependently when administered to urethane anaesthetized albino rats of both sexes (Sambo et al. 2007). Gastric acid secretion stimulation was mediated by H₂ receptor stimulation.

Under conditions whereby the stomach (acid secretion was inhibited by omeprazole given i.p.) or the duodenum was perfused with saline (pH 4.5), mucosal application of capsaicin (0.3–6 mg/mL for 30 min) caused significantly increased pH and HCO₃⁻ output in a concentration-related manner in both tissues, while transmucosal potential difference increased in the duodenum and decreased in the stomach of anaesthetized rats (Takeuchi et al. 1992). The results indicated that mucosal application of capsaicin increased the gastroduodenal HCO₃⁻ output by stimulation of capsaicin-sensitive sensory neurons and that the action may be in part mediated by endogenous prostaglandins.

Mitogenic Activity

A monomeric mannose/glucose-binding lectin, with a molecular mass of 29.5 kDa and an N-terminal sequence GQRELKL showing resemblance to that of the lectin-like oxidized low-density lipoprotein receptor from the rabbit, was isolated from the seeds of red cluster pepper *Capsicum frutescens* var. *fasciculatum* (Ngai and Ng 2001). The lectin showed strong mitogenic activity toward spleen cells isolated from BALB/c mice. The mitogenic activity, which reached a peak at a lectin concentration of 0.27 μM , was inhibited specifically by D(+)-mannose.

Aflatoxin Contamination

Samples of sundried, matured red pepper, *Capsicum annum* were found to have on a dry weight basis 12.7–26.8% moisture content, 5.0–6.4 mg/100 g vitamin C, 0.8–1.2% crude protein, 3.3–4.1% total soluble solids, and fungal counts of log 4.4–4.5/g (Adegoke et al. 1996). Ordinary matured red *C. annum* had 75.7–78.2% moisture content, 36.1–38.5 mg/100 g vitamin C, 2.4–2.8% crude protein, 9.3–9.9% total soluble solids, and fungal count of log 3.32–3.39/g. Sundried matured red *C. frutescens* had corresponding values of 9.4–18.7%, 5.8–6.3 mg/100 g, 0.8–1.1, 0.9–2.6% and fungal counts log 3.2–3.4/g. No aflatoxins were detected in sundried, matured red *C. frutescens*, but aflatoxin B1 values obtained from *C. annum* varied from non-detectable to 2.2 $\mu\text{g}/\text{kg}$. Dominant fungi isolated from *C. annum* and *C. frutescens* were *Rhizopus oryzae*, *Aspergillus niger*, *A. flavus*, *Geotrichum candidum* and *Saccharomyces* spp.

Cytopathic/Carcinogenic/Clastogenic/Genotoxic Effects/Toxicological Studies

Although capsaicin had been reported to exhibit antitumour activity, carcinogenic and mutagenic potential had also been reported but results of studies had been conflicting (Surh and Lee 1995).

Toth et al. (1984) found that capsaicin-treated Swiss albino mice (10%) developed adenocarcinomas of the duodenum while no such tumour occurred in the untreated control mice. Capsaicin exhibited a low level of mutagenicity in the Ames assay with *Salmonella typhimurium* strain TA98 in the presence of liver activating enzymes from Aroclor-induced rats. A crude mixture of capsaicinoids from *Capsicum frutescens*, capsaicin and dihydrocapsaicin (DC) but not 4-methyl-dihydrocapsaicin, a synthetic homolog of DC, were mutagenic in the Chinese hamster lung fibroblast V79 cell assay (Lawson and Gannett 1989). Chilli extract and capsaicin were found to be mutagenic in *Salmonella typhimurium* histidine-deficient tester strains TA 98, TA 100, TA 1535, TA 1537, and TA 1538 with metabolic activation, with capsaicin being more potent (Nagabhushan and Bhide 1985). Both were negative in the V79 Chinese hamster cell assay. In the micronucleus test, only capsaicin was positive near the LD₅₀ dose. Capsaicin also inhibited DNA synthesis in the testes of Swiss mice injected at two dose levels.

In-vivo studies using the mouse-bone-marrow micronucleus (mouse-MN) assay showed *C. frutescens* fruit extract to have clastogenic activity similar to that of tetracycline, a known clastogen (Villaseñor and de Ocampo 1994). Chilli (*Capsicum frutescens*) extract was found to inhibit proliferation of human buccal mucosa fibroblast cell at concentrations of 300–500 µg/mL (Van Wyk et al. 1995). Total cell death occurred at 16 days with 300 µg/mL and at 6 days with 400–500 µg/mL. The cytopathic effect of chilli extract to fibroblasts was concentration dependent. Oikawa et al. (2006) reported that capsaicin induced oxidative damage in the presence of metal ion and various kinds of cytochrome P450 (CYP). They concluded that Cu(II)-mediated oxidative DNA damage by CYP-treated capsaicin would be relevant for the expression of its carcinogenicity.

Capsaicin, at non-toxic amounts of 0.25 and 0.5 µmole/plate, expressed a dose-dependent inhibition of the mutagenicity of heterocyclic amines Glu-P-1 and PhIP in *Salmonella typhimurium* TA98 when they were metabolically

activated by rat, hamster and human liver S9 and of heterocyclic amine Trp-P-2 when activated by rat and hamster liver S9 (Huynh and Teel 2005). In contrast, capsaicin enhanced the mutagenicity of Trp-P-2 in *Salmonella typhimurium* TA98 when incubated with human liver S9. The lack of consistency in the anti-mutagenic action of capsaicin toward heterocyclic amines was unresolved.

In a study of 114 consecutive patients with confirmed gallbladder cancer, diagnosed 1992–1995, significant red chili pepper consumption was observed in gallbladder cancer patients (Serra et al. 2002). Multivariate analysis deemed only a very low socioeconomic status and red chili pepper consumption as significant independent risk factors for gallbladder cancer. Subsequent studies showed that pure capsaicin did not show mutagenic activity in *Salmonella typhimurium* strain TA98 with without metabolic activation (S9 mix) (Tsuchiya et al. 2011). Aflatoxin contamination of red chili pepper was confirmed, and the concentrations of aflatoxins B1 and G1 were 4.4 and 0.5 ng/g, respectively. Their findings suggested that low-level but protracted exposure to aflatoxins may be associated with the development of gallbladder cancer in Chilean women who carry gallstones.

A single topical application of capsaicin (10 µmol) followed by twice-weekly applications of 12-O-tetradecanoylphorbol-13-acetate onto shaven backs of female ICR mice resulted in no significant increases in incidence and multiplicity of skin tumours, compared with the solvent-pretreated control animals (Park and Surh 1997). Repeated topical applications of capsaicin alone failed to promote 7,12-dimethylbenz[a]anthracene-initiated mouse skin tumorigenesis, but moderately inhibited the papilloma formation when given prior to each topical dose of phorbol ester.

Studies showed that male Wistar rats fed a commercial diet mixed with 2% ground *Capsicum frutescens* fruits for 8 weeks did not adversely affect general health, body weight gain, feed intake and feed efficiency (al-Qarawi and Adam 1999). The feed intake and growth rate were depressed and exfoliation of the intestinal

epithelium into the lumen and cytoplasmic fatty vacuolation and necrosis of the centrilobular hepatocytes occurred at 4 and 8 weeks in rats fed with 10% *Capsicum*. This correlated with changes in hematology, serum enzyme profiles and other serum constituents.

Rats fed the 10% *C. frutescens* diet exhibited impaired growth but did not develop nephropathy nor diarrhoea; in contrast body weight loss, inefficiency of feed utilization, diarrhoea, and enterohepatonephropathy characterized *Citrullus colocynthis* toxicosis in rats (AL-Qarawi and Adam 2003). Feeding the mixture of *C. frutescens* and *C. colocynthis* caused more pronounced effects and death of rats. Vital organ lesions accompanied by anaemia and leucopenia were correlated with changes in serum ALP, AST and ALT activities with alterations in concentrations of total protein, albumin, urea and other serum constituents.

Studies by Chanda et al. (2004) showed that the genotoxic potential of pure *trans*-capsaicin was very low. In the Ames assay, pure *trans*-capsaicin was not mutagenic to *Salmonella typhimurium* or *Escherichia coli* when tested at concentrations extending into the toxic range but was weakly mutagenic in mouse lymphoma L5178Y cells, in the presence of S9 mix. *Trans*-capsaicin did not induce micronuclei in bone marrow cells when tested to the maximum tolerated dose of 800 mg/kg/day in male and 200 mg/kg/day in female CD-1 mice. *Trans*-capsaicin did not induce structural or numerical chromosomal aberrations when evaluated for its ability to induce clastogenicity in blood lymphocytes. They added the purity and source of capsaicin should always be an important consideration for toxicological evaluations. The results of a series of standard assays performed in accordance with the Organisation for Economic Cooperation and Development guidance, confirmed the absence of genotoxic activity of high-purity capsaicin in the bacterial mutation and chromosome aberration tests (Proudlock et al. 2004). In addition, no evidence of cytotoxicity or genotoxicity was seen in the rat bone marrow micronucleus test, where systemic exposure to pure capsaicin was achieved using the subcutaneous route and a rising dose

toleration protocol. They added that earlier reported in-vitro genotoxic activity was probably associated with mutagenic impurities in commercial grades of the material.

Capsicum and paprika are generally recognized as safe by the U.S. Food and Drug Administration for use in food (Anonymous 2007). Based on provocative and predictive investigations in human subject, capsaicin could be irritating at low concentrations; its double edge sword effects of being anticarcinogenic and antigenotoxic, and also carcinogenic and genotoxic, and that capsaicin enhanced the penetration of an antiinflammatory agent through human skin, the Panel recommends that care should be exercised in using ingredients that contain capsaicin in cosmetic products (Anonymous 2007).

Traditional Medicinal Uses

C. frutescens and *C. annum* have been used as a carminative, digestive irritant, stomachic, antihaemorrhoidal, antirheumatic, antiseptic, stimulant, rubefacient, antispasmodic, diaphoretic, stomachic, digestive, sialagogue and tonic and as folk remedies for dropsy, colic, diarrhea, asthma, arthritis, muscle cramps, and toothache (Burkill 1966; Grieve 1971; Bown 1995; Chevallier 1996; Chai 2006; Tolan et al. 2001; Stuart 2011). In European medicine, pepper has been used as a carminative and stimulant to dispel flatulence and to rouse appetite. The fruit is used externally as a strong rubefacient stimulating the circulation, aiding the removal of waste products and increasing the flow of nutrients to the tissues. As rubefacient, it is mixed with cotton-seed oil, applied as cataplasm or as liniment. It has also been powdered and placed inside socks as a traditional remedy for those prone to cold feet. In Peninsular Malaysia the fruit is used for diarrhoea, vomiting and dyspepsia. It has also been administered applied internally after childbirth as a stimulant and is applied to the skin in childbirth as a counter-irritant. In Java the leaves are used instead of the fruit for this purpose. It also has hypoglycemic properties. In Sarawak, the Iban and Malay apply a paste of the leaves mixed with

ashes for ringworm; the Kenyah use pounded fruit and cooking ash to treat cuts and wounds; the Bisayas rub pounded roots on the legs to counter black magical spells; and the Melanau consume a leaf decoction to ease pain in urinating.

Capsicum frutescens has been used to treat diabetes mellitus by traditional healers in Jamaica. The ancient Mayans have been reported to use it for treatment of coughs, sore throat and coughs. A weak fruit infusion can be employed as a gargle to treat throat complaints. Fruit juice is applied to the tooth cavity for toothache by the Aztecs. A poultice of chilli pepper is used as a poultice over affected rheumatic parts. Applied to the skin it desensitizes nerve endings and so has been used as a local anaesthetic. A strong fruit infusion is used as a remedy for scalp ringworm. It has proved efficacious in dilating blood vessels and thus relieving chronic congestion of people addicted to drink. However, excessive consumption of red pepper may aggravate symptoms of duodenal ulcers and cause gastroenteritis and kidney damage.

Other Uses

C. frutescens cultivars can be used in chilli breeding for genetic improvement purposes. Chilli pepper extracts and oleoresin are used in production of self-defence and less than-lethal (LTL) weaponry. Hot pepper extracts has been found to repel to exhibit toxic and repellent effects against spider mites (Antonious et al. 2006b). Capsaicin is also employed in a gel-based product as a feral pigeon deterrent from specific roosting and loafing areas.

Comments

Some well-known cultivars of *Capsicum frutescens* encountered around the globe are: African Birdseye or African Devil (also called Piri-piri), Cabe Rawit, Chilli Padi, Demon Red, Kambuzi Pepper, Malagueta Pepper, Malawian Pepper Siling Labuyo, Tabasco Pepper.

Refer also to notes in chapters on *Capsicum annum*, *C. baccatum* and *C. chinense*.

Selected References

- Abdel-Salam OM, Szolcsányi J, Mózsik G (1997) Capsaicin and the stomach. A review of experimental and clinical data. *J Physiol Paris* 91(3–5):151–171
- Abdel-Salam OM, Debreceni A, Mózsik G, Szolcsányi J (1999) Capsaicin-sensitive afferent sensory nerves in modulating gastric mucosal defense against noxious agents. *J Physiol Paris* 93(5):443–454
- Abdel-Salam OM, Abdel-Rahman RF, Sleem AA, Farrag AR (2012) Modulation of lipopolysaccharide-induced oxidative stress by capsaicin. *Inflammopharmacology* 20(4):207–217
- Adegoke GO, Allamu AE, Akingbala JO, Akanni AO (1996) Influence of sundrying on the chemical composition, aflatoxin content and fungal counts of two pepper varieties—*Capsicum annum* and *Capsicum frutescens*. *Plant Foods Hum Nutr* 49(2):113–117
- Al-Qarawi AA, Adam SE (1999) Effects of red chilli (*Capsicum frutescens* L.) on rats. *Vet Hum Toxicol* 41(5):293–295
- Al-Qarawi AA, Adam SE (2003) Effect of combination of *Capsicum frutescens* and *Citrullus colocynthis* on growth, haematological and pathophysiological parameters of rats. *Phytother Res* 17(1):92–95
- Anandakumar P, Kamaraj S, Jagan S, Ramakrishnan G, Naveenkumar C, Asokkumar S, Devaki T (2009) Capsaicin alleviates the imbalance in xenobiotic metabolizing enzymes and tumor markers during experimental lung tumorigenesis. *Mol Cell Biochem* 331(1–2):135–143
- Anonymous (2007) Final report on the safety assessment of *Capsicum annum* extract, *Capsicum annum* fruit extract, *Capsicum annum* resin, *Capsicum annum* fruit powder, *Capsicum frutescens* fruit, *Capsicum frutescens* fruit extract, *Capsicum frutescens* resin, and capsaicin. *Int J Toxicol* 26(Suppl 1):3–106
- Anonymous (2011) Capsaicin patch (Qutenza) for postherpetic neuralgia. *Med Lett Drugs Ther* 53(1365):42–43
- Antonious GF, Jarret RL (2006) Screening *Capsicum* accessions for capsaicinoids content. *J Environ Sci Health B* 41(5):717–729
- Antonious GF, Kochhar TS, Jarret RL, Snyder JC (2006a) Antioxidants in hot pepper: variation among accessions. *J Environ Sci Health B* 41(7):1237–1243
- Antonious GF, Meyer JE, Snyder JC (2006b) Toxicity and repellency of hot pepper extracts to spider mite, *Tetranychus urticae* Koch. *J Environ Sci Health B* 41(8):1383–1391
- Backonja MM, Wallace MS, Blonsky ER, Cutler BJ, Malan P Jr, Rauck R, Tobias J, NGX-4010 C116 Study Group (2008) NGX-4010, a high-concentration

- apsaicin patch, for the treatment of postherpetic neuralgia: a randomised, double-blind study. *Lancet Neurol* 7(12):1106–1112
- Backonja MM, Malan TP, Vanhove GF, Tobias JK, C102/106 Study Group (2010) NGX-4010, a high-concentration capsaicin patch, for the treatment of postherpetic neuralgia: a randomized, double-blind, controlled study with an open-label extension. *Pain Med* 11(4):600–608
- Basu S, Srivastava P (2005) Immunological role of neuronal receptor vanilloid receptor 1 expressed on dendritic cells. *Proc Natl Acad Sci USA* 102(14):5120–5125
- Beltran J, Ghosh AK, Basu S (2007) Immunotherapy of tumors with neuroimmune ligand capsaicin. *J Immunol* 178(5):3260–3264
- Belza A, Jessen AB (2005) Bioactive food stimulants of sympathetic activity: effect on 24-h energy expenditure and fat oxidation. *Eur J Clin Nutr* 59(6):733–741
- Belza A, Frandsen E, Kondrup J (2007) Body fat loss achieved by stimulation of thermogenesis by a combination of bioactive food ingredients: a placebo-controlled, double-blind 8-week intervention in obese subjects. *Int J Obes (Lond)* 31(1):121–130
- Bernstein JE, Bickers DR, Dahl MV, Roshal JY (1987) Treatment of chronic postherpetic neuralgia with topical capsaicin. A preliminary study. *J Am Acad Dermatol* 17(1):93–96
- Bernstein JE, Korman NJ, Bickers DR, Dahl MV, Millikan LE (1989) Topical capsaicin treatment of chronic postherpetic neuralgia. *J Am Acad Dermatol* 21(2 Pt 1):265–270
- Bortolotti M, Coccia G, Grossi G (2002) Red pepper and functional dyspepsia. *N Engl J Med* 346:947–948
- Bosland PW (1996) Capsicums: innovative uses of an ancient crop. In: Janick J (ed) *Progress in new crops*. ASHS Press, Arlington, pp 479–487
- Bosland PW, Baral JB (2007) Bhut Jolokia — the world's hottest known chile pepper is a putative naturally occurring interspecific hybrid. *HortSci* 42(2):222–224
- Bown D (1995) *Encyclopaedia of herbs and their uses*. Dorling Kindersley, London, 424 pp
- Brook RA, Kleinman NL, Choung RS, Melkonian AK, Smeeding JE, Talley NJ (2010) Functional dyspepsia impacts absenteeism and direct and indirect costs. *Clin Gastroenterol Hepatol* 8(6):498–503
- Brown KC, Witte TR, Hardman WE, Luo H, Chen YC, Carpenter AB, Lau JK, Dasgupta P (2010) Capsaicin displays anti-proliferative activity against human small cell lung cancer in cell culture and nude mice models via the E2F pathway. *PLoS One* 5(4):e10243
- Brzozowski T, Konturek SJ, Sliwowski Z, Pytko-Polo@zyk J, Szlachcic A, Drozdowicz D (1996) Role of capsaicin-sensitive sensory nerves in gastroprotection against acid-independent and acid-dependent ulcerogens. *Digestion* 57(6):424–432
- Burkill IH (1966) *A dictionary of the economic products of the Malay Peninsula*, Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Cameron-Smith D, Colquhoun EQ, Ye JM, Hettiarachchi M, Clark MG (1990) Capsaicin and dihydrocapsaicin stimulate oxygen consumption in the perfused rat hindlimb. *Int J Obes* 14(3):259–270
- Cardeal ZL, Gomes da Silva MDR, Marriott PJ (2006) Comprehensive two-dimensional gas chromatography/mass spectrometric analysis of pepper volatiles. *Rapid Commun Mass Spectrom* 20:2823–2836
- Chai PPK (2006) *Medicinal plants of Sarawak*. Lee Ming Press, Kuching, 212 pp
- Chaiyasit K, Khovidhunkit W, Wittayalerpanya S (2009) Pharmacokinetic and the effect of capsaicin in *Capsicum frutescens* on decreasing plasma glucose level. *J Med Assoc Thai* 92(1):108–113
- Chaiyaya P, Puttadechakum S, Komindr S (2003) Effect of chili pepper (*Capsicum frutescens*) ingestion on plasma glucose response and metabolic rate in Thai women. *J Med Assoc Thai* 86(9):854–860
- Chanda S, Erexson G, Riach C, Innes D, Stevenson F, Murli H, Bley K (2004) Genotoxicity studies with pure *trans*-capsaicin. *Mutat Res* 557(1):85–97
- Chevallier A (1996) *The encyclopedia of medicinal plants*. Dorling Kindersley, London, 336 pp
- Chiej R (1984) *Encyclopaedia of medicinal plants*. MacDonald, London, 447 pp
- Chile Head (2011) Varieties database. <http://www.g6csy.net/chile/database.html>
- Ching LS, Mohamed S (2001) Alpha-tocopherol content in 62 edible tropical plants. *J Agric Food Chem* 49(6):3101–3105
- Choi SE, Kim TH, Yi SA, Hwang YC, Hwang WS, Choe SJ, Han SJ, Kim HJ, Kim DJ, Kang Y, Lee KW (2011) Capsaicin attenuates palmitate-induced expression of macrophage inflammatory protein 1 and interleukin 8 by increasing palmitate oxidation and reducing c-Jun activation in THP-1 (human acute monocytic leukemia cell) cells. *Nutr Res* 31(6):468–478
- Cichewicz RH, Thorpe PA (1996) The antimicrobial properties of chile peppers (*Capsicum* species) and their uses in Mayan medicine. *J Ethnopharmacol* 52(2):61–70
- Cordell GA, Araujo OE (1993) Capsaicin: identification, nomenclature, and pharmacotherapy. *Ann Pharmacother* 27(3):330–336
- D'Arcy WG, Eshbaugh WH (1974) New world peppers (*Capsicum* - Solanaceae) north of Colombia: a résumé. *Baileya* 19:93–105
- De Lucca AJ, Bland JM, Vigo CB, Cushion M, Selitrennikoff CP, Peter J, Walsh TJ (2002) CAY-1, a fungicidal saponin from *Capsicum* sp. fruit. *Med Mycol* 40(2):131–137
- De Lucca AJ, Bland JM, Boue S, Vigo CB, Cleveland TE, Walsh TJ (2006a) Synergism of CAY-1 with amphotericin B and itraconazole. *Chemotherapy* 52(6):285–287
- De Lucca AJ, Boue S, Palmgren MS, Maskos K, Cleveland TE (2006b) Fungicidal properties of two saponins

- from *Capsicum frutescens* and the relationship of structure and fungicidal activity. *Can J Microbiol* 52(4):336–342
- De AK, Ghosh JJ (1988) Inflammatory effects of acute and chronic capsaicin treatment on rat paw. *Phytother Res* 2:175–179
- Deal CL, Schnitzer TJ, Lipstein E, Seibold JR, Stevens RM, Levy MD, Albert D, Renold F (1991) Treatment of arthritis with topical capsaicin: a double-blind trial. *Clin Ther* 13(3):383–395
- Diepvens K, Westerterp KR, Westerterp-Plantenga MS (2007) Obesity and thermogenesis related to the consumption of caffeine, ephedrine, capsaicin, and green tea. *Am J Physiol Regul Integr Comp Physiol* 292(1):R77–R85
- Eshbaugh WH (1980) The taxonomy of the genus *Capsicum* (Solanaceae). *Phytologia* 47(3):153–165
- Frerick H, Keitel W, Kuhn U, Schmidt S, Bredehorst A, Kuhlmann M (2003) Topical treatment of chronic low back pain with a capsaicin plaster. *Pain* 106(1–2):59–64
- Frucht-Pery J, Feldman ST, Brown SI (1997) The use of capsaicin in herpes zoster ophthalmicus neuralgia. *Acta Ophthalmol Scand* 75(3):311–313
- Führer M, Hammer J (2009) Effect of repeated, long term capsaicin ingestion on intestinal chemo- and mechanosensation in healthy volunteers. *Neurogastroenterol Motil* 21(5):521–527
- Führer M, Vogelsang H, Hammer J (2011) A placebo-controlled trial of an oral capsaicin load in patients with functional dyspepsia. *Neurogastroenterol Motil* 23(10):918–e397
- Gagnier JJ, van Tulder MW, Berman B, Bombardier C (2007) Herbal medicine for low back pain: a Cochrane review. *Spine (Phila Pa 1976)* 32(1):82–92
- Grieve M (1971) A modern herbal. Penguin, 2 vols. Dover publications, Dover/New York, 919 pp
- Hammer J, Führer M, Pipal L, Matiassek J (2008) Hypersensitivity for capsaicin in patients with functional dyspepsia. *Neurogastroenterol Motil* 20(2):125–133
- Henry CJ, Emery B (1986) Effect of spiced food on metabolic rate. *Hum Nutr Clin Nutr* 40(2):165–168
- Higashiguchi F, Nakamura H, Hayashi H, Kometani T (2006) Purification and structure determination of glucosides of capsaicin and dihydrocapsaicin from various *Capsicum* fruits. *J Agric Food Chem* 54(16):5948–5953
- Howard LR, Talcott ST, Brenes CH, Villalon B (2000) Changes in phytochemical and antioxidant activity of selected pepper cultivars (*Capsicum* species) as influenced by maturity. *J Agric Food Chem* 48(5):1713–1720
- Huang SP, Chen JC, Wu CC, Chen CT, Tang NY, Ho YT, Lo C, Lin JP, Chung JG, Lin JG (2009) Capsaicin-induced apoptosis in human hepatoma HepG2 cells. *Anticancer Res* 29(1):165–174
- Huh HC, Lee SY, Lee SK, Park NH, Han IS (2011) Capsaicin induces apoptosis of cisplatin-resistant stomach cancer cells by causing degradation of cisplatin-inducible Aurora-A protein. *Nutr Cancer* 63(7):1095–1103
- Hursel R, Westerterp-Plantenga MS (2010) Thermogenic ingredients and body weight regulation. *Int J Obes (Lond)* 34(4):659–669
- Huynh HT, Teel RW (2005) In vitro antimutagenicity of capsaicin toward heterocyclic amines in *Salmonella typhimurium* strain TA98. *Anticancer Res* 25(1A):117–120
- Ip SW, Lan SH, Lu HF, Huang AC, Yang JS, Lin JP, Huang HY, Lien JC, Ho CC, Chiu CF, Wood WG, Chung JG (2012) Capsaicin mediates apoptosis in human nasopharyngeal carcinoma NPC-TW 039 cells through mitochondrial depolarization and endoplasmic reticulum stress. *Hum Exp Toxicol* 31(6):539–549
- Islam MS, Choi H (2008) Dietary red chilli (*Capsicum frutescens* L.) is insulinotropic rather than hypoglycemic in type 2 diabetes model of rats. *Phytother Res* 22(8):1025–1029
- Jaiarj P, Saichompoo S, Wongkrajang Y, Vongswan N, Peungvicha P, Jiratchariyakul W (1998) Cardiovascular actions of capsaicinoids extract from Thai *Capsicum*. *Thai J Phytopharm* 5:1–13
- Junior SB, Tavares AM, Filho JT, Zini CI, Godoy HT (2012) Analysis of the volatile compounds of Brazilian chilli peppers (*Capsicum* spp.) at two stages of maturity by solid phase micro-extraction and gas chromatography-mass spectrometry. *Food Res Int* 48(1):96–107
- Katzer G (2012) Chile (*Capsicum frutescens* L. and others). http://www.uni-graz.at/~katzer/engl/Caps_fru.html
- Keitel W, Frerick H, Kuhn U, Schmidt U, Kuhlmann M, Bredehorst A (2001) *Capsicum* pain plaster in chronic non-specific low back pain. *Arzneimittelforschung* 51(11):896–903
- Kempaiah RK, Manjunatha H, Srinivasan K (2005) Protective effect of dietary capsaicin on induced oxidation of low-density lipoprotein in rats. *Mol Cell Biochem* 275(1–2):7–13
- Kim MY (2012) Nitric oxide triggers apoptosis in A375 human melanoma cells treated with capsaicin and resveratrol. *Mol Med Report* 5(2):585–591
- Kim CS, Kawada T, Kim BS, Han IS, Choe SY, Kurata T, Yu R (2003) Capsaicin exhibits anti-inflammatory property by inhibiting I κ B- α degradation in LPS-stimulated peritoneal macrophages. *Cell Signal* 15(3):299–306
- Kim JY, Kim EH, Kim SU, Kwon TK, Choi KS (2010) Capsaicin sensitizes malignant glioma cells to TRAIL-mediated apoptosis via DR5 upregulation and survivin downregulation. *Carcinogenesis* 31(3):367–375
- Kosuwon W, Sirichatiwapee W, Wisanuyotin T, Jeeravipoolvarn P, Laupattarakasem W (2010) Efficacy of symptomatic control of knee osteoarthritis with 0.0125% of capsaicin versus placebo. *J Med Assoc Thai* 93(10):1188–1195
- Kozukue N, Han JS, Kozukue E, Lee SJ, Kim JA, Lee KR, Levin CE, Friedman M (2005) Analysis of eight capsaicinoids in peppers and pepper-containing foods by high-performance liquid chromatography and liquid chromatography-mass spectrometry. *J Agric Food Chem* 53(23):9172–9181

- Lawson T, Gannett P (1989) The mutagenicity of capsaicin and dihydrocapsaicin in V79 cells. *Cancer Lett* 48(2):109–113
- Lee JS, Chang JS, Lee JY, Kim JA (2004) Capsaicin-induced apoptosis and reduced release of reactive oxygen species in MBT-2 murine bladder tumor cells. *Arch Pharm Res* 27(11):1147–1153
- Lim K, Yoshioka M, Kikuzato S, Kiyonaga A, Tanaka H, Shindo M, Suzuki M (1979) Dietary red pepper ingestion increases carbohydrate oxidation at rest and during exercise in runners. *Med Sci Sports Exerc* 29(3):355–361
- Liu R, Ke X, Yang CL, Xiong ZD, Zhi ML, Wen TX (2009) Changes in volatile compounds of a native Chinese chilli pepper (*Capsicum frutescens* var) during ripening. *Int J Food Sci Technol* 44:2470–2475
- Lu HF, Chen YL, Yang JS, Yang YY, Liu JY, Hsu SC, Lai KC, Chung JG (2010) Antitumor activity of capsaicin on human colon cancer cells in vitro and colo 205 tumor xenografts in vivo. *J Agric Food Chem* 58(24):12999–13005
- Luo XJ, Peng J, Li YJ (2011) Recent advances in the study on capsaicinoids and capsinoids. *Eur J Pharmacol* 650(1):1–7
- Lynn B (1990) Capsaicin: actions on nociceptive C-fibres and therapeutic potential. *Pain* 41(1):61–69
- Malagarie-Cazenave S, Olea-Herrero N, Vara D, Morell C, Díaz-Laviada I (2011) The vanilloid capsaicin induces IL-6 secretion in prostate PC-3 cancer cells. *Cytokine* 54(3):330–337
- Manizakiza P, Covaci A, Schepens P (1999) Solid phase extraction and gas chromatography with MS determination of Capsaicin and some of its analogues from chili peppers (*Capsicum* spp). *J AOAC Int* 82:1399–1405
- Manjunatha H, Srinivasan K (2006) Protective effect of dietary curcumin and capsaicin on induced oxidation of low-density lipoprotein, iron-induced hepatotoxicity and carrageenan-induced inflammation in experimental rats. *FEBS J* 273(19):4528–4537
- Manjunatha H, Srinivasan K (2007a) Hypolipidemic and antioxidant effects of curcumin and capsaicin in high-fat-fed rats. *Can J Physiol Pharmacol* 85(6):588–596
- Manjunatha H, Srinivasan K (2007b) Hypolipidemic and antioxidant effects of dietary curcumin and capsaicin in induced hypercholesterolemic rats. *Lipids* 42(12):1133–1142
- McCarthy GM, McCarthy DJ (1992) Effect of topical capsaicin in the therapy of painful osteoarthritis of the hands. *J Rheumatol* 19(4):604–607
- McCormack PL (2010) Capsaicin dermal patch: in non-diabetic peripheral neuropathic pain. *Drugs* 70(14):1831–1842
- McMahon SB, Lewin G, Bloom SR (1991) The consequences of long-term topical capsaicin application in the rat. *Pain* 44(3):301–310
- Mori A, Lehmann S, O'Kelly J, Kumagai T, Desmond JC, Pervan M, McBride WH, Kizaki M, Koeffler HP (2006) Capsaicin, a component of red peppers, inhibits the growth of androgen-independent, p53 mutant prostate cancer cells. *Cancer Res* 66(6):3222–3229
- Mózsik G, Vincze A, Szolcsányi J (2001) Four response stages of capsaicin-sensitive primary afferent neurons to capsaicin and its analog: gastric acid secretion, gastric mucosal damage and protection. *J Gastroenterol Hepatol* 16(10):1093–1097
- Mózsik G, Szolcsányi J, Rácz I (2005) Gastroprotection induced by capsaicin in healthy human subjects. *World J Gastroenterol* 11(33):5180–5184
- Nagabhushan M, Bhide SV (1985) Mutagenicity of chili extract and capsaicin in short-term tests. *Environ Mutagen* 7(6):881–888
- Ngai PH, Ng TB (2001) A lectin with antifungal and mitogenic activities from red cluster pepper (*Capsicum frutescens*) seeds. *Appl Microbiol Biotechnol* 74(2):366–371
- Nyren O, Lindberg G, Lindstrom E, Marke LA, Seensalu R (1992) Economic cost of functional dyspepsia. *Pharmacoeconomics* 1(5):312–324
- Oboh G, Ogunraku OO (2010) Cyclophosphamide-induced oxidative stress in brain: protective effect of hot short pepper (*Capsicum frutescens* L. var. *abbreviatum*). *Exp Toxicol Pathol* 62(3):227–233
- Oikawa S, Nagao E, Sakano K, Kawanishi S (2006) Mechanism of oxidative DNA damage induced by capsaicin, a principal ingredient of hot chili pepper. *Free Radic Res* 40(9):966–973
- Otero R, Núñez V, Barona J, Fonnegra R, Jiménez SL, Osorio RG, Saldarriaga M, Díaz A (2000) Snakebites and ethnobotany in the northwest region of Colombia. Part III: neutralization of the haemorrhagic effect of *Bothrops atrox* venom. *J Ethnopharmacol* 73(1–2):233–241
- Pacific Island Ecosystems at Risk (PIER) (2011) *Capsicum frutescens* L. Solanaceae. http://www.hear.org/pier/species/capsicum_frutescens.htm
- Park KK, Surh YJ (1997) Effects of capsaicin on chemically-induced two-stage mouse skin carcinogenesis. *Cancer Lett* 114(1–2):183–184
- Park HS, Kim KS, Min HK, Kim DW (2004) Prevention of postoperative sore throat using capsicum plaster applied at the Korean hand acupuncture point. *Anaesthesia* 59:647–651
- Peppin JF, Majors K, Webster LR, Simpson DM, Tobias JK, Vanhove GF (2011) Tolerability of NGX-4010, a capsaicin 8% patch for peripheral neuropathic pain. *J Pain Res* 4:385–392
- Porcher MH et al (1995–2020) Searchable world wide web multilingual multiscript plant name database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Poulos JM (1994) *Capsicum* L. In: Siemonsma JS, Piluek K (eds) Plant resources of south-east Asia, no. 8. Vegetables. Pudoc, Wageningen, pp 136–140
- Proudlock R, Thompson C, Longstaff E (2004) Examination of the potential genotoxicity of pure capsaicin in bacterial mutation, chromosome aberration, and rodent micronucleus tests. *Environ Mol Mutagen* 44(5):441–447
- Qin HJ, Lin CW, Jiang LB, Zhong YM, Huang KJ (2004) The GC/MS analysis of the chemical components of oil

- from *Capsicum*. Frontier Separ Sci Technol. In: Proceedings of the 4th international conference nanning, Guangxi, China, 18–21 Feb 2004, pp 485–486
- Quijano CE, Pino JA (2010) Volatile compounds of *Capsicum frutescens* L. cultivars from Colombia. J Essent Oil Res 22(6):503–506
- Rau O, Wurglics M, Dingermann T, Abdel-Tawab M, Schubert-Zsilavecz M (2006) Screening of herbal extracts for activation of the human peroxisome proliferator-activated receptor. Pharmazie 61(11):952–956
- Renault S, De Lucca AJ, Boue S, Bland JM, Vigo CB, Selitrennikoff CP (2003) CAY-1, a novel antifungal compound from cayenne pepper. Med Mycol 41(1):75–81
- Reuter J, Wölfe U, Weckesser S, Schempp C (2010) Which plant for which skin disease? Part 1: atopic dermatitis, psoriasis, acne, condyloma and herpes simplex. J Dtsch Dermatol Ges 8(10):788–796
- Rodríguez-Burruezo A, Kollmannsberger H, González-Mas MC, Nitz S, Fernando N (2010) HS-SPME comparative analysis of genotypic diversity in the volatile fraction and aroma-contributing compounds of *Capsicum* fruits from the *annuum-chinense-frutescens* complex. J Agric Food Chem 58(7):4388–4400
- Rodríguez-Stanley S, Collings KL, Robinson M, Owen W, Miner PB Jr (2000) The effects of capsaicin on reflux, gastric emptying and dyspepsia. Aliment Pharmacol Ther 14(1):129–134
- Rothwell NJ, Stock MJ (1981) A role for insulin in the diet-induced thermogenesis of cafeteria-fed rats. Metabolism 30(7):673–678
- Sambo N, Odeh SO, Ibu JO, Onyikwola O (2007) The effects of *Capsicum annum* and *Capsicum frutescens*-induced gastric acid secretion in the rat is by H2 receptor stimulation. Highland Med Res J 5(2):38–41
- Serra I, Yamamoto M, Calvo A, Cavada G, Báez S, Endoh K, Watanabe H, Tajima K (2002) Association of chili pepper consumption, low socioeconomic status and longstanding gallstones with gallbladder cancer in a Chilean population. Int J Cancer 102(4):407–411
- Shubha MC, Reddy RR, Srinivasan K (2011) Antilithogenic influence of dietary capsaicin and curcumin during experimental induction of cholesterol gallstone in mice. Appl Physiol Nutr Metab 36(2):201–209
- Simpson DM, Gazda S, Brown S, Webster LR, Lu SP, Tobias JK, Vanhove GF, NGX-4010 C118 Study Group (2010) Long-term safety of NGX-4010, a high-concentration capsaicin patch, in patients with peripheral neuropathic pain. J Pain Symptom Manage 39(6):1053–1064
- Singh S, Jarret R, Russo V, Majetich G, Shimkus J, Bushway R, Perkins B (2009) Determination of capsinoids by HPLC-DAD in *Capsicum* species. J Agric Food Chem 57(9):3452–3457
- Smith AC (1991) Flora Vitiensis nova: a new flora of Fiji, vol 5. National Tropical Botanical Garden, Lawai, 626 pp
- Solanke TF, Ayeni O, Osanyintuyi SO (1976) Effect of a mixture of red pepper (*Capsicum frutescens*) and an amino-acid on gastric acid secretion. Niger Med J 6(1):23–25
- Stergiopoulou T, De Lucca AJ, Meletiadiis J, Sein T, Boue SM, Schaufele R, Roilides E, Ghannoum M, Walsh TJ (2008) In vitro activity of CAY-1, a saponin from *Capsicum frutescens*, against *Microsporum* and *Trichophyton* species. Med Mycol 46(8):805–810
- Stuart M (ed) (1987) The encyclopedia of herbs and herbalism. Crescent, London, 304 pp
- Stuart GU (2011) Philippine alternative medicine. Manual of Some Philippine Medicinal Plants. <http://www.stuartxchange.org/OtherHerbals.html>
- Surh YJ (2002) Anti-tumor promoting potential of selected spice ingredients with antioxidative and anti-inflammatory activities: a short review. Food Chem Toxicol 40(8):1091–1097
- Surh YJ, Lee SS (1995) Capsaicin, a double-edged sword: toxicity, metabolism, and chemopreventive potential. Life Sci 56(22):1845–1855
- Szolcsányi J, Barthó L (2001) Capsaicin-sensitive afferents and their role in gastroprotection: an update. J Physiol Paris 95(1–6):181–188
- Takeuchi K, Tachibana K, Ueshima K, Matsumoto J, Okabe S (1992) Stimulation by capsaicin of gastric alkaline secretion in anesthetized rats. Jpn J Pharmacol 59(2):151–157
- Tanaka Y, Hosokawa M, Otsu K, Watanabe T, Yazawa S (2009) Assessment of capsinoninoid composition, nonpungent capsaicinoid analogues, in *Capsicum* cultivars. J Agric Food Chem 57(12):5407–5412
- Tee ES, Noor MI, Azudin MN, Idris K (1997) Nutrient composition of Malaysian foods, 4th edn. Institute for Medical Research, Kuala Lumpur, p 299
- Tesfaye S, Vileikyte L, Rayman G, Sindrup S, Perkins B, Baconja M, Vinik A, Boulton A, Toronto Expert Panel on Diabetic Neuropathy (2011) Painful diabetic peripheral neuropathy: consensus recommendations on diagnosis, assessment and management. Diabetes Metab Res Rev 27:629–638
- Thoenissen NH, O’Kelly J, Lu D, Iwanski GB, La DT, Abbassi S, Leiter A, Karlan B, Mehta R, Koeffler HP (2010) Capsaicin causes cell-cycle arrest and apoptosis in ER-positive and -negative breast cancer cells by modulating the EGFR/HER-2 pathway. Oncogene 29(2):285–296
- Tolan I, Ragoobirsingh D, Morrison EY (2001) The effect of capsaicin on blood glucose, plasma insulin levels and insulin binding in dog models. Phytother Res 15(5):391–394
- Tolan I, Ragoobirsingh D, Morrison EY (2004) Isolation and purification of the hypoglycaemic principle present in *Capsicum frutescens*. Phytother Res 18(1):95–96
- Toth B, Rogan E, Walker B (1984) Tumorigenicity and mutagenicity studies with capsaicin of hot peppers. Anticancer Res 4(3):117–119
- Tsuchiya Y, Terao M, Okano K, Nakamura K, Oyama M, Ikegami K, Yamamoto M (2011) Mutagenicity and mutagens of the red chili pepper as gallbladder cancer risk factor in Chilean women. Asian Pac J Cancer Prev 12(2):471–476

- Uchida M, Yano S, Watanabe K (1991) The role of capsaicin-sensitive afferent nerves in protective effect of capsaicin against absolute ethanol-induced gastric lesions in rats. *Jpn J Pharmacol* 55(2):279–282
- U.S. Department of Agriculture, Agricultural Research Service (USDA) (2012) USDA National Nutrient Database for Standard Reference, Release 25, Nutrient Data Laboratory Home Page, <http://www.ars.usda.gov/ba/bhnrc/ndl>
- van Wyk CW, Olivier A, de Miranda C, van der Bijl P, Grobler-Rabie AF, Chalton DO (1995) Effect of chilli (*Capsicum frutescens*) extract on proliferation of oral mucosal fibroblasts. *Indian J Exp Biol* 33(4):244–248
- Villaseñor IM, de Ocampo EJ (1994) Clastogenicity of red pepper (*Capsicum frutescens* L.) extracts. *Mutat Res* 312(2):151–155
- Vinayaka KS, Nandini KC, Rakshitha MN, Martis R, Shruthi J, Hegde SV, Kekuda TR, Raghavendra HL (2010) Proximate composition, antibacterial and anthelmintic activity of *Capsicum frutescens* (L.) var. *longa* (Solanaceae) leaves. *Pharmacogn J* 2(12):486–491
- Wagner WL, Herbst DR, Sohmer SH (1999) Manual of the flowering plants of Hawaii, 2 vols, Rev edn. Bernice P. Bishop Museum special publication. University of Hawai'i Press/Bishop Museum Press, Honolulu, 1919 pp
- Wallace M, Pappagallo M (2011) Qutenza®: a capsaicin 8% patch for the management of postherpetic neuralgia. *Expert Rev Neurother* 11(1):15–27
- Wang JP, Hsu MF, Hsu TP, Teng CM (1985) Antihemostatic and antithrombotic effects of capsaicin in comparison with aspirin and indomethacin. *Thromb Res* 37(6):669–679
- Wu CC, Lin JP, Yang JS, Chou ST, Chen SC, Lin YT, Lin HL, Chung JG (2006) Capsaicin induced cell cycle arrest and apoptosis in human esophagus epidermoid carcinoma CE 81 T/VGH cells through the elevation of intracellular reactive oxygen species and Ca(2+) productions and caspase-3 activation. *Mutat Res* 601(2):71–82

Lycium barbarum

Scientific Name

Lycium barbarum L.

Synonyms

Boberella halimifolia (Mill.) E.H.L. Krause, *Jasminoides flaccida* Veillard, *Jasminoides flaccidum* Moench, *Lycium barbarum* var. *auranticarpum* K.F. Ching, *Lycium europaeum* hort., *Lycium flaccidum* (Veillard) K. Koch, *Lycium halimifolium* Miller, *Lycium lanceolatum* Veillard, *Lycium subglobosum* Dunal, *Lycium turbinatum* Veillard, *Lycium vulgare* Dunal, *Teremis elliptica* Raf.

Family

Solanaceae

Common/English Names

Barbary Boxthorn, Barbary Matrimony Vine, Box Thorn, Barbary Wolfberry, Chinese Teaplant, Chinese Wolfberry, Common Matrimoney-Vine, Common Matrimony Vine, Duke Of Argyll's Tea Tree, Duke Of Argyll's Teaplant, Goji, Gojiberry, Himalayan Goji, Lycium, Mede Berry, Matrimony Vine, Red Medlar, Tibetan Goji, Wolfberry.

Vernacular Names

Chinese: Di Gu Pi, Gou Qi Zi, Ning Xia Gou Qi;

Czech: Kustovnice Cizí, Kustovnice Obecná;

Danish: Almindelig Bukketorn, Bredbladet Bukketorn, Bukketorn;

Dutch: Boksdoorn, Goji Bes, Goji Bessen;

French: Lyciet À Feuilles D'halimus, Lyciet À Feuilles D'obione, Lyciet Commun, Lyciet De Barbarie;

German: Bocksdoorn, Fasanenschwanz, Gemeiner Bocksdoorn, Gemeiner Teufelszwirn, Gewöhnlicher Bocksdoorn, Judnzaussert, Laubenkraut, Litz, Litzchen, Lizium, Teufelszwirn, Wangerooger Busk, Wolfsdoorn;

Hungarian: Semfüsemfa, Ördögcérna;

Icelandic: Laufskálafletta;

India: Murali;

Italian: Spina-Santa Di Barberia;

Korean: Gu Gi Ja, Tangkugijjanamu;

Norwegian: Bukketorn, Kinabukketorn;

Polish: Kolcowój Szkarłatny;

Slovenčina: Kustovnica Cudzia;

Spanish: Cambrонера, Mora De La Vista

Swedish: Bocktörne, Bredbladigt Bocktörne;

Tibetan: Dre Tsher Ma;

Vietnamese: Cẩu Kỳ, Câu Kỳ Tử, Kỳ Tử.

Origin/Distribution

The original habitat of the species is obscure but probably in southeastern Europe to southwest Asia. The species has naturalized in Britain, Europe and Asia and is widely cultivated in northern and southern China, especially in Ningxia and Tianjin Shi.

Agroecology

As described for *Lycium chinense* in next chapter.

Edible Plant Parts and Uses

Fully ripe fruit is eaten raw, fresh or dried, processed into juice, wine or cooked as described for *Lycium chinense*. *L. barbarum* is available in health food stores in United States and is marketed via the Internet in juice form, typically blended with the juices of other berries and fruits (Cassileth 2010). Dried fruit are often added to rice congee, Chinese herbal medicinal soups slow-cooked with chicken, pork and various vegetables. The fruit is also consumed as herbal tea or processed into wine, blended wines and beer. Young leaves are also eaten cooked as potherb. Leaves are made into herbal teas. The roasted seed is also used as a coffee substitute.

Botany

Erect, deciduous shrub 0.8–2 m tall. Stems and branches glabrous, branches thorny (Plate 1). Leaves solitary or whorled, lanceolate or long elliptic (Plate 1–4), 2–3 cm by 3–6 mm, membranous. Inflorescences solitary or 2–3-flowered clusters. Pedicel 1–2 cm. Calyx campanulate, 4–5 mm, usually 2-lobed, lobes 2-toothed or 3-toothed at apex, tube longer than



Plate 1 Lanceolate leaves and spiny branches



Plate 2 Whorled lanceolate leaves and solitary axillary flower buds and flower



Plate 3 Solitary and axillary funnel-form purple flower

lobes. Corolla purple, funnellform (Plate 4); tube 8–10 mm, distinctly longer than limb and lobes; lobes 5–6 mm, spreading, margin glabrescent. Stamens and style slightly exserted. Berry red or orange-red, oblong or ovoid, 0.4–2 cm × 6–10 mm (Plates 4 and 5). Seeds usually 4–20, brown-yellow, 2 mm across.



Plate 4 Leafy shoot eaten as vegetables and dried fruits



Plate 5 Close up of dried fruits

Nutritive/Medicinal Properties

Polysaccharides comprised quantitatively the most important groups of compounds in *L. barbarum* fruit (Potterat 2010). The polysaccharide fraction referred to as *Lycium barbarum* polysaccharide or LBP consists of a complex mixture of highly branched polysaccharides and proteoglycans. Five homogenous polysaccharide-protein complex fractions were obtained from *L. barbarum* and designated LBPF1, LBPF2, LBPF3, LBPF4 with molecular weight of approximately 150,000 and LBPF5 with molecular weight of 29,300 (Chen et al. 2008). The carbohydrate contents were 48.2, 30.5, 34.5, 20.3, and 23.5% respectively. Four homogenous polysaccharides found to be peptidoglycans and designated LBPC4, LPBA3, LBPB, LBPC2 were isolated from *L. barbarum* fruit

(Zhao et al. 1997). LBPC4 was composed of glucans with a molecular weight of 10,000. LPBA3, LBPB, LBPC2 were composed of heteroglycans and their molecular weights were 66000, 18,000, and 20,000 respectively.

Three glycoconjugates, LbGp3, LbGp4 and LbGp5, with molecular weights of 92,500, 214,800, and 23,700 respectively were isolated from *L. barbarum* fruit (Huang et al. 1998a 1999a). LbGp3 was composed of Ara and Gal in a molar ratio of 1:1. LbGp4 was composed of Ara, Gal, Rha and Glc in a molar ratio of 1.5:2.5:0.43:0.23. LbGp5 was composed of Rha, Ara, Xyl, Gal, Man and Glc in a molar ratio of 0.33:0.52:0.42:0.94:0.85:1. Elemental analysis of N contents was: LbGp3 0.83%, LbGp4 1.72%, LbGp5 9.58%. A glycoconjugate designated as LbGp2 with molecular weight 68.2 kDa and carbohydrate content of up to 90.71% composed of Ara, Gal and amino acids was isolated from *L. barbarum* fruit (Peng and Tian 2001). The glycan possesses a backbone consisting of (1 → 6)- β -galactosyl residues. A glycoconjugate designated as LbGp5B isolated from the fruit was found to have a molecular weight of 23,700 and to compose of rhamnose, arabinose, galactose, glucose (0.1:1:1.2:0.3), galacturonic acid (0.9%) and 17 amino acids (Peng et al. 2001b). A glycoconjugate (LbGp2) with molecular weight of 68.2 kDa, a carbohydrate content of 90.7% and comprising arabinose and galactose in a molar ratio of 3:4, and 18 kinds of amino acids was isolated from *L. barbarum* fruit (Peng et al. 2001c).

Duan et al. (2001) reported four homogenous polysaccharides: LBP 1a-1, LBP 1a-2, LBP 3a-1 and LBP 3a-2 with molecular weight 115,000, 94,000, 103,000, and 82,000 respectively from goji fruit. LBP 1a-1 and LBP 1a-2 were α -(1 → 6)-D-glucans. LBP 3a-1 and LBP 3a-2 were found to be α -(1 → 4)-D-polygalacturonans.

Gan et al. (2004) reported the detection of the glycoconjugate LBP3p with a molecular weight of 157,000 and a carbohydrate content of 92.4% comprising galactose, glucose, rhamnose, arabinose, mannose and xylose in the ratio of (1:2.12:1.25:1.10:1, 95:1.76). Tian and Wang (2006) described *L. barbarum* polysaccharide (LBP) as a complex mixture of polysaccharides

consisting of acidic heteropolysaccharides and polypeptide or protein, and with glycan-O-Ser glycopeptide structures. They reported LBP to have a molecular weight of 15,240 and to compose of 4 water soluble polysaccharides, 6 monosaccharides (Ara, Rha, Xyl, Man, Gal and Glc), galacturonic acid and 18 kinds of amino acids. An acidic polysaccharide LBP-1 isolated from *L. barbarum* fruit with molecular weight of 2.25×10^6 Da was found to compose of with rhamnose, arabinose, xylose, galactose, mannose, galacturonic acid in the ratio of 1.00:7.85:0.37:0.65:3.01:8.16 (Zou et al. 2010). The backbone were mainly composed of (1, 5)-linkage arabinose, (1, 4)-linkage galacturonic acid, -(1)-mannose-(3, 6)-linkage and terminated with -(1)-mannose. The molecular weight of two major polysaccharide fractions in *L. barbarum* with molecular weight of 79,250 and 24,468 Da were found to have rhamnose, arabinose, xylose, mannose, glucose and galactose, with the molar ratio at 0.3:2.7:0.3:0.2:2.7:0.9, respectively (Wang et al. 2009a). A complex water-soluble polysaccharide, named LBPF5 from dried *L. barbarum* fruit with a molecular mass of 53,000 Da was found to consist of arabinose, mannose, xylose, glucose and rhamnose (Ke et al. 2011).

Eight free monosaccharides were detected in amounts between 0.26 and 368.65 $\mu\text{g}/\text{mg}$ in *L. barbarum* fruit (Ye et al. 2006). The following monosaccharide and oligosaccharide: of fructose, glucose, sucrose, maltose and rhamnose were detected in *Lycium barbarum* fruit (Ouyang et al. 2007).

The fruit also contained vitamins: riboflavin, thiamine and vitamin C (ascorbic acid) (Qi et al. 1986). A stable, glucosylated precursor of ascorbic acid, 2-O-(β -D-glucopyranosyl) ascorbic acid was isolated from both the ripe fresh fruit and dried fruit (Toyoda-Ono et al. 2004). The dried fruit contained 0.5% of it, which was comparable to the ascorbic acid content of fresh lemons. This ascorbic acid analogue increased the blood ascorbic acid by oral administration to rats, and it was also detected in blood from the portal vein. Studies using inherently scorbutic (osteogenic disorder Shionogi [ODS]) rats showed that it had pro-vitamin C activity (Toyoda-Ono et al. 2005).

The fruit was reported to also contain 1–2.7% free amino acids with proline as the major amino acid, and non-proteinogenic amino acids γ -aminobutyric acid and taurine as well as betaine (Chen et al. 1991; Cao et al. 2003).

Another important major group of compounds in the fruit is the carotenoids (Potterat 2010). Total carotenoid content found in *L. barbarum* fruit amounted to 0.386% of which zeaxanthin dipalmitate predominated with 0.214%, constituting 55.44% of the total carotenoids (Peng et al. 2005). The amount of zeaxanthin dipalmitate increased to 983 mg/g in liquid anti-solvent precipitates with 29.1% recovery and increased to 929 mg/g in supercritical anti-solvent precipitates with 59.6% recovery, respectively from the ultrasonic acetone extract of *L. barbarum* fruit (Chang et al. 2011). Piao et al. (2005) reported 65% of total carotenoids in the full matured fruit was zeaxanthin and 13% was lutein. Other detectable carotenoids were identified as β -cryptoxanthin and β -carotene. A total of 11 free carotenoids and 7 carotenoid esters were isolated from *L. barbarum* fruit (Inbaraj et al. 2008). Zeaxanthin dipalmitate (1143.7 $\mu\text{g}/\text{g}$) was present in the largest amount, followed by β -cryptoxanthin monopalmitate and its two isomers (32.9–68.5 $\mu\text{g}/\text{g}$), zeaxanthin monopalmitate and its two isomers (11.3–62.8 $\mu\text{g}/\text{g}$), all-*trans*- β -carotene (23.7 $\mu\text{g}/\text{g}$) and all-*trans*-zeaxanthin (1.4 $\mu\text{g}/\text{g}$). Carotenoids, flavonoids and polysaccharides were isolated from *Lycium barbarum* fruit (Wang et al. 2010). The following carotenoids were found: zeaxanthin, β -cryptoxanthin and neoxanthin. Of 52 phenolic compounds, 15 phenolic acids and flavonoids were positively identified in *L. barbarum* fruit (Inbaraj et al. 2010). Among the 15 positively identified compounds, quercetin-rhamno-di-hexoside was present in largest mass fraction (438.6 $\mu\text{g}/\text{g}$), followed by quercetin-3-O-rutinoside (281.3 $\mu\text{g}/\text{g}$), dicaffeoylquinic acid isomers (250.1 $\mu\text{g}/\text{g}$), chlorogenic acid (237.0 $\mu\text{g}/\text{g}$), quercetin-di-(rhamnohexoside) (117.5 $\mu\text{g}/\text{g}$), quercetin-di-(rhamno)-hexoside (116.8 $\mu\text{g}/\text{g}$), kaempferol-3-O-rutinoside (97.7 $\mu\text{g}/\text{g}$), isorhamnetin-3-O-rutinoside (72.1 $\mu\text{g}/\text{g}$), *p*-coumaric acid (64.0 $\mu\text{g}/\text{g}$), caffeic acid (23.7 $\mu\text{g}/\text{g}$) and vanillic acid (22.8 $\mu\text{g}/\text{g}$).

L. barbarum fruit was found to be rich in flavonoids (1.56 mg quercetin-equivalents/g extract) comprising substantial amounts of kaempferol (135 µg/g), quercetin (296 µg/g) and myricetin (247 µg/g) which together accounted for 43% of total flavonoid content (Le et al. 2007). The following flavonoids were isolated from *L. barbarum* fruit: chlorogenic acid, caffeoyl quinic acid, caffeic acid, *p*-coumaric acid, quercetin-diglycoside, rutin and kaempferol-O-rutinoside (Wu et al. 2012).

Four glycerogalactolipids: (2S)-L-O-palmitoyl-2-O-linolenoyl-3-O-[α-D-galactopyranosyl-(1" → 6')-(3"-O-linolenoyl)-β-D-galactopyranosyl]glycerol (1), (2S)-1-O-palmitoyl-2-O-linolenoyl-3-O-[α-D-galactopyranosyl-(1" → 6')-(3"-O-linoleoyl)-β-D-galactopyranosyl]glycerol (2), (2S)-1-O-palmitoyl-2-O-linolenoyl-3-O-[α-D-galactopyranosyl-(1" → 6')-(3"-O-palmitoyl)-β-D-galactopyranosyl]glycerol (3) and (2S)-1-O-palmitoyl-2-O-linoleoyl-3-O-[α-D-galactopyranosyl-(1" → 6')-(3"-O-palmitoyl)-β-D-galactopyranosyl]glycerol (4) together with 11 other previously known homologues were isolated from *Lycium barbarum* fruit (Gao et al. 2008).

Twenty-one components were found in the essential oil of *L. barbarum* fruit and the main components were found to be hexadecanoic acid (47.5%), linoleic acid (9.1%), β-elemene (5.4%), myristic acid (4.2%), ethyl hexadecanoate (4%) and ethyl linoleate (2.5%) (Altintas et al. 2006). Other minor components included: (E)-geranylacetone (1.8%), dodecanoic acid (1.5%), 2-pentadecanone (1.3%), methyl salicylate (1.1%), nonacosane (1.1%), ethyl linolenate (0.9%), (E)-2-nonenal (0.9%), (E)-β-Ionone (0.5%), farnesylacetone (0.5%), 1-octen-3-ol (0.4%), selin-11-en-4α-ol (0.3%), linalool (0.2%), limonene (0.2%), and heneicosane (0.2%).

Harsh (1989) reported the presence of atropine in the fruit. Taurine (0.1–1 mmol/l) was determined quantitatively in dried *L. barbarum* fruit (Xie and Zhang 1997). A new dopamine derivative, lyciumide A, was isolated from *Lycium barbarum* fruits and its structure was elucidated as *p*-methoxy-*cis*-cinnamoyl dopamine (Zou et al. 1999). The following compounds: scopoletin, β-sitosterol, *p*-coumaric acid, glucose, daucos-

terol and betaine were isolated from *L. barbarum* fruit (Xie et al. 2001). Monomenthyl succinate was identified in *Lycium barbarum* by high performance liquid chromatography-tandem mass spectrometry (Hiserodt et al. 2004). Monomenthyl succinate, monomenthyl glutarate, and dimethyl glutarate provide a cooling effect without the burning sensation associated with menthol. Atropine was found in eight samples of dried ripe wolfberry (*L. barabrum*) fruit in concentrations of maximally 19 ppb (w/w) which was far below toxic levels (Adams et al. 2006). A contradictory and doubtful analysis reported a high level of atropine in the fruit (0.95%) and in the roots (Harsh 1989). *L. barbarum* fruit was found to contain 2-O-β-D-glucopyranosyl-L-ascorbic acid (AA-2βG), a novel stable bioactive vitamin C analog (Zhang et al. 2011a).

Carotenoids found in *Lycium barbarum* fruits (seeds) purchased from China included zeaxanthin (83%), β-cryptoxanthin (7%), β-carotene (0.9%), (13Z)-zeaxanthin and (9Z)-zeaxanthin (4%) and (3S,5R,8R,3'R)-mutatoxanthin (1.4%) (Molnar et al. 2003). In addition, auroxanthin (1.9%) and (15Z)-zeaxanthin were tentatively identified. In the hypophase of the mother liquor of the crystallized residue after evaporation of the extract, the following carotenoids were identified: acarotene (in traces), (Z)-isomers of β-cryptoxanthin (0.6%; tentatively identified), (13Z)-zeaxanthin (19%), (9Z)-zeaxanthin (9%), zeaxanthin (44%), (3S,5R,8R,3'R)-mutatoxanthin (7%), auroxanthin (1.4%; tentatively identified), β-citraurin (0.5%; tentatively identified) and various C25-apocarotenals (3.2%; tentatively identified). The epiphase carotenoids of the mother liquor were identified as β-carotene (13%), (Z)-isomers of β-cryptoxanthin (tentatively identified), β-cryptoxanthin (68%), (15Z)-zeaxanthin (tentatively identified), (13Z)-zeaxanthin (5.8%), (9Z)-zeaxanthin (1.9%) and zeaxanthin (7%). Carotenoids in *L. barbarum* purchased from Hungary identified were: zeaxanthin (92.6%), β-carotene (2%), β-cryptoxanthin (2.8%), (13Z)- and (9Z)-zeaxanthin (1%) and β-citraurin (<1%; tentatively identified). The main fatty acids found in *Lycium barbarum* seed oils were: C18:2, C18:1, C16,

C20:6, C18:3, and C20 (Li et al. 2011a, b). Two novel steroidal alkaloid glycosides, lycioside A and lycioside B were isolated from the seeds of *L. barbarum* seeds (Wang et al. 2011).

Phytochemicals in Flower, Leaves and Roots

Diosgenin, β -sitosterol and lanosterol were isolated from the flowers (Harsh and Nag 1981).

Four water-soluble polysaccharide fractions: LBP-I, LBP-II, LBP-III and LBP-IV were isolated from *L. barbarum* leaves (Liu et al. 2012). LBP-II and LBP-IV had average molecular weight of 9.39×10^4 Da and 4.18×10^5 Da. LBP-IV was mainly composed of rhamnose, arabinose, xylose, glucose and galactose with molar ratio of 1.61:3.82:3.44:7.54:1.00, and the uronic acid content was 47.68%.

Five flavonol glycosides and two genins were isolated from goji berry leaves of: quercetin 3-O-rutinoside-7-O-glucoside (1), kaempferol 3-O-rutinoside-7-O-glucoside (2), rutin (3), nicotiflorin (4), isoquercitrin (5), quercetin (6), and kaempferol (7) (Christen and Kapetanidis 1987). The leaf was also reported to contain damascenone and its precursor 3-(2,4-dihydroxy-2,6,6-trimethylcyclohexylidene)-1-methylprop-2-enyl β -D-glucopyranoside (Näf et al. 1990), choline (Drost-Karbowska et al. 1984), and nicotinic acid (Qi et al. 1986). Zhao et al. (1987) reported the leaves to contain scopoletin, vanillic acid and salicylic acid. Leaves of *Lycium barbarum* were found to be rich in flavonoids especially rutin (16.03–16.33 mg/g) compared to the low content in the fruit (0.09–1.38 mg/g) (Dong et al. 2009). The contents of total flavonoids (21.25 mg/g) of cultivated *L. barbarum* leaves were much higher than those in the wild *L. barbarum* leaves (17.86 mg/g), so cultivated *L. barbarum* leaves are a suitable source for medicine vegetables and functional tea. Using far infrared-assisted extraction followed by capillary electrophoresis, bioactive compounds rutin, gentisic acid, and quercetin at levels of 0.31, 0.48, and 0.78 μ M respectively were detected in *L. barbarum* leaves (Duan et al. 2010). Atropine was also detected in the roots (Harsh 1989).

The cyclooctapeptides lyciumins A and B found in *L. chinense* were also reported in *L. barbarum* roots (Yahara et al. 1993). The roots also contained betian, linoleic acid and β -sitosterol (Mizobuchi et al. 1963) and choline (Drost-Karbowska et al. 1984).

Antioxidant Activity

In-Vitro Studies

Ren et al. (1995) reported that *L. barbarum* and betaine inhibited H_2O_2 -induced lipid peroxidation in the following order of antioxidant activity: dry *L. barbarum* fruit > *L. barbarum* polysaccharide > *L. barbarum* residue > betaine. *Lycium barbarum* flavonoids (LBF) (0–217 mg/l) scavenged O_2^- in xanthine/xanthine oxidase (Xan/XO) system, with scavenging rate of 0–51% (Huang et al. 1998b). At 7.5–200 mg/l it scavenged OH produced in Fenton reaction with scavenging rate between 20 and 72%. In addition, the flavonoid extract (0.56 g/l) completely inhibited the heat output from phorbol-12-myristate-13-acetate (PMA)-stimulated polymorphonuclear leukocyte and at a dose of 1–5 g/l inhibited heat output from mouse lymphocytic leukemia cells L1210 cells. Of the glycoconjugates and their glycans from *L. barbarum*, glycoconjugate LbGp5 showed the best effect in inhibiting LDL peroxidation in-vitro (Huang et al. 2001). Li et al. (2002) found that *L. barbarum* could not increase the hypoxic tolerance of mice but might have a protective effect on free radical injury caused by hypoxia. It could not prolong the survival time, but increase the activities of superoxide dismutase, catalase and total anti-oxidative capacity as compared with the control group. Pretreatment of *Lycium barbarum* polysaccharides significantly decreased damage frequencies in mice testicle cells caused by H_2O_2 oxidative stress by scavenging free radicals (Huang et al. 2003).

Studies showed that aqueous extracts of *Angelica sinensis* (AS), *Lycium barbarum* (LB) and *Poria cocos* (PC), three popular ingredients of traditional Chinese medicine, exhibited antioxidant activities in-vitro in a concentration-dependent manner (Wu et al. 2004). All extracts

displayed an inhibitory effect on FeCl_2 -ascorbic acid induced lipid peroxidation in rat liver homogenate in-vitro, with the order of activity $\text{LB} > \text{AS} > \text{PC}$. The tested extracts showed a superoxide anion scavenging activity ranging from 28.8 to 82.2% and anti-superoxide activity varying from 38 to 84.5%. Among the different extracts, LB extract exhibited the lowest IC_{50} values (0.77–2.55 $\mu\text{g/mL}$) in all model systems tested. The results indicated that *L. barbarum* extract possessed the strongest inhibition on malondialdehyde formation in rat liver homogenate, and superoxide anion scavenging and anti-superoxide formation activities, suggesting it to be a good source of antioxidant agent in the daily dietary supplement. *Lycium barbarum* fruit polysaccharides (LBL) with carbohydrate content of 97.54% mainly composed of D-rhamnose, D-xylose, D-arabinose, D-fucose, D-glucose, and D-galactose, displayed potent antioxidant potency (Li et al. 2007a) LBP exhibited significant inhibitory activity in the β -carotene–linoleate model system in a concentration-dependent manner. It exhibited a moderate concentration-dependent inhibition of the $\text{DPPH}^\cdot$ radical. The multiple antioxidant activity of the polysaccharides was evident as it showed significant reducing power, superoxide scavenging ability, inhibition of mice erythrocyte hemolysis mediated by peroxyl free radicals and also ferrous ion chelating potency.

The ethanol fruit extract of *L. barbarum* rich in flavonoids, exhibited antioxidative activities (Le et al. 2007) as determined: by (a) radical-scavenging activity (80 μmol trolox equivalent antioxidant capacity/g), measured by its ability to scavenge 2,2'-azinobis-3-ethylbenzothiazoline-6-sulfonic acid radical (ABTS), (b) reducing capacity (301 μmol trolox equivalent reducing capacity/g), measured by its ability to directly donate an electron in the reduction of Fe(III) to Fe(II) , and (c) chelating activity (2.5 μmol ethylenediamine-tetraacetic acid equivalents/g), measured by its ability to remove Fe(II) ion from complexation with ferrozine. Carotenoids, flavonoids and polysaccharides were isolated from *Lycium barbarum* fruit (Wang et al. 2010). For antioxidant activity, the flavonoid fraction was the most effective in scavenging $\text{DPPH}^\cdot$ and $\text{ABTS}^\cdot$ + free radicals, chelating metal ions and

reducing power, while the zeaxanthin fraction and polysaccharides showed the most pronounced effect in scavenging hydroxy free radicals and superoxide anions, respectively.

Lbp2, a glycoconjugate from *L. barbarum* fruit exhibited good immunoactivity and antioxidative activity (Peng et al. 2001c). It was shown to increase rate of phagocytic action and phagocytic index, promote lymphocyte translation and accelerate the production of serum hemolysin. LbGp2 also had distinct effect of antioxidation and the superoxide anion produced by DMSO-NaOH system which was scavenged effectively. The hydrogen free radical scavenging activity of *Lycium barbarum* polysaccharides at concentrations of 0.25 mg/mL and 1 mg/mL were found to be 18.64% and 87.29% respectively (Ni et al. 2004).

A total of 4 fractions, including 1 neutral polysaccharide (LBPN) and 3 acidic polysaccharides were obtained from *L. barbarum*, and compared with crude polysaccharide (CP), crude extract of polysaccharide (CE), deproteinated polysaccharide (DP), and deproteinated and dialyzed polysaccharide (DDP) for antioxidative activity (Lin et al. 2009). With the exception of CE and DDP, most polysaccharides were effective in scavenging $\text{DPPH}^\cdot$ and $\text{ABTS}^\cdot$ + free radicals, superoxide anion and hydroxyl radical at 1,000 $\mu\text{g/mL}$.

In-vitro radical scavenging assays demonstrated that 2-O- β -D-glucopyranosyl-L-ascorbic acid (AA-2 β G), a natural derivative of vitamin C (L-ascorbic acid) isolated from goji berry (*Lycium barbarum*) was capable of scavenging $\text{DPPH}^\cdot$ and hydroxyl peroxide and inhibiting H_2O_2 -induced hemolysis better than AA (Zhang et al. 2011c). AA-2 β G and ascorbic acid had similar hydroxyl radical scavenging capabilities, but AA-2 β G was incapable of scavenging superoxide anion radicals, and its capacity to scavenge nitrite (NO_2^-) was lower than that of ascorbic acid. The overall in-vitro reduction capability of AA-2 β G was also significantly lower than that of ascorbic acid. Moreover, in-vivo studies demonstrated that AA-2 β G was capable of protecting the liver against carbon tetrachloride-induced acute liver injury in mice. The results suggested AA-2 β G to be an important antioxidant component of Goji berry fruit, which may share similar but distinct

antioxidant mechanistic properties with ascorbic acid.

L. barbarum seed oil exhibited excellent antioxidant activity in 2,2-diphenyl-1-picrylhydrazyl(DPPH) radical scavenging assay and β -carotene bleaching test, and its antioxidant activity compared well with the references ascorbic acid and α -tocopherol (Li et al. 2011a, b).

Animal Studies

Administration of *L. barbarum* polysaccharide to aged mice over a period of 30 days restored to normal levels the elevated endogenous lipid peroxidation, and decreased antioxidant activities, as assessed by superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GSH-Px) and total antioxidant capacity (TAOC), and decreased immune function observed in aged mice (Li et al. 2007b). Antioxidant activities of *L. barbarum* polysaccharides could be comparable with normal antioxidant, vitamin C. Moreover, addition of vitamin C to the polysaccharides further increased the in-vivo antioxidant activity of the latter. The authors concluded that *L. barbarum* polysaccharides could be used in compensating the decline in TAOC, immune function and the activities of antioxidant enzymes and thereby reduced the risks of lipid peroxidation accelerated by age-induced free radicals. Niu et al. (2008) demonstrated that *L. barbarum* polysaccharides administration to Wistar rats on a 30 day exhaustive exercise program, significantly increased glycogen level and antioxidant enzyme activities, and decreased malondialdehyde (MDA) level and creatine kinase activities, thus suggesting *L. barbarum* polysaccharides administration could significantly decrease the oxidative stress induced by the exhaustive exercise.

Administration of *Lycium barbarum* polysaccharides (mainly composed of xylose and glucose and smaller amount of rhamnose, mannose and galactose), to rats fed a high fat diet significantly increased antioxidant enzymes activities and decreased MDA level in mice compared to model group (Wu et al. 2010). Studies indicated that *Lycium barbarum* polysaccharides (LBP) was effective in preventing oxidative stress after exhaustive exercise in rats (Shan et al. 2011). After

exhaustive exercise, the mean endurance time of treadmill running to exhaustion of rats in LBP treated groups were significantly prolonged compared with that in the normal control group. MDA levels of rats in LBP treated groups were significantly decreased compared with that in the normal control group. SOD and GPX levels of rats in LBP treated groups were significantly increased compared with that in the normal control group.

Clinical Studies

In a 30 day randomized, double-blind, placebo-controlled clinical study involving 50 Chinese healthy adults aged 55–72 years, the group administered goji (*L. barbarum*) juice antioxidant markers significantly increased by 8.4% for SOD and 9.9% for GSH-Px between the preintervention and postintervention measurements, whereas MDA were significantly decreased by 8.7% (Amagase et al. 2009a). In addition, the SOD, GSH-Px, and MDA levels in the goji group were significantly different from those in the placebo group at the postintervention time point, with increases of 8.1% and 9% and a decrease of 6%, respectively. These results indicated that goji increased antioxidant efficacies in humans by stimulating endogenous factors and suggest that continued use beyond 30 days might help prevent or reduce free radical-related conditions. Earlier in a randomized, double-blind, placebo-controlled, clinical study, the goji group (N=16) that consumed 120 mL goji juice/day for 14 days registered increases in subjective feelings of general well-being, and improves neurologic/psychologic performance and gastrointestinal functions (Amagase and Nance 2008).

Immunomodulatory Activity

The repeat unit of the glycan of glycoconjugate LbGp3 isolated from *L. barbarum* fruit exhibited pronounced immunoactivity (Huang et al. 1999a). *Lycium barbarum* polysaccharides (LBP-X) exhibited prominent effect on immunological enhancement at a dose of 10 mg/kg/day in mice (Luo et al. 1999). Four polysaccharides from goji berry: Four polysaccharides were shown to enhance splenocyte proliferation induced by ConA

(Duan et al. 2001). LBP 1a-1 and LBP 1a-2 were α -(1 $\rightarrow$ 6)-D-glucans. LBP 3a-1 and LBP 3a-2 were found to be α -(1 $\rightarrow$ 4)-D-polygalacturonans. Polysaccharides with main chain of α -(1 $\rightarrow$ 4)-D-polygalacturonans showed stronger immunomodulation activity. In-vitro studies showed that *Lycium barbarum* glycopeptide had high immunoactivity and could enhance murine splenic lymphocyte proliferation (Du et al. 2004). Combined use of *L. barbarum* glycopeptide and concanavalin A had synergic effects.

A glycoconjugate with pronounced immunoactivity, designated as LbGp2, was isolated from *Lycium barbarum* fruit (Peng and Tian 2001). The results of in-vitro studies suggested that the immunoactive components of the fruit of *Lycium barbarum* could enhance the splenocyte proliferation in normal mice and the effects of glycan chain were stronger than those of glycoconjugate (Peng et al. 2001a). Further, the immuno-stimulatory effect of glycoconjugate (LbGp4) and its glycan (LbGp4-OL) was associated with activating the expression of nuclear factor KB (NF-KB) and activator protein 1 (AP-1). LbGp5B, a glycoconjugate, isolated from *L. barbarum* fruit promoted splenocyte proliferation in mice and inhibited the peroxidation of low density lipoprotein (LDL) (Peng et al. 2001b).

Lycium barbarum polysaccharide at 100 mg/ and 200 mg/kg significantly ameliorated the decrease of peripheral red blood cells (RBC), haemoglobin and hematocrit of mitomycin C-induced myelosuppressive mice compared to the control (Gong et al. 2004). Both doses also significantly enhanced peripheral platelet recovery of myelosuppressive mice compared to the control. The higher dose significantly inhibited the increase of mean platelet volume of myelosuppressive mice compared to the control. They also found that 50 mg/kg LBP significantly ameliorated the decrease of peripheral white blood cells of irradiated myelosuppressive mice (Gong et al. 2005). All doses (50 and 100 mg/kg) significantly ameliorated the decrease of peripheral RBC of irradiated myelosuppressive mice and significantly enhanced peripheral platelet counts of chemotherapy-induced myelosuppressive mice. LBP was found to stimulate human peripheral blood mononuclear

cells (PBMCs) to produce granulocyte colony-stimulating factor (G-CSF). The results indicated that LBP promoted the peripheral blood recovery of irradiation or chemotherapy-induced myelosuppressive mice, and the effects may be the result of the stimulation of PBMCs to produce G-CSF.

Separate studies showed that oral administration of *Lycium barbarum* polysaccharide (LBP) exerted anti-tumour effect by significantly increasing the numbers of CD4⁺ and CD8⁺ T cells in tumour-infiltrating lymphocytes to relieve the immunosuppression and enhance the anti-tumor function of the immune system in H22-bearing mice (He et al. 2005). LBP also increased the number of dendritic cells and B7-1 expression.

The polysaccharide-protein complex from *L. barbarum* (LBP) and its fractions LBPF4, and LBPF5 significantly stimulated proliferation of mouse T lymphocytes and markedly reduced sub-G1 cells (Chen et al. 2008). LBP, LBPF4, and LBPF5 could activate transcription factors NFAT and AP-1, prompt CD25 expression, and induce IL-2 and IFN-gamma gene transcription and protein secretion. The results suggested that activation of T lymphocytes by LBP may contribute to one of its immuno-enhancement functions. They also found that LBP (50 mg/kg, i.p.) markedly upregulated the expressions of CD40, CD80, CD86 and MHC class II molecules on peritoneal macrophages and significantly enhanced macrophage endocytic and phagocytic capacities in-vivo (Chen et al. 2009b). In-vitro studies showed that LBP and LBPF1-5 activated transcription factors NF-kappaB and AP-1 by RAW264.7 macrophage cells, induced TNF-alpha, IL-1beta, IL-12p40 mRNA expression, and enhanced TNF-alpha production in a dose-dependent manner. Chen et al. (2009a) also found that LBP induced phenotypic and functional maturation of dendritic cells with strong immunogenicity. LBP up-regulated DC expression of CD40, CD80, CD86, and MHC class II molecules; down-regulated DC uptake of Ag; enhanced DC allostimulatory activity; and induced IL-12p40 and p70 production. All of its five fractions were active. LBP developed enhanced Th1 response, and LBP-treated DCs enhanced Th1 and Th2 responses in-vitro and in-vivo. Their study provided evidence and

rationale on using LBP in various clinical conditions to enhance host immunity and suggested LBP as a potent adjuvant for the design of dendritic cell-based vaccines.

Zhu et al. (2006) reported that *Lycium barbarum* polysaccharides (LBPs) stimulated the maturation of murine bone marrow derived dendritic cells (BMDCs) in-vitro and also immune response initiation induced by BMDCs. In further in-vitro studies they found that *Lycium barbarum* polysaccharides (LBPs) were capable of promoting both the phenotypic and functional maturation of murine bone marrow derived dendritic cells (BMDC) (Zhu et al. 2007). LBP stimulated the co-expression of I-A/I-E, CD11c and secretion of IL-12 p40 and enhanced proliferation of allogenic lymphocytes by BMDC. Dendritic cells (DC) are potent antigen-presenting cells that play pivotal roles in the initiation of the primary immune response. Zhang et al. (2011a) found in in-vitro and in-vivo studies using Balb/C mice that macrophages rather than T and B cells were the principal immunostimulatory target cells of the polysaccharide LBPF4-OL, the glycan part of *L. barbarum* polysaccharide-protein complex fraction 4 which is known for its immunoregulatory and antitumor effects in traditional Chinese medicine. LBPF4-OL induced IL-6, IL-8, IL-10 and TNF- α production of the spleen cells in a concentration-dependent manner. Further, LBPF4-OL (i.p.) induced CD86 and MHC-II molecules expression on macrophages and greatly strengthened macrophage release of TNF- α and IL-1 β .

A water soluble polysaccharide fraction LBP-IV isolated from *L. barbarum* leaves significantly enhanced the proliferation of splenocyte stimulated by concanavalin A or Lipopolysaccharide, indicating the fraction had the beneficial effect on immunostimulating activity (Liu et al. 2012).

Clinical Studies

In a randomized, double-blind, placebo-controlled clinical study in 60 older healthy adults (55–72 years old), the group given *L. barbarum* (goji) fruit juice showed a statistically significant increase in the number of lymphocytes and levels

of interleukin-2 and immunoglobulin G compared to pre-intervention and the placebo group, whereas the number of CD4, CD8, and natural killer cells or levels of interleukin-4 and immunoglobulin A were not significantly altered (Amagase et al. 2009b). The goji group showed a significant increase in general feelings of well-being, such as fatigue and sleep, and showed a tendency for increased short-term memory and focus between pre- and post-intervention, the placebo group showed no significant positive changes in these measures. No adverse reactions, abnormal symptoms, or changes in body weight, blood pressure, pulse, visual acuity, urine, stool, or blood biochemistry were seen in either group.

In a 3 month randomized, double-blinded, placebo-controlled study conducted on 150 healthy community-dwelling Chinese elderly (65–70 years old) supplemented with Lacto-Wolfberry (*L. barbarum* fruit) or placebo (13.7 g/day), dietary supplementation with Lacto-Wolfberry in elderly subjects enhanced their capacity to respond to antigenic challenge without over-affecting their immune system (Vidal et al. 2012). The subjects receiving Lacto-Wolfberry had significantly higher post-vaccination serum influenza-specific immunoglobulin G levels and sero-conversion rate, between days 30 and 90, compared with the placebo group. The post-vaccination positive rate was greater in the Lacto-Wolfberry group compared to the placebo group, but did not reach statistical significance. Lacto-Wolfberry supplementation had no significant effect on delayed-type hypersensitivity response and inflammatory markers. No changes in body weight and blood pressure, blood chemistry or cells composition, as well as auto-antibodies levels were observed.

Anticancer Activity

In-Vitro Studies

Scopoletin was the active component isolated from *L. barbarum* fruit that strongly inhibited prostate carcinoma PC3 cell proliferation (Liu et al. 2000).

L. barbarum polysaccharide (LBP-X) inhibited the growth of human leukemia HL-60 cells in dose-dependent manner from 20, 100, 500, 1,000 mg/l and decreased the membrane fluidity of the cell (Gan et al. 2001). The results showed that the apoptosis of HL-60 cells induced by LBP-X maybe its important mechanism on anti-tumorigenesis. Hot water-extracted crude *Lycium barbarum* (2–5 g/l) and *Rehmannia glutinosa* (5–10 g/l) inhibited proliferation human hepatocellular carcinoma cells and stimulated p53-mediated apoptosis in the cells (Chao et al. 2006).

Administration of *Lycium barbarum* polysaccharide-protein complex LBP(3p) to human peripheral blood mononuclear cells increased the expression of interleukin-2 and tumour necrosis factor- α at both mRNA and protein levels in a dose-dependent manner (Gan et al. 2003). The results suggest that LBP(3p) may induce immune responses and possess potential therapeutic efficacy in cancer. Subsequently they reported that administration of *Lycium barbarum* polysaccharides (LBP3p) could inhibit the growth of S180 solid sarcoma tumour in experimental animals and exerted its antitumor activity through potentiation of the host animal's defense system (Gan and Zhang 2003). The immunomodulating and antitumor activity of LBP3p may be at least partly related to the level of expression of interleukin-2 and tumour necrosis factor- α . LBP3P, was also found to significantly inhibit the growth of transplantable sarcoma S180 and to increase macrophage phagocytosis, the form of antibody secreted by spleen cells, spleen lymphocyte proliferation, CTL activity, IL-2 mRNA expression level and reduce the lipid peroxidation in S180-bearing mice (Gan et al. 2004). The dose of 10 mg/kg dose was more effective than 5 and 20 mg/kg doses. This suggested that LBP3p at 10 mg/kg had a highly significant effect on tumour weight and improved the immune system. *Lycium barbarum* polysaccharide (LBP) treatment inhibited human hepatoma QGY7703 cell growth with cycle arrest in S phase and apoptosis induction (Zhang et al. 2005). The results suggested that the induction of cell cycle arrest and the increase of intracellular calcium in apoptotic

system may participate in the antiproliferative activity of LBP in QGY7703 cells.

Treatment of 17 β -estradiol-stimulated MCF-7 breast cancer cells with *L. barbarum* (LB) elicited a dose-dependent growth inhibition of 9.5 and 42.8% at Day 3 and 33.9 and 83.9% at Day 7 (Li et al. 2009). The 3 day inhibitory response to 1% LB (maximum cytostatic concentration) exhibited 84.8% increased estrone, 3.6-fold increased 16 α -hydroxyestrone, 33.3% decreased 16 α -hydroxyestrone, and 9.2-fold increased estriol formation. Thus, MCF-7 cells retained their mitogenic and metabolic response to 17 β -estradiol and LB downregulated 17 β -estradiol-stimulated growth via the formation of antiproliferative 16 α -hydroxyestrone and accelerated conversion of mitogenic 16 α -hydroxyestrone to antimitogenic estriol.

In-vitro studies showed that -O- β -D-glucopyranosyl-L-ascorbic acid (AA-2 β G) isolated from *L. barbarum* fruit exhibited cytotoxic and antiproliferative activity of human cervical cancer Hela cells in a time- and dose-dependent manner (Zhang et al. 2011b). Similar to vitamin C, the AA-2 β G selectively induced cell death repressed the proliferation of Hela cells by the mechanism of cell apoptosis and cell cycle arrest induced by AA-2 β G through a mechanism of stabilizing p53 protein. The findings suggested that the AA-2 β G and vitamin C may share a similar mechanism of inducing Hela cell suppression by downregulating the expression of proteins involved in cell apoptosis and proliferation and consequently inducing Hela cell apoptosis and cell cycle arrest. The results also suggested that *L. barbarum* fruit may be a potential dietary supplement and anticancer agent aimed at the prevention and treatment of cervical cancer. In a more recent study, *Lycium barbarum* polysaccharide (LBP) was found to inhibit the proliferation of human cervical carcinoma cells (HeLa cells) by altering cell cycle distribution and inducing apoptosis via the mitochondrial pathway with the loss of mitochondrial transmembrane potential and increase of intracellular Ca(2+) concentration in apoptotic cells (Zhu and Zhang 2012). At the same time, the nitric oxide content, nitric

oxide synthase and inducible nitric oxide synthase activities were also increased.

Lycium barbarum polysaccharide (LBP) treatment inhibited growth of human gastric cancer MGC-803 and SGC-7901 cells with cell-cycle arrest at the G0/G1 and S phase, respectively (Miao et al. 2010). The study showed that LBP arrested different cell lines from the same types of cancer at different phases. The changes in cell-cycle-associated protein, cyclins, and cyclin-dependent kinases were consistent with the changes in cell-cycle distribution. In another study, at concentrations from 400 to 1,000 mg/l, *L. barbarum* polysaccharide (LBP) significantly inhibited the growth of human colon cancer SW480 cells; while at concentrations from 200 to 1,000 mg/l, LBP significantly inhibited the growth of Caco-2 cells (Mao et al. 2011). Cells were arrested at the G0/G1 phase. Crystal violet assay showed that LBP had a long-term anti-proliferative effect.

In-Vitro and In-Vivo Animal Studies

LBPF5, a water-soluble polysaccharide from *L. barbarum* fruit, from showed strong free radicals scavenging activities in-vitro (Ke et al. 2011). The oxidative hemolysis of erythrocytes induced by AAPH was suppressed by the LBPF5 in a concentration- and time-dependent manner. Furthermore LBPF5 and anthocyan could inhibit the growth of human bladder carcinoma cell line BIU87 and induce BIU87 apoptosis. The results demonstrated that LBPF5 had the ability to protect against damage from oxidative stress in-vitro and in vivo.

In-vitro studies showed that *L. barbarum* polysaccharides (LBP) could dose- and time-dependently inhibit the growth of both PC-3 and DU-145 human prostate cancer cells (Luo et al. 2009). LBP caused the breakage of DNA strands of PC-3 and DU-145 cells and markedly induced PC-3 and DU-145 cell apoptosis, with the highest apoptosis rates at 41.5% and 35.5%, respectively. The ratio of Bcl-2/Bax protein expression following LBP treatments decreased significantly with a dose-effect relationship, which suggested that LBP could regulate the expression of Bcl-2 and

Bax to induce apoptosis of PC-3 and DU-145 cells. The in-vivo experimental results indicated that LBP significantly inhibited PC-3 tumour growth in nude mice. Both the tumour volume and weight of the LBP treatment group were significantly lower than those of the control group.

L. barbarum polysaccharide (LBP) was found to inhibit autophagy and the formation of traumatic neuroma after transection of sciatic nerve in rats (Fan et al. 2010). Light microscopy observations showed that there were unorganized growth cells in the neuroma, infiltrated muscle cells, the regeneration of axons and ensheathing cells to form small patch and funicular structure in the control group, while in the LBP group there were less proliferation of nerve fibres with a regular arrangement. Transmission electron microscopy showed that there were lots of axons in nerve tumour, more fusoid fibroblasts, more collagen fibre, and hyperplasia and degenerated myelin sheath in the control group, while in the LBP group there were less myelin sheath in the proximal end of injured nerves, less Schwann cells and fibroblasts, and sparse collagen fibres.

Clinical Studies

In a clinical trial, 79 advanced cancer patients were treated with a combined treatment of lymphokine-activated killer cells and interleukin-2 (LAK/IL-2) plus *Lycium barbarum* polysaccharides (LBP) (Cao et al. 1994). Initial results from 75 patients indicated that objective regression of cancer was achieved in patients with malignant melanoma, renal cell carcinoma, colorectal carcinoma, lung cancer, nasopharyngeal carcinoma, and malignant hydrothorax. The response rate of patients treated with LAK/IL-2 plus LBP was 40.9% while that of patients treated with LAK/IL-2 was 16.1%. The mean remission in patients treated with LAK/IL-2 plus LBP also lasted significantly longer. LAK/IL-2 plus LBP treatment led to more marked increase in natural killer and lymphokine-activated killer cell activity than LAK/IL-2 without LBP. The results indicated that LBP could be used as an adjuvant in the bio-therapy of cancer.

Anti-angiogenic Activity

Flavonoid extract from *L. barbarum* fruit was effective in inhibiting expression of intercellular adhesion molecule-1 (ICAM-1) and vascular cell adhesion molecule (VCAM-1) induced by TNF- α in human umbilical vein endothelial cells (HUVECs) (Wu et al. 2012). The flavonoid extract attenuated TNF- α -induced I κ B phosphorylation as well as NF- κ B, p65 and p50 translocation from cytosol to nucleus, through inhibition on TNF- α - and H₂O₂-induced intracellular reactive oxygen species (ROS) production. For the anti-angiogenic study, the flavonoid extract inhibited vascular endothelial growth factor (VEGF)-induced cell proliferation and migration in HUVECs, as well as angiogenesis. However, the flavonoid extract did not inhibit VEGF signaling.

Hypotensive Activity

Studies showed that the increase of blood pressure in hypertensive rats (HR) could be prevented significantly by treatment with 10% *Lycium barbarum* polysaccharide (LBP) (Jia et al. 1998). In isolated aortic rings of LBP-treated rats, the contraction of phenylephrine was reduced as compared with HR rats. Removal of the endothelium abolished the difference of PE-induced vasoconstriction among groups. In-vitro incubation of aortic rings from LBP-treated rats with methyl blue or N-nitro-L-arginine methyl ester (L-NAME) increased the magnitude of PE-induced contraction. Meanwhile the response to acetylcholine (ACh) was significantly increased in LBP-treated rats. Pretreatment with L-arginine partially restored ACh-induced relaxation in RH rats, but no effect in LBP-treated rats. The results suggested that the role of LBP in decreasing vaso-constriction to phenylephrine may be mediated by increase of the effects or/and production of endothelium-derived relaxation factor (EDRF). LBP increased formation of EDRF may be related to increase the substrate of EDRF.

Antidiabetic/Hypoglycemic Activity

L. barbarum polysaccharide (LBP) was found to have a protective effect against alloxan-induced damage to isolated islet cells from rats (Xu et al. 2002). LBP inhibited the significant decrease in SOD activity and an increase in MDA production. An acidic polysaccharide LBP-1 isolated from *L. barbarum* fruit, protected the pancreatic islets cells from oxidative damage and enhanced cell survival ratio significantly (Zou et al. 2010). Moreover, its application inhibited the development of insulin resistance in HepG2 cells.

Treatment of D-galactose induced aging mouse with *Lycium barbarum* polysaccharide (LBP) and *Achyranthes bidentata* polysaccharide (ABP) inhibited nonenzyme glycation (Deng et al. 2003). Decreased levels of serum advanced glycated end products (AGE), hydroxyproline concentration in mouse skin and spontaneous motor activity in D-galactose mouse aging model were detected after treated with ABP or LBP, while lymphocyte proliferation and interleukin IL-2 activity, learning and memory abilities, super oxide dismutase activity of erythrocytes, were enhanced.

Luo et al. (2004) reported that *Lycium barbarum* fruit water decoction, crude polysaccharide extracts (crude LBP), and purified polysaccharide fractions (LBP-X) could significantly reduce blood glucose levels and serum total cholesterol (TC) and triglyceride (TG) concentrations and at same time markedly increase high density lipoprotein cholesterol (HDL-c) levels after 10 days treatment in tested rabbits, indicating that there were substantial hypoglycemic and hypolipidemic effects. Hypoglycemic effect of LBP-X was greater than those of the water decoction and crude LBP, but its hypolipidemic effect appeared to be weaker. Total antioxidant capacity assay showed that all three extracts/fractions possessed antioxidant activity. Crude extracts were found to be rich in antioxidants (e.g., carotenoids, riboflavin, ascorbic acid, thiamine, nicotinic acid). *L. barbarum* polysaccharides (glycoconjugates), containing several monosaccharides and 17 amino acids, were major bioactive constituents for the

hypoglycemic effect. Both polysaccharides and vitamin antioxidants from the fruits were possible active principles responsible for the hypolipidemic effect.

Studies showed that *Lycium barbarum* polysaccharide (LBP) treatment for 3 weeks resulted in a significant decrease in the concentration of plasma triglyceride and weight in non-insulin dependent diabetes mellitus (NIDDM) rats (Zhao et al. 2005b). Further, LBP markedly decreased the plasma cholesterol levels and fasting plasma insulin levels, and the postprandial glucose level at 30 min during oral glucose tolerance test and significantly increased the Insulin Sensitive Index in NIDDM rats. The results showed that LBP could ameliorate insulin resistance by increasing cell-surface level of glucose transporter 4 (GLUT4) in skeletal muscle of NIDDM rats and improving GLUT4 trafficking and intracellular insulin signalling. The results of another study suggested that LBP could control blood glucose and modulate the metabolism of glucose, leading to significant improvement of oxidative stress markers (superoxidedismutase, malondialdehyde) in rats with NIDDM and that, LBP decreased DNA damage possibly via a decrease in oxidative stress levels (Wu et al. 2006). Administration of *L. barbarum* polysaccharides (LBP) in drinking water through oral gavage to streptozotocin-induced diabetic rats for 30 days restored abnormal oxidative indices in blood, liver and kidney to near normal levels. (Li 2007) The results suggested that LBP may be of use as an antihyperglycemia agent.

Streptozotocin-induced diabetic rats treated with *L. barbarum* polysaccharide 4 (LBP-4) (10 mg/kg) for 8 weeks showed increased activity of antioxidant enzymes and increased scavenging of oxygen radicals, while the activity of protein kinase C in the renal cortex was maintained at a physiological level (Zhao et al. 2009). The decreased activation of extracellular signal-regulated kinases 1 and 2 (ERK1/2) in mesangial cells, through the involvement of PKC, could explain the protective mechanism in kidneys of diabetic rats treated with LBP-4.

The polysaccharide extracted from *Lycium barbarum* (LBP) exhibited hypoglycaemic activity (Jing et al. 2009). LBP treatment (20, 40 mg/

kg body weight) for 28 days resulted in a significant decrease in the concentration of fasting blood glucose levels, total cholesterol and triglyceride in diabetes mellitus mice and increased body weight. Steroidal alkaloid glycosides, lycioside A and lycioside B isolated from *L. barbarum* seeds showed inhibitory activities with the IC₅₀ values of 75.3 and 72.8 μ M against rat intestinal sucrase, and 63.4 and 59.1 μ M against rat intestinal maltase (Wang et al. 2011).

Antihyperlipidemic/Antiobesity Activity

Feeding weanling mice for 21 days with *L. barbarum* polysaccharides (LBP-4) composed of six kinds of monosaccharides, was found to enhance food conversion rate and the content of zinc and iron in pygal muscles and femora of mice, and reduce the body weight (Zhang et al. 2002). After 10 weeks feeding of *L. barbarum* polysaccharide (LBP) and 1.5% cholesterol to rabbits, concentration of triglyceride, total cholesterol, c reactive protein, nitric oxide were lowered and superoxide dismutase activity and high-density lipoprotein cholesterol(HDLC)/total cholesterol were increased compared with the group fed high cholesterol (Ma et al. 2005). The results suggested that LBP exerted hypocholesterolemic effect via antioxidative mechanism against atherosclerosis in rabbits.

The administration of *Lycium barbarum* polysaccharides did not show any effect on the body weight of the experimental mice, but significantly decreased the levels of low density lipoprotein, total cholesterol, triacylglycerols, high density lipoprotein, blood glucose and thiobarbituric acid reactive substances (TBARS) and increased the activities of antioxidant enzymes when compared with mice in the high fat diet group (Ma et al. 2009). Studies showed that supplementation of *L. barbarum* aqueous and ethanol extracts for 8 weeks exerted a protective effects against high-fat-diet induced oxidative stress in rat (Cui et al. 2011). Rats fed the high fat diet alone had deleterious metabolic effects with increased hepatocellular enzyme activities in plasma, a significant decline in antioxidant enzyme activities, and elevated liver lipid peroxidation indices. Supplementation of both

L. barbarum extracts significantly reduced liver damage and oxidative changes, and brought back the antioxidants and lipids towards normal levels.

The results of two separate randomized, double-blind, placebo-controlled, small clinical studies showed that *L. barbarum* juice consumption for 14 days increased postprandial energy expenditure and reduced the waist circumference, relative to placebo treated control adult subjects (Amagase and Nance, 2011).

Fertility Enhancing Activity

L. barbarum polysaccharide (LBP) was found to inhibit time- and hyperthermia-induced structural damage in murine seminiferous epithelium, in-vitro (Wang et al. 2002b). Oxidative stress was reported to be a major cause of structural degradation and apoptosis in hyperthermic testes, and thus the protective effect of LBP could implicate an antioxidant mechanism of action. LBP was subsequently confirmed to be a potent inhibitor on ultraviolet light-induced lipid peroxidation, and cytochrome c reduction by free radicals. The results supported the traditional use of the plant by Chinese physicians for treatment of infertility.

Studies by Luo et al. (2006) showed that *L. barbarum* polysaccharides (LBP) provided a protective effect against rat testicular tissue damage induced by heat exposure (43 °C). Compared with negative control, LBP significantly increased testis and epididymis weights, improved superoxide dismutase (SOD) activity, and raised sexual hormone levels in the damaged rat testes. LBP had a dose-dependent protective effect against DNA oxidative damage of mouse testicular cells induced by H₂O₂. LBP improved the copulatory performance and reproductive function of hemicastrated male rats, such as shortened penis erection latency and mount latency, regulated secretion of sexual hormones and increased hormone levels, raised accessory sexual organ weights, and improved sperm quantity and quality. The findings supported the folk notion of *L. barbarum* fruit as an aphrodisiac and fertility-facilitating agent, and provided scientific evidence for the extensive

use of *L. barbarum* fruits as a traditional remedy for male infertility in China.

Lycium barbarum polysaccharides elicited significant protective effects against damage induced by local subchronic exposure to (60) Co-γ irradiation, allowing rats to achieve near-complete recovery (Luo et al. 2011). LBP significantly increased the sperm quantity and motility, shortened the erection, capture and ejaculation latencies, increased the number of captures and ejaculations, and improved the sexual ability of male rats. LBP also played a significant role in the recovery of serum testosterone levels, increased superoxide dismutase activity, decreased malondialdehyde levels, promoted oxidative balance and rescued testicular DNA damage. In another study oral feeding of male rats with *Lycium barbarum* polysaccharides (LBP) for 21 days significantly improved the male copulatory performance including increase of copulatory efficiency, increase of ejaculation frequency and shortening of ejaculation latency (Lau et al. 2012). In addition, sexual inhibition caused by chronic corticosterone was prevented by LBP. Concomitantly, corticosterone suppressed neurogenesis in subventricular zone and hippocampus in adult rats was reversed by LBP. The neurogenic effect of LBP was also shown in-vitro. Significant correlation was found between neurogenesis and sexual performance, suggesting that the newborn neurons were associated with reproductive successfulness. Blocking neurogenesis in male rats abolished the pro-sexual effect of LBP. The results demonstrated the pro-sexual effect of LBP on normal and sexually-inhibited rats, and that LBP may modulate sexual behaviour by regulating neurogenesis.

Pretreatment of male Sprague–Dawley rats with *Lycium barbarum* polysaccharides (LBP) ameliorated doxorubicin-induced reduction in the testicular weights, sperm concentrations and percentage of motile sperms, as well as the increase in abnormal sperm rate (Xin et al. 2012). LBP administration to doxorubicin-treated rats successfully reversed the changes in MDA and GHS-Px levels. Compared with the control, LBP pretreatment significantly increased the plasma testosterone level in the LBP+ doxorubicin group.

The histopathology examinations further confirmed that LBP effectively diminished doxorubicin-induced severe degenerative changes of seminiferous tubules. This study illustrated the capability of LBP in mitigating testicular oxidative stress and protecting testis-specific toxicity in doxorubicin-exposed rats.

Hepatoprotective Activity

The liver mitochondrial lipid peroxidation (measured as malondialdehyde, MDA) was significantly inhibited dose-dependently by *L. barbarum* flavonoids and the fluidity of mitochondria membrane and shape of red blood cells was also effectively protected from damage (Huang et al. 1999b). Studies showed that *Lycium barbarum* polysaccharide (LBP) administration could effectively prevent alcoholic fatty liver (AFL) in Wistar rats (Gu et al. 2007). At the end of 10 weeks the activity of serum AST and GGT, content of liver MDA and H_2O_2 were significantly lower than those of the alcohol group. The activity of SOD and GSH-Px and content of GSH were significantly higher than those of the alcohol group. Levels of CYP2E1 gene and protein expression were all significantly lower than those of the alcohol group. The results suggested that the preventive effect of LBP may be due to its effects in inhibiting the hepatocyte CYP2E1 expression and prevention of lipid peroxidation.

Administration of *Lycium barbarum* polysaccharide to rats significantly ameliorated ethanol-induced liver injury, prevented the progression of alcohol-induced fatty liver, and improved the antioxidant functions (Cheng and Kong 2011). In contrast a significant elevation of enzymes and lipid in serum, increased MDA level and depletion of SOD, CAT, GSH-Px and GSH in liver were observed in the ethanol group. Histopathological examination of rat liver revealed that LBP administration protected liver cells from the damage induced by ethanol. The results suggested LBP to be a promising agent to protect the liver from hepatotoxicity and fatty liver induced by ethanol intake.

Contradictory results were obtained in one study. The liver ischemia/reperfusion protocol,

induced by clamping the common hepatic artery and portal vein of rats for 40 min, resulted in oxidative and nitrosative stress and liver injury (Wang et al. 2009a). Ascorbic acid showed significant protective effects on reperfusion liver injury by attenuating hydroxyl radical and NO release. In contrast, *Lycium barbarum* aggravated liver injury by increasing hydroxyl radical release.

Wu et al. (2011) reported that treatment of rats with water extracted *Lycium barbarum* and *Rehmannia glutinosa* (0.05% and 0.15% for each) for 8 weeks protected against necrotic damage, indicated by decreases in plasma alanine aminotransferase and aspartate aminotransferase activities, and suppressed liver fibrosis by down-regulation of liver inflammation in rats with CCl_4 -induced liver injury

Pre-treatment with *Lycium barbarum* polysaccharides (LBP) effectively reduced the hepatic necrosis and the serum ALT level induced by CCl_4 intoxication in mice (Xiao et al. 2012). LBP notably inhibited cytochrome P450 2E1 expression and restored the expression levels of antioxidant enzymes. It also lowered the level of nitric oxide metabolism and lipid peroxidation induced by CCl_4 . LBP attenuated hepatic inflammation via down-regulation of proinflammatory mediators and chemokines. In addition, LBP promoted liver regeneration after CCl_4 treatment. The protective effects of LBP against hepatotoxicity were partly through the down-regulation of nuclear factor kappa-B activity.

Cardioprotective Activity

Pretreatment with *Lycium barbarum* (LB) significantly prevented the loss of myofibrils and improved the heart function of the doxorubicin-treated rats as evidenced from lower mortality (13%), normalization of antioxidative activity and serum aspartate aminotransferase and creatine kinase, as well as improving arrhythmias and conduction abnormalities (Xin et al. 2007, 2011a, b). LB treatment significantly increased SOD and GSH-Px activity and decreased the MDA level of heart tissues damaged by doxorubicin exposure in rats. The results suggested that

LB elicited a typical cardioprotective effect on doxorubicin-related oxidative stress.

Studies showed that *L. barbarum* polysaccharides (composed of glucose and fructose in the molar ratio of 1:2:1) significantly decreased the myocardium lactate dehydrogenase level, increased Na(+)-K(+)-ATPase and Ca(2+)-ATPase activities in ischemia reperfusion (IR) rat heart (Lu and Zhao 2010). Additionally, *L. barbarum* polysaccharides markedly decreased myocardium Bax positive rate and myocardial cell apoptosis and increased Bcl-2 positive rate in a dose-dependent manner. The authors concluded that administration of *L. barbarum* polysaccharides could prevented the development of cardiovascular diseases.

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Anti-Ageing and Neuroprotective Activities

Fructus lycii (the fruit of *Lycium barbarum* and *L. chinense*) have been used in oriental medicine as an anti-aging agent since ancient times. There are increasing lines of evidence showing that the molecular signaling pathways in aged cells are altered so that cells are susceptible to injury (Yu et al. 2007). Numerous studies had demon-

strated that various extracts/fractions isolated from *L. barbarum* exhibited significant protection on cultured neurons against harmful chemical toxins such as β -amyloid (A β) peptide and dithiothreitol in neurodegenerative diseases by attenuation of stress kinases and pro-apoptotic signalling pathways (Yu et al. 2005, 2006, 2007; Ho et al. 2007, 2009; Chang and So 2008). Polysaccharides extracted from *L. barbarum* can protect neurons against β -amyloid peptide toxicity in neuronal cell cultures, and retinal ganglion cells in an experimental model of glaucoma and diabetic retinopathy (Chan et al. 2007; Chang and So 2008; Chiu et al. 2009, 2010; Feng et al. 2010; Li et al. 2011a, b; Chang et al. 2011; Yang et al. 2011, 2012; Yao et al. 2011; Song et al. 2011, 2012; Hu et al. 2012; Chen et al. 2012). Several clinical studies had also attested to the beneficial effects of Goji berry on age-related macular degeneration (Breithaupt et al. 2004; Cheng et al. 2005; Bucheli et al. 2011). Polysaccharides isolated from *Lycium barbarum* fruits had also been reported to exhibit anti-aging function in fruit flies and mice (Wang et al. 2002a). The study demonstrated that LBP at 16 mg/kg could significantly increase the maximal and average life span of the male fruitfly.

L. barbarum extract exhibited cytoprotective effects against reducing stress by lowering dithiothreitol-induced lactate dehydrogenase release and caspase-3 activity in neurons (Yu et al. 2006). Dithiothreitol could trigger endoplasmic reticulum (ER) stress leading to PKR-like ER kinase (PERK) activation. LBG also attenuated dithiothreitol-induced PERK phosphorylation. The results suggested that *L. barbarum* extract was not simply an antioxidant; it could also exhibit cytoprotective effects against reducing stress by dithiothreitol. Pre-treatment of primary rat cortical neurons with *L. barbarum* extract significantly reduced the release of lactate dehydrogenase and attenuated Abeta peptide-activated caspases-3-like activity (Yu et al. 2005). The extract markedly reduced the phosphorylation of JNK-1 (Thr183/Tyr185) and its substrates c-Jun-I (Ser 73) and c-Jun-II (Ser 63). The extract elicited a typical dose-dependent neuroprotective effect. In-vitro studies exposure of primary cultures of rat cortical neurons to *L. barbarum* polysaccharides

(LBA) prevented neurotoxicity elicited by glutamate (Ho et al. 2009). LBA reduced glutamate-induced phosphorylation of c-jun N-terminal kinase (JNK). In addition to glutamate, LBA attenuated N-methyl-D-aspartate (NMDA)-induced neuronal damage.

Pretreatment of primary cortical neurons with *L. barbarum* alkaline extract significantly reduced the level of lactate dehydrogenase (LDH) release and the activity of caspase-3 triggered by Abeta (Ho et al. 2007). Three subfractions isolated from the extract, namely LBB-0, LBB-I and LBB-II. LBB-I and LBB-II showed differential neuroprotective effects. LBB-I and LBB-II markedly enhanced the phosphorylation of Akt. The results suggested that the glycoconjugates isolated from novel alkaline extraction method had neuroprotective activity and could have potential in neurodegenerative diseases. In another study, pretreatment of *L. barbarum* polysaccharide (LBP) effectively protected neurons against A beta-induced apoptosis by reducing the activity of both caspase-3 and -2, but not caspase-8 and -9 (Yu et al. 2007). A new arabinogalactan-protein (LBP-III) was isolated from LBP and attenuated Abeta peptide-activated caspase-3-like activity. LBP-III markedly reduced the phosphorylation of PKR triggered by Abeta peptide. Since the phosphorylation state of PKR increased with age, reduction of its phosphorylation triggered by Abeta peptide may implicate LBP-III from *L. barbarum* to be a potential neuroprotective agent in Alzheimer's disease. Studies showed that *L. barbarum* polysaccharide (LBA) treatment significantly attenuated Hcy-induced neuronal cell death and apoptosis in primary cortical neurons as demonstrated by lactate dehydrogenase and caspase-3 like activity assay (Ho et al. 2010). LBA also significantly reduced homocysteine-induced tau phosphorylation at tau-1 (Ser198/199/202), pS396 (Ser396), and pS214 (Ser214) epitopes as well as cleavage of tau. LBA treatment suppressed elevation of both p-ERK and p-JNK. The results demonstrated that LBA exerted neuroprotective effects on cortical neurons exposed to Hcy and may have potential to be a disease modifying agent for the prevention of Alzheimer's disease.

Lycium barbarum extract protected against 1-methyl-4-phenylpyridinium (MPP⁺)-induced loss of viability and dopaminergic neurodegeneration in *Caenorhabditis elegans* in a dose-dependent manner. Similar neuroprotection was replicated in MPP⁺-neuronal PC12 cell model (Yao et al. 2011). *L. barbarum* extract attenuated MPP⁺-induced intracellular reactive oxygen species (ROS) accumulation, loss of mitochondrial membrane potential and restored total GSH levels in PC12 cells.

Treatment of primary cultured rat hippocampal neurons with *Lycium barbarum* polysaccharide (LBP) (10–40 mg/l) significantly attenuated neuronal damage and inhibited lactate dehydrogenase release in a dose-dependent manner (Chen et al. 2012). In addition, LBP enhanced activities of SOD and GSH-PX but it decreased their MDA content, inhibited [Ca(2+)]_i elevation and decrease of MMP in ischemia-reperfusion treated hippocampal neurons. The findings suggested that LBP may be a potential neuroprotective agent for cerebral ischemia-reperfusion injury.

Animal Studies

Lycium barbarum polysaccharides (LBP) was found to reduce neuronal damage, blood-retinal barrier disruption and oxidative stress in retinal ischemia/reperfusion injury in mice (Li et al. 2011a, b). Pre-treatment with LBP for 1 week effectively protected the retina from neuronal death, apoptosis, glial cell activation, aquaporin water channel up-regulation, disruption of blood-retinal barrier and oxidative stress. The study suggested that LBP may have a neuroprotective role to play in ocular diseases for which ischemia/reperfusion is a feature. Wen et al. (2010) found that *Lycium barbarum* polysaccharides could enhance the learning and memory capability of the manganese poisoned mice as evaluated by the Morris water maze training test by promoting neurogenesis in hippocampus.

Pretreatment of the mother rats with milk-based wolfberry (*L. barbarum*) preparation significantly prevented the prenatal stress-induced cognitive dysfunction (assessed by Morris water maze test) (Feng et al. 2010). In-vitro studies showed that wolfberry preparation dose-

independently scavenged hydroxyl and superoxide radicals (determined by an electron spin resonance spectrometric assay), and inhibited FeCl₂/ascorbic acid-induced dysfunction in brain tissue and tissue mitochondria, including increases in reactive oxygen species and lipid peroxidation and decreases in the activities of complex I, complex II, and glutamate cysteine ligase. The results suggested that dietary supplementation with wolfberry preparation may be an effective strategy for preventing the brain oxidative mitochondrial damage and cognitive dysfunction associated with prenatal stress.

Seven-day oral pre-treatment of mice with *L. barbarum* extract (LBP) effectively improved neurological deficits, decreased infarct size and cerebral edema as well as protected the brain from blood–brain barrier disruption, aquaporin-4 up-regulation, and glial activation (Yang et al. 2012). The results suggested that LBP may be used as a prophylactic neuroprotectant in patients at high risk for ischemic stroke.

Antiageing and Effects on Ocular Macular Disorders and Retinopathy

Lycium barbarum polysaccharide (LBP) (10 mg/mL dose) was found to increase the survival rate and promote the growth of mixed cultured rat retinal ganglion cells in-vitro (Yang et al. 2011). Zeaxanthin dipalmitate compounds from *L. barbarum* exhibited anti-oxidative abilities by proliferating human adult retinal pigment epithelial cells (from 22 to 31%) (Chang et al. 2011). In glaucoma, wolfberry exerted its beneficial effects on the retina based on suppressing the neurodestructive factors, modulating the inflammatory responses and modulating the activation of microglia (Chiu et al. 2009). They further demonstrated that neuroprotective effect of-wolfberry extract-*L. barbarum* polysaccharide on the survival of retinal ganglion cell (RGC) in an experimental model of glaucoma may be mediated via direct up-regulation of neuronal survival signal betaB2-crystallin chaperone (Chiu et al. 2010).

Song et al. (2011) demonstrated that *L. barbarum* fruit extract and its taurine component dose-

dependently enhanced PPAR- γ luciferase activity in human embryonic kidney 293 (HEK 293) cell line transfected with PPAR- γ reporter gene. This activity was significantly decreased by a selective PPAR- γ antagonist GW9662. Further, *L. barbarum* extract and taurine dose-dependently enhanced the expression of PPAR- γ mRNA and protein. In an inflammation model where retinal ARPE-19 cells were exposed to high glucose, *L. barbarum* extract and taurine down-regulated the mRNA of pro-inflammatory mediators encoding MMP-9, fibronectin and the protein expression of COX-2 and iNOS proteins. The authors concluded that PPAR- γ activation by *L. barbarum* extract (LB) was associated with its taurine content and may explain at least in part its use in diabetic retinopathy progression. They also showed that *L. barbarum* fruit extract and the active ligand, taurine, dose-dependently enhanced cell viability following high glucose treatment in the ARPE-19 retinal epithelial cell line (Song et al. 2012). This cytoprotective effect was associated with the attenuation of high glucose-induced apoptosis and the dose-dependent decrease in the number of apoptotic cells. Also, LB extract and taurine dose-dependently downregulated caspase-3 protein expression and the enzymatic activity of caspase-3. They concluded that taurine, a major component of LB, and the LB extract, had a cytoprotective effect against glucose exposure in a human retinal epithelial cell line and may provide useful approaches to delaying diabetic retinopathy progression.

Lycium barbarum and *Chrysanthemum morifolium* extract combination were found to have protective effects on diabetic retinopathy in streptozotocin-induced diabetic rats (Hu et al. 2012). Diabetic rats suffered from retinal dysfunction, the electroretinographic amplitudes of the a- and b-waves were significantly decreased in the diabetic animals, and the implicit time of the b-wave was also delayed, compared to the control group. However, reductions in the a- and b-wave amplitudes were not observed in the *Lycium*-treated group. Histopathological studies showed no significant differences between the *Lycium*-treated, *Chrysanthemum*-treated, *Lycium/Chrysanthemum*-treated groups, and the control group.

Oral administration of *L. barbarum* to Sprague–Dawley rats (250–280 g) significantly reduced the loss of retinal ganglion cells (RGCs) in retina, although elevated intraocular pressure was not significantly altered (Chan et al. 2007). Rats fed with the 1 mg/kg extract could nearly totally escape from pressure-induced loss of RGCs. The results demonstrated that wolfberry extract may be a potential candidate for the development of neuroprotective drug against the loss of RGCs in glaucoma.

In a randomised, single-blind cross-over study, twelve volunteers were administered non-esterified or esterified 3R, 3'R-zeaxanthin (5 mg) from *L. barabrum* suspended in yoghurt together with a balanced breakfast as lutein and zeaxanthin had been suggested may reduce the risk for age-related macular degeneration (Breithaupt et al. 2004). It was found that independent of the consumed diet, plasma 3R, 3'R-zeaxanthin concentrations increased significantly and peaked after 9–24 h. Although the concentration curves were not distinguishable, the respective areas under the curve were distinguishable according to a two-sided F and *t* test. The study indicated an enhanced bioavailability of 3R, 3'R-zeaxanthin dipalmitate compared with the non-esterified form 3R, 3'R-zeaxanthin.

In a double-masked, randomized, placebo-controlled trial of healthy elderly subjects (age 65–70 years) daily dietary supplementation with goji berry (*L. barbarum*) for 90 days increased plasma zeaxanthin (by 26%) and antioxidant levels (by 57%) as well as protected from hypopigmentation and soft drusen accumulation in the macula of elderly subjects (Bucheli et al. 2011). In another single-blinded, placebo-controlled, human intervention trial of parallel design of 14 subjects ingestion of 15 g/daily wolfberry (estimated to contain almost 3 mg zeaxanthin) for 28 days resulted in a 2.5-fold increase in plasma zeaxanthin for the supplementation group (Cheng et al. 2005). The result suggested that zeaxanthin in whole wolfberries was bioavailable and that intake of a modest daily amount markedly increased fasting plasma zeaxanthin levels and may help in preventing age-related macular degeneration.

Antifatigue Activity

A purified component of *L. barbarum* (goji berry) polysaccharide (LBP-X) at five different doses (5, 10, 20, 50, and 100 mg/kg/day) induced marked adaptability to exercise load, enhanced resistance and accelerated elimination of fatigue in mice (Luo et al. 2000). LBP-X could enhance the storage of muscle and liver glycogen, increase the activity of LDH before and after swimming, decrease the increase of blood urea nitrogen (BUN) after strenuous exercise, and accelerate the clearance of BUN after exercise. The dosage of LBP-X at 10 mg/kg/day was the best amount among the five tested doses.

Photoprotective/Radioprotective Activity

L. barbarum fruit polysaccharides (LBP) and *Ganoderma lucidum* polysaccharides (GLP) significantly and dose-dependently protected against γ -irradiation-induced loss of protein thiols and inactivation of superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GSH-Px) in the mitochondrial membranes of rat liver (Li et al. 2007c). Both polysaccharides were more effective than α -tocopherol (VE) in inhibiting irradiation-induced oxidative injury.

The radiosensitizing effects of the *Lycium barbarum* polysaccharide (LBP) were observed using the transplanted Lewis lung cancer on C57 BL mice model (Lu and Cheng 1991). When LBP alone was administered, it was not obvious that LBP inhibited the growth of Lewis lung cancer. The significant radiosensitizing effects were obtained by combination of LBP and radiation. Studies showed that orally consumed goji berry juice altered the photodamage induced in the skin of Skh:hr-1 hairless mice by acute solar simulated UV (SSUV) irradiation; 5% goji berry juice significantly reduced the inflammatory oedema of the sunburn reaction (Reeve et al. 2010). Dilutions of goji berry juice between 1 and 10% dose-dependently protected against SSUV-induced immunosuppression, and against suppression induced by the mediator, *cis*-urocanic acid, measured by contact hypersensitivity

reaction. Antioxidant activity in the skin was demonstrated by the significant protection by 5% goji juice against lipid peroxidation induced by UVA radiation. Furthermore, two known inducible endogenous skin antioxidants, heme oxygenase-1 and metallothionein, were found to be involved in the photoimmune protection.

Skin Protective Activity

Zhao et al. (2005a) found that *Lycium barbarum* glycoconjugates (LbGp) decreased the level of MMP (matrix metalloproteinase)-1 significantly, but not that of MMP-3 or -13, in the whole human skin system, without compromising the viability of the skin., LbGp inhibited skin expansion under mechanical stress. They also found one the glycoconjugates, the LbGp5, promoted the survival of human fibroblasts cultured in sub-optimal conditions. in the presence of LbGp5, these cultures were found to have higher levels of the MMP-1 substrate – collagen type I. The results suggested that *L. barbarum* glycoconjugates in general, and LbGp5 in particular, may have important skin-protective properties

Otoprotective Activity

Studies indicated that *Lycium barbarum* polysaccharides was effective in attenuating cisplatin-induced hair cell loss in the neonatal (P2-3) rat organ of Corti explant by reducing the production of reactive oxygen species (ROS) and maintaining mitochondrial membrane potential (Liu et al. 2011).

Bioavailability of Carotenoids

Results of a cross-over trial, with a 3–5 week washout period between treatments of 12 healthy subjects clearly showed that homogenisation of wolfberry (*L. barbarum*) in hot skimmed milk resulted in a formulation that had a 3-fold enhanced bioavailability of zeaxanthin compared with both the ‘classical’ hot water and warm skimmed milk treatment of the berries (Benzie et al. 2006).

Goji Berry – Warfarin Interaction

Lam et al. (2001) reported a 61 year old Chinese patient who was stabilized on warfarin and developed an elevated international normalized ratio (INR) after drinking a concentrated Chinese herbal tea of *L. barbarum*. In-vitro evaluation showed weak inhibition of S-warfarin metabolism by CYP2C9 by *L. barbarum* tea. Leung et al. (2008) reported an 80 year-old Chinese woman on chronic stable dose of warfarin who experienced two episodes of an elevated international normalized ratio (INR) after drinking herbal tea containing *Lycium barbarum*. Recently, Rivera et al. (2012) described a 71 year-old Ecuadorean-American woman who was taking warfarin and was hospitalized for a markedly elevated, indeterminate international normalized ratio (INR) (prothrombin time > 120 s) after consumption of goji juice. She developed symptoms of epistaxis, bruising, and rectal bleeding. The authors cautioned that patients taking warfarin should avoid popular herbal drinks, such as goji juice.

Allergy Problem

Two cases of allergic reaction following Goji berry (*L. barabrum*) ingestion were reported by Monzón Ballarín et al. (2011). A positive skin prick test and specific immunoglobulin (Ig) E to Goji berry was detected in both cases. Lipid transfer proteins appeared to be involved in allergic sensitization to Goji berries, as evidenced by cross-reactivity with tomato.

Traditional Medicinal Uses

The berries and root bark and less so the leaf of both *Lycium barbarum* and *L. chinense*, are widely used in traditional Oriental medicine for more than 2,000 years ago. Fructus Lycii, known as “Gou-Qi-Zi” in Chinese, has a long history of applications as a valuable tonic medicine and health food supplement for promoting good health, improving vision, antiageing, strengthening the immune system, liver and

kidney, improving blood circulation and sperm production and enhancing sexual performance, (Duke and Ayensu 1985; Peng et al. 2005; Chang and So 2008; Potterat 2010). It has been used as emmenagogue, diuretic, antipyretic, and to treat diabetes, anaemia, tinnitus, liver and lung diseases.

Other Uses

The plant has an extensive root system and has been used to stabilize banks and control soil erosion. It is also planted as a hedge.

Comments

See notes on *Lycium chinense*.

Selected References

- Adams M, Wiedenmann M, Tittel G, Bauer R (2006) HPLC-MS trace analysis of atropine in *Lycium barbarum* berries. *Phytochem Anal* 17(5):279–283
- Altintas A, Kosar M, Kirimer N, Baser KH, Demirci B (2006) Composition of the essential oils of *Lycium barbarum* and *Lycium ruthenicum* fruits. *Chem Nat Comp* 41:24–25
- Amagase H, Nance DM (2008) A randomized, double-blind, placebo-controlled, clinical study of the general effects of a standardized *Lycium barbarum* (Goji) Juice, GoChi. *J Altern Complement Med* 14(4):403–412
- Amagase H, Nance DM (2011) *Lycium barbarum* increases caloric expenditure and decreases waist circumference in healthy overweight men and women: pilot study. *J Am Coll Nutr* 30(5):304–309
- Amagase H, Sun B, Borek C (2009a) *Lycium barbarum* (goji) juice improves in vivo antioxidant biomarkers in serum of healthy adults. *Nutr Res* 29(1):19–25
- Amagase H, Sun B, Nance DM (2009b) Immunomodulatory effects of a standardized *Lycium barbarum* fruit juice in Chinese older healthy human subjects. *J Med Food* 12(5):1159–1165
- Benzie IF, Chung WY, Wang J, Richelle M, Bucheli P (2006) Enhanced bioavailability of zeaxanthin in a milk-based formulation of wolfberry (Gou Qi Zi; *Fructus barbarum* L.). *Br J Nutr* 96(1):154–160
- Breithaupt DE, Weller P, Wolters M, Hahn A (2004) Comparison of plasma responses in human subjects after the ingestion of 3R, 3R'-zeaxanthin dipalmitate from wolfberry (*Lycium barbarum*) and non-esterified 3R, 3R'-zeaxanthin using chiral high-performance liquid chromatography. *Br J Nutr* 91(5):707–713
- Bucheli P, Vidal K, Shen L, Gu Z, Zhang C, Miller LE, Wang J (2011) Goji berry effects on macular characteristics and plasma antioxidant levels. *Optom Vis Sci* 88(2):257–262
- Cao GW, Yang WG, Du P (1994) Observation of the effects of LAK/IL-2 therapy combining with *Lycium barbarum* polysaccharides in the treatment of 75 cancer patients. *Zhonghua Zhong Liu Za Zhi* 16(6):428–431
- Cao Y, Zhang X, Chu Q, Fang Y, Ye J (2003) Determination of taurine in *Lycium barbarum* L. and other foods by capillary electrophoresis with electrochemical detection. *Electroanalysis* 15:898–902
- Cassileth B (2010) *Lycium* (*Lycium barbarum*). *Oncology* (Williston Park) 24(14):1353
- Chan HC, Chang RC, Koon-Ching Ip A, Chiu K, Yuen WH, Zee SY, So KF (2007) Neuroprotective effects of *Lycium barbarum* Lynn on protecting retinal ganglion cells in an ocular hypertension model of glaucoma. *Exp Neurol* 203(1):269–273
- Chang RCC, So KF (2008) Use of anti-aging herbal medicine, *Lycium barbarum*, against aging-associated diseases. What do we know so far? *Cell Mol Neurobiol* 28:643–652
- Chang LP, Cheng JH, Hsu SL, Liao BC, Wu TM, Chang CMJ (2011) Application of continuous supercritical anti-solvents for rapid recrystallization and purification of zeaxanthin dipalmitates from de-glycosides of *Lycium barbarum* fruits. *J Supercrit Fluids* 57(2):155–161
- Chao JC, Chiang SW, Wang CC, Tsai YH, Wu MS (2006) Hot water-extracted *Lycium barbarum* and *Rehmannia glutinosa* inhibit proliferation and induce apoptosis of hepatocellular carcinoma cells. *World J Gastroenterol* 12(28):4478–4484
- Chen S, Wang Q, Gong S, Wu J, Yu X, Lin S (1991) Analysis of amino acid in *Fructus lycii*. *Zhongguo Yaoke Daxue Xuebao* 22:53–55
- Chen Z, Tan BKH, Chan SH (2008) Activation of T lymphocytes by polysaccharide-protein complex from *Lycium barbarum* L. *Int Immunopharmacol* 8:1663–1671
- Chen Z, Lu J, Srinivasan N, Tan BK, Chan SH (2009a) Polysaccharide-protein complex from *Lycium barbarum* L. is a novel stimulus of dendritic cell immunogenicity. *J Immunol* 182(6):3503–3509
- Chen Z, Soo MY, Srinivasan N, Tan BK, Chan SH (2009b) Activation of macrophages by polysaccharide-protein complex from *Lycium barbarum* L. *Phytother Res* 23(8):1116–1122
- Chen R, Li YX, Hao YJ, Zhu QL, Wu Y, Z QP, Wang H, Ma L, Liu J, Zhao CJ, Jiang YX, Wang YR, Dai XY, Zhang WN, Sun T, Y JQ (2012) Protective effects of *Lycium barbarum* polysaccharide on neonatal rat primary cultured hippocampal neurons injured by oxygen-glucose deprivation and reperfusion. *J Mol Histol*. doi:10.1007/s10735-012-9420-4 [Epub ahead of print]

- Cheng D, Kong H (2011) The effect of *Lycium barbarum* polysaccharide on alcohol-induced oxidative stress in rats. *Molecules* 16(3):2542–2550
- Cheng CY, Chung WY, Szeto YT, Benzie IF (2005) Fasting plasma zeaxanthin response to *Fructus barbarum* L. (wolfberry; Kei Tze) in a food-based human supplementation trial. *Br J Nutr* 93(1):123–130
- Chiu K, Chan HC, Yeung SC, Yuen WH, Zee SY, Chang RCC, So KF (2009) Modulation of microglia by wolfberry on the survival of retinal ganglion cells in a rat ocular hypertension model. *J Ocul Biol Dis Infor* 2(3):127–136
- Chiu K, Zhou Y, Yeung SC, Lok CK, Chan OO, Chang RC, So KF, Chiu JF (2010) Up-regulation of crystallins is involved in the neuroprotective effect of wolfberry on survival of retinal ganglion cells in rat ocular hypertension model. *J Cell Biochem* 110(2):311–320
- Christen P, Kapetanidis I (1987) Flavonoids from *Lycium halimifolium* L. *Planta Med* 53(6):571–572
- Cui B, Liu S, Lin X, Wang J, Li S, Wang Q, Li S (2011) Effects of *Lycium barbarum* aqueous and ethanol extracts on high-fat-diet induced oxidative stress in rat liver tissue 16(11):9116–9128
- Deng HB, Cui DP, Jiang JM, Feng YC, Cai NS, Li DD (2003) Inhibiting effects of *Achyranthes bidentata* polysaccharide and *Lycium barbarum* polysaccharide on nonenzyme glycation in D-galactose induced mouse aging model. *Biomed Environ Sci* 16(3):267–275
- Dong JZ, da Lu Y, Wang Y (2009) Analysis of flavonoids from leaves of cultivated *Lycium barbarum* L. *Plant Foods Hum Nutr* 64(3):199–204
- Drost-Karbowska K, Hajdrych-Szauffer M, Kowalewski Z (1984) Search for alkaloid-type bases in *Lycium halimifolium*. *Acta Pol Pharm* 41:127–129
- Du G, Liu L, Fang J (2004) Experimental study on the enhancement of murine splenic lymphocyte proliferation by *Lycium barbarum* glycopeptide. *J Huazhong Univ Sci Technolog Med Sci* 24(5):518–520, 527
- Duan CL, Qiao SY, Wang NL, Zhao YM, Qi CH, Yao XS (2001) Studies on the active polysaccharides from *Lycium barbarum* L. *Yao Xue Xue Bao* 36(3):196–199 (In Chinese)
- Duan H, Chen Y, Chen G (2010) Far infrared-assisted extraction followed by capillary electrophoresis for the determination of bioactive constituents in the leaves of *Lycium barbarum* Linn. *J Chromatogr A* 1217(27):4511–4516
- Duke JA, Ayensu ES (1985) Medicinal plants of China, vol 1 & 2. Reference Publications, Inc, Algonac, 705 pp
- Facciola S (1990) Cornucopia. A source book of edible plants. Kampong Publ, Vista, 677 pp
- Fan H, Deng C, Fu J, Ding L, Yin G, Ma Y (2010) Effects of *Lycium barbarum* polysaccharide on formation of traumatic neuroma and pain after transection of sciatic nerve in rats. *Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi* 24(11):1298–1301 (In Chinese)
- Feng Z, Jia H, Li X, Bai Z, Liu Z, Sun L, Zhu Z, Bucheli P, Ballèvre O, Wang J, Liu J (2010) A milk-based wolfberry preparation prevents prenatal stress-induced cognitive impairment of offspring rats, and inhibits oxidative damage and mitochondrial dysfunction in vitro. *Neurochem Res* 35(5):702–711
- Gan L, Zhang SH (2003) Effect of *Lycium barbarum* polysaccharides on anti-tumor activity and immune function. *Acta Nutr Sin* 25:200–202 (In Chinese)
- Gan L, Wang J, Zhang S (2001) Inhibition the growth of human leukemia cells by *Lycium barbarum* (Goji) polysaccharide. *Wei Sheng Yan Jiu* 30(6):333–335 (In Chinese)
- Gan L, Zhang SH, Liu Q, Xu HB (2003) A polysaccharide-protein complex from *Lycium barbarum* upregulates cytokine expression in human peripheral blood mononuclear cells. *Eur J Pharmacol* 471(3):217–222
- Gan L, Zhang SH, Yang XL, Xu HB (2004) Immunomodulation and antitumor activity by a polysaccharide-protein complex from *Lycium barbarum*. *Int Immunopharmacol* 4(4):563–569
- Gao Z, Ali Z, Khan IA (2008) Glycerogalactolipids from the fruit of *Lycium barbarum*. *Phytochemistry* 69(16):2856–2861
- Gong HY, Shen P, Jin L, Xin CH, Tang F (2004) Therapeutic effects of *Lycium barbarum* polysaccharide (LBP) on mitomycin C (MMC)-induced myelosuppressive mice. *J Exp Ther Oncol* 4(3):181–187
- Gong HY, Shen P, Jin L, Xing CH, Tang F (2005) Therapeutic effects of *Lycium barbarum* polysaccharide (LBP) on irradiation or chemotherapy-induced myelosuppressive mice. *Cancer Biother Radiopharm* 20(2):155–162
- Gu S, Wang PL, Jiang R (2007) A study on the preventive effect of *Lycium barbarum* polysaccharide on the development of alcoholic fatty liver in rats and its possible mechanisms. *Zhonghua Gan Zang Bing Za Zhi* 15(3):204–208 (In Chinese)
- Harsh ML (1989) Tropane alkaloids from *Lycium barbarum* Linn., in vivo and in vitro. *Curr Sci* 58:817–818
- Harsh ML, Nag TN (1981) Diosgenin and phytosterols from *Lycium barbarum* Linn. *Curr Sci* 50:235
- He YL, Ying Y, Xu YL, Su JF, Luo H, Wang HF (2005) Effects of *Lycium barbarum* polysaccharide on tumor microenvironment T-lymphocyte subsets and dendritic cells in H22-bearing mice. *Zhong Xi Yi Jie He Xue Bao* 3(5):374–377 (In Chinese)
- Hedrick UP (1972) Sturtevant's edible plants of the world. Dover Publications, New York, 686 pp
- Hiserodt RD, Adedeji J, John TV, Dewis ML (2004) Identification of monomethyl succinate, monomethyl glutarate, and dimethyl glutarate in nature by high performance liquid chromatography-tandem mass spectrometry. *J Agric Food Chem* 52(11):3536–3541
- Ho YS, Yu MS, Lai CS, So KF, Yuen WH, Chang RC (2007) Characterizing the neuroprotective effects of alkaline extract of *Lycium barbarum* on beta-amyloid peptide neurotoxicity. *Brain Res* 1158:123–134
- Ho YS, Yu MS, Yik SY, So KF, Yuen WH, Chang RC (2009) Polysaccharides from wolfberry antagonizes glutamate excitotoxicity in rat cortical neurons. *Cell Mol Neurobiol* 29(8):1233–1244

- Ho YS, Yu MS, Yang XF, So KF, Yuen WH, Chang RC (2010) Neuroprotective effects of polysaccharides from wolfberry, the fruits of *Lycium barbarum*, against homocysteine-induced toxicity in rat cortical neurons. *J Alzheimers Dis* 19(3):813–827
- Hu CK, Lee YJ, Colitz CM, Chang CJ, Lin CT (2012) The protective effects of *Lycium barbarum* and *Chrysanthemum morifolium* on diabetic retinopathies in rats. *Vet Ophthalmol*. doi:10.1111/j.1463-5224.2012.01018.x [Epub ahead of print]
- Huang L, Lin Y, Tian G, Ji G (1998a) Isolation, purification and physico-chemical properties of immunoactive constituents from the fruit of *Lycium barbarum* L. *Yao Xue Xue Bao* 33(7):512–516 (In Chinese)
- Huang Y, Tan A, Shen Y, Lu J (1998b) Scavenging effect of total flavonoids of *Lycium barbarum* L. on active oxygen radicals and inhibitory effects on heat output from L1210 cells. *Wei Sheng Yan Jiu* 27(2):109–111, 115. (In Chinese)
- Huang LJ, Tian GY, Ji GZ (1999a) Structure elucidation of glycan of glycoconjugate LbGp3 isolated from the fruit of *Lycium barbarum* L. *J Asian Nat Prod Res* 1(4):259–267
- Huang Y, Lu J, Shen Y, Lu J (1999b) The protective effects of total flavonoids from *Lycium barbarum* L. on lipid peroxidation of liver mitochondria and red blood cell in rats. *Wei Sheng Yan Jiu* 28(2):115–116 (In Chinese)
- Huang LJ, Tian GY, Wang ZF, Dong JB, Wu MP (2001) Studies on the glycoconjugates and glycans from *Lycium barbarum* L. in inhibiting low density lipoprotein (LDL) peroxidation. *Yao Xue Xue Bao* 36(2):108–111 (In Chinese)
- Huang X, Yang M, Wu X, Yan J (2003) Study on protective action of *Lycium barbarum* polysaccharides on DNA impairments of testicle cells in mice. *Wei Sheng Yan Jiu* 32(6):599–601 (In Chinese)
- Inbaraj BS, Lu H, Hung CF, Wu WB, Lin CL, Chen BH (2008) Determination of carotenoids and their esters in fruits of *Lycium barbarum* Linnaeus by HPLC-DAD-APCI-MS. *J Pharm Biomed Anal* 47(4–5):812–818
- Inbaraj BS, Lu H, Kao TH, Chen BH (2010) Simultaneous determination of phenolic acids and flavonoids in *Lycium barbarum* Linnaeus by HPLC-DAD-ESI-MS. *J Pharm Biomed Anal* 51(3):549–556
- Jia YX, Dong JW, Wu XX, Ma TM, Shi AY (1998) The effect of *Lycium barbarum* polysaccharide on vascular tension in two-kidney, one clip model of hypertension. *Sheng Li Xue Bao* 50(3):309–314 (In Chinese)
- Jing L, Cui G, Feng Q, Xiao Y (2009) Evaluation of hypoglycemic activity of the polysaccharides extracted from *Lycium barbarum*. *Afr J Tradit Complement Altern Med* 6(4):579–584
- Ke M, Zhang XJ, Han ZH, Yu HY, Lin Y, Zhang WG, Sun FH, Wang TJ (2011) Extraction, purification of *Lycium barbarum* polysaccharides and bioactivity of purified fraction. *Carbohydr Polym* 86(1):136–141
- Lam AY, Elmer GW, Mohutsky MA (2001) Possible interaction between warfarin and *Lycium barbarum* L. *Ann Pharmacother* 35(10):1199–1201
- Larkcom J (1991) Oriental vegetables. John Murray Publishers Ltd., London, 232 pp
- Lau BW, Lee JC, Li Y, Fung SM, Sang YH, Shen J, Chang RC, So KF (2012) Polysaccharides from wolfberry prevents corticosterone-induced inhibition of sexual behavior and increases neurogenesis. *PLoS One* 7(4):e33374
- Le K, Chiu F, Ng K (2007) Identification and quantification of antioxidants in *Fructus lycii*. *Food Chem* 105(1):353–363
- Leung H, Hung A, Hui AC, Chan TY (2008) Warfarin overdose due to the possible effects of *Lycium barbarum* L. *Food Chem Toxicol* 46(5):1860–1862
- Li XM (2007) Protective effect of *Lycium barbarum* polysaccharides on streptozotocin-induced oxidative stress in rats. *Int J Biol Macromol* 40(5):461–465
- Li G, Yang J, Ren B, Wang Z (2002) Effect of *Lycium barbarum* L. on defending free radicals of mice caused by hypoxia. *Wei Sheng Yan Jiu* 31(1):30–31 (In Chinese)
- Li X, Zhou AG, Li XM (2007a) Inhibition of *Lycium barbarum* polysaccharides and *Ganoderma lucidum* polysaccharides against oxidative injury induced by γ -irradiation in rat liver mitochondria. *Carbohydr Polym* 69:172–178
- Li XM, Li XL, Zhou AG (2007b) Evaluation of antioxidant activity of the polysaccharides extracted from *Lycium barbarum* fruits in vitro. *Eur Polym J* 43(2):488–497
- Li XM, Ma YL, Liu XJ (2007c) Effect of the *Lycium barbarum* polysaccharides on age-related oxidative stress in aged mice. *J Ethnopharmacol* 111(3):504–511
- Li G, Sepkovic DW, Bradlow HL, Telang NT, Wong GY (2009) *Lycium barbarum* inhibits growth of estrogen receptor positive human breast cancer cells by favorably altering estradiol metabolism. *Nutr Cancer* 61(3):408–414
- Li G, Shi J, Suo Y, Sun Z, Xia L, Zheng J, You J, Liu Y (2011a) Supercritical CO₂ cell breaking extraction of *Lycium barbarum* seed oil and determination of its chemical composition by HPLC/APCI/MS and antioxidant activity. *LWT- Food Sci Technol* 44(4):1172–1178
- Li SY, Yang D, Yeung CM, Yu WY, Chang RC, So KF, Wong D, Lo AC (2011b) *Lycium barbarum* polysaccharides reduce neuronal damage, blood-retinal barrier disruption and oxidative stress in retinal ischemia/reperfusion injury. *PLoS One* 6(1):e16380
- Lin CL, Wang CC, Chang SC, Inbaraj BS, Chen BH (2009) Antioxidative activity of polysaccharide fractions isolated from *Lycium barbarum* Linnaeus. *Int J Biol Macromol* 45(2):146–151
- Liu XL, Sun JY, Li HY, Zhang L, Qian BC (2000) Extraction and isolation of active component for inhibiting PC3 cell proliferation in vitro from the fruit of *Lycium barbarum* L. *Zhongguo Zhong Yao Za Zhi* 25(8):481–483 (In Chinese)
- Liu Q, Li Y, Hu L, Wang D (2011) *Lycium barbarum* polysaccharides attenuate cisplatin-induced hair cell loss in rat cochlear organotypic cultures. *Int J Mol Sci* 12(12):8982–8992

- Liu H, Fan Y, Wang W, Liu N, Zhang H, Zhu Z, Liu A (2012) Polysaccharides from *Lycium barbarum* leaves: isolation, characterization and splenocyte proliferation activity. *Int J Biol Macromol* 51(4):417–422
- Lu CX, Cheng BQ (1991) Radiosensitizing effects of *Lycium barbarum* polysaccharide for Lewis lung cancer. *Zhong Xi Yi Jie He Za Zhi* 11(10):611–612, 582. (In Chinese)
- Lu SP, Zhao PT (2010) Chemical characterization of *Lycium barbarum* polysaccharides and their reducing myocardial injury in ischemia/reperfusion of rat heart. *Int J Biol Macromol* 47(5):681–684
- Luo Q, Yan J, Zhang S (1999) Effects of pure and crude *Lycium barbarum* polysaccharides on immunopharmacology. *Zhong Yao Cai* 22(5):246–249 (In Chinese)
- Luo Q, Yan J, Zhang S (2000) Isolation and purification of *Lycium barbarum* [Goji] polysaccharides and its anti-fatigue effect. *Wei Sheng Yan Jiu* 29(2):115–117
- Luo Q, Cai Y, Yan J, Sun M, Corke H (2004) Hypoglycemic and hypolipidemic effects and antioxidant activity of fruit extracts from *Lycium barbarum*. *Life Sci* 76(2):137–149
- Luo Q, Li Z, Huang X, Yan J, Zhang S, Cai YZ (2006) *Lycium barbarum* polysaccharides: protective effects against heat-induced damage of rat testes and H₂O₂-induced DNA damage in mouse testicular cells and beneficial effect on sexual behavior and reproductive function of hemicastrated rats. *Life Sci* 79(7):613–621
- Luo Q, Li Z, Yan J, Zhu F, Xu RJ, Cai YZ (2009) *Lycium barbarum* polysaccharides induce apoptosis in human prostate cancer cells and inhibits prostate cancer growth in a xenograft mouse model of human prostate cancer. *J Med Food* 12(4):695–703
- Luo Q, Cui X, Yan J, Yang M, Liu J, Jiang Y, Li J, Zhou Y (2011) Antagonistic effects of *Lycium barbarum* polysaccharides on the impaired reproductive system of male rats induced by local subchronic exposure to 60Co- γ irradiation. *Phytother Res* 25(5):694–701
- Ma L, Chen Q, Yang W, Xi S, Wan X, Tang X, Yu Y, Kang J (2005) Effect of *Lycium barbarum* polysaccharide against atherosclerosis in rabbits. *Zhengzhou Daxue Xuebao Yixueban* 40:328–330
- Ma M, Liu GH, Yu ZH, Chen G, Zhang X (2009) Effect of the *Lycium barbarum* polysaccharides administration on blood lipid metabolism and oxidative stress of mice fed high-fat diet in vivo. *Food Chem* 113(4):872–877
- Mao F, Xiao B, Jiang Z, Zhao J, Huang X, Guo J (2011) Anticancer effect of *Lycium barbarum* polysaccharides on colon cancer cells involves G0/G1 phase arrest. *Med Oncol* 28(1):121–126
- Miao Y, Xiao B, Jiang Z, Guo Y, Mao F, Zhao J, Huang X, Guo J (2010) Growth inhibition and cell-cycle arrest of human gastric cancer cells by *Lycium barbarum* polysaccharide. *Med Oncol* 27(3):785–790
- Mizobuchi K, Inoue Y, Kiuchi T, Higashi J (1963) Constituents of box thorn. II. Chemical components of the root bark of box thorn. *Shoyakugaku Zasshi* 17:16–18
- Molnar P, Pfander H, Olah P, Deli J, Toth G (2003) Carotenoid composition of *Lycium barbarum* L. seeds of Chinese and Hungarian origin. *Olaj Szappan Kozmetika* 52:50–55
- Monzón Ballarín S, López-Matas MA, Sáenz Abad D, Pérez-Cinto N, Carnés J (2011) Anaphylaxis associated with the ingestion of Goji berries (*Lycium barbarum*). *J Investig Allergol Clin Immunol* 21(7):567–570
- Näf R, Velluz A, Thommen W (1990) Isolation of a glucosidic precursor of damascenone from *Lycium halimifolium* Mil. *Tetrahedron Lett* 31(45):6521
- Ni H, Qing D, Kaisa S, Lu J (2004) The study on the effect of LBP on cleaning hydroxygen free radical by EPR technique. *Zhong Yao Cai* 27(8):599–600 (In Chinese)
- Niu AJ, Wu JM, Yu DH, Wang R (2008) Protective effect of *Lycium barbarum* polysaccharides on oxidative damage in skeletal muscle of exhaustive exercise rats. *Int J Biol Macromol* 42(5):447–449
- Ouyang HX, Li YQ, Xiao QW (2007) Simultaneous determination of monosaccharides and oligosaccharides in *Lycium barbarum* L. by high performance liquid chromatography. *Sichuan Da Xue Xue Bao Yi Xue Ban* 38(6):1040–1042
- Peng X, Tian GY (2001) Structural characterization of the glycan part of glycoconjugate LbGp2 from *Lycium barbarum* L. *Carbohydr Res* 331(1):95–99
- Peng X, Huang J, Qi C, Zhang YX, Tian GY (2001a) Studies on chemistry and immuno-modulating mechanism of a glycoconjugate from *Lycium barbarum* L. *Chin J Chem* 19:1190–1197
- Peng X, Qi C, Tian G, Zhang XX (2001b) Physico-chemical properties and bioactivities of a glycoconjugate LbGp5B from *Lycium barbarum* L. *Chin J Chem* 19:842–846
- Peng XM, Wang ZF, Tian GY (2001c) Physico-chemical properties and activity of glycoconjugate LbGp2 from *Lycium barbarum* L. [Goji]. *Yao Xue Xue Bao* 36(8):599–602
- Peng Y, Ma C, Li YW, Leung KSY, Jiang ZH, Zhao ZZ (2005) Quantification of zeaxanthin dipalmitate and total carotenoids in *Lycium* fruits (*Fructus Lycii*). *Plant Foods Hum Nutr* 60:161–164
- Piao M, Murata Y, Zhu B, Shimoishi Y, Tada M (2005) Changes in carotenoid content and its composition during maturation of *Fructus lycii* fruits. *Jpn J Food Chem* 12:5–39
- Porcher MH et al (1995–2020) Searchable World Wide Web multilingual multiscrypt plant name database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Potterat O (2010) Goji (*Lycium barbarum* and *L. chinense*): phytochemistry, pharmacology and safety in the perspective of traditional uses and recent popularity. *Planta Med* 76(1):7–19
- Qi Z, Li S, Wu J, Qu R, Yang Y, Zhang L, Yang X (1986) Chemical constituents of *Fructus lycii* and *Folium lycii*

- nutrients in *Fructus lycii* and *Folium lycii*. *Zhongyao Tongbao* (B) 11:169–171
- Reeve VE, Allanson M, Arun SJ, Domanski D, Painter N (2010) Mice drinking goji berry juice (*Lycium barbarum*) are protected from UV radiation-induced skin damage via antioxidant pathways. *Photochem Photobiol Sci* 9(4):601–607
- Ren B, Ma Y, Shen Y, Gao B (1995) Protective action of *Lycium barbarum* L. (LbL) and betaine on lipid peroxidation of erythrocyte membrane induced by H₂O₂. *Zhongguo Zhong Yao Za Zhi* 20(5):303–304 (In Chinese)
- Rivera CA, Ferro CL, Bursua AJ, Gerber BS (2012) Probable interaction between *Lycium barbarum* (goji) and warfarin. *Pharmacotherapy* 32(3):e50–e53
- Shan X, Zhou J, Ma T, Chai Q (2011) *Lycium barbarum* polysaccharides reduce exercise-induced oxidative stress. *Int J Mol Sci* 12(2):1081–1088
- Song MK, Salam NK, Roufogalis BD, Huang TH (2011) *Lycium barbarum* (Goji Berry) extracts and its taurine component inhibit PPAR- γ -dependent gene transcription in human retinal pigment epithelial cells: possible implications for diabetic retinopathy treatment. *Biochem Pharmacol* 82(9):1209–1218
- Song MK, Roufogalis BD, Huang TH (2012) Reversal of the caspase-dependent apoptotic cytotoxicity pathway by taurine from *Lycium barbarum* (Goji Berry) in human retinal pigment epithelial cells: potential benefit in diabetic retinopathy. *Evid Based Complement Alternat Med* 2012:323784
- Tanaka T (1976) Tanaka's Cyclopaedia of edible plants of the world. Keigaku Publishing, Tokyo, 924 pp
- Tian M, Wang M (2006) Studies on extraction, isolation and composition of *Lycium barbarum* [Goji] polysaccharides. *Zhongguo Zhong Yao Za Zhi* 31(19):1603–1607 (In Chinese)
- Toyoda-Ono Y, Maeda M, Nakao M, Yoshimura M, Sugiura-Tomimori N, Fukami H (2004) 2-O-(β -D-Glucopyranosyl)ascorbic acid, a novel ascorbic acid analogue isolated from *Lycium* fruit. *J Agric Food Chem* 52(7):2092–2096
- Toyoda-Ono Y, Maeda M, Nakao M, Yoshimura M, Sugiura-Tomimori N, Fukami H, Nishioka H, Miyashita Y, Kojo S (2005) A novel vitamin C analog, 2-O-(β -D-Glucopyranosyl)ascorbic acid: examination of enzymatic synthesis and biological activity. *J Biosci Bioeng* 99(4):361–365
- Uphof JCTh (1968) Dictionary of economic plants, 2nd edn (1st edn 1959). Cramer, Lehre, 591 pp
- Vidal K, Bucheli P, Gao Q, Moulin J, Shen LS, Wang J, Blum S, Benyacoub J (2012) Immunomodulatory effects of dietary supplementation with a milk-based wolfberry formulation in healthy elderly: a randomized, double-blind, placebo-controlled trial. *Rejuvenation Res* 15(1):89–97
- Wang JH, Wang HZ, Zhang M, Zhang SH (2002a) Anti-aging function of polysaccharides from *Lycium barbarum*. *Acta Nutr Sin* 24:189–191 (In Chinese)
- Wang Y, Zhao H, Sheng X, Gambino PE, Costello B, Bojanowski K (2002b) Protective effect of *Fructus Lycii* polysaccharides against time and hyperthermia-induced damage in cultured seminiferous epithelium. *J Ethnopharmacol* 82(2–3):169–175
- Wang CC, Chang SC, Chen BH (2009a) Chromatographic determination of polysaccharides in *Lycium barbarum* Linnaeus. *Food Chem* 116:595–603
- Wang NT, Lin HI, Yeh DY, Chou TY, Chen CF, Leu FC, Wang D, Hu RT (2009b) Effects of the antioxidants *Lycium barbarum* and ascorbic acid on reperfusion liver injury in rats. *Transplant Proc* 41(10):4110–4113
- Wang CC, Chang SC, Inbaraj BS, Chen BH (2010) Isolation of carotenoids, flavonoids and polysaccharides from *Lycium barbarum* L. and evaluation of antioxidant activity. *Food Chem* 120(1):184–192
- Wang K, Sasaki T, Li W, Li Q, Wang Y, Asada Y, Kato H, Koike K (2011) Two novel steroidal alkaloid glycosides from the seeds of *Lycium barbarum*. *Chem Biodivers* 8(12):2277–2284
- Wen J, Yang BN, Ren D (2010) Effect of *Lycium barbarum* polysaccharides on neurogenesis and learning & memory in manganese poisoning mice. *Zhongguo Zhong Xi Yi Jie He Za Zhi* 30(3):295–298 (In Chinese)
- Wu SJ, Ng LT, Lin CC (2004) Antioxidant activities of some common ingredients of traditional Chinese medicine, *Angelica sinensis*, *Lycium barbarum* and *Poria Cocos*. *Phytother Res* 18(12):1008–1012
- Wu H, Guo H, Zhao R (2006) Effect of *Lycium barbarum* polysaccharide on the improvement of antioxidant ability and DNA damage in NIDDM rats. *Yakugaku Zasshi* 126(5):365–371
- Wu HT, He XJ, Hong YK, Ma T, Xu YP, Li HH (2010) Chemical characterization of *Lycium barbarum* polysaccharides and its inhibition against liver oxidative injury of high-fat mice. *Int J Biol Macromol* 46(5):540–543
- Wu PS, Wu SJ, Tsai YH, Lin YH, Chao JC (2011) Hot water extracted *Lycium barbarum* and *Rehmannia glutinosa* inhibit liver inflammation and fibrosis in rats. *Am J Chin Med* 39(6):1173–1191
- Wu WB, Hung DK, Chang FW, Ong ET, Chen BH (2012) Anti-inflammatory and anti-angiogenic effects of flavonoids isolated from *Lycium barbarum* Linnaeus on human umbilical vein endothelial cells. *Food Funct*. doi:10.1039/C2FO30051F [Epub ahead of print]
- Xiao J, Liong EC, Ching YP, Chang RC, So KF, Fung ML, Tipoe GL (2012) *Lycium barbarum* polysaccharides protect mice liver from carbon tetrachloride-induced oxidative stress and necroinflammation. *J Ethnopharmacol* 139(2):462–470
- Xie H, Zhang S (1997) Determination of taurine in *Lycium barbarum* L. by high performance liquid chromatography with OPA-urea pre-column derivatization. *Se Pu* 15(1):54–56 (In Chinese)
- Xie C, Xu LZ, Li XM, Li KM, Zhao BH, Yang SL (2001) Studies on chemical constituents in fruit of *Lycium barbarum* L. *Zhongguo Zhong Yao Za Zhi* 26(5):323–324 (In Chinese)
- Xin YF, Zhou GL, Deng ZY, Chen YX, Wu YG, Xu PS, Xuan YX (2007) Protective effect of *Lycium barbarum* on doxorubicin-induced cardiotoxicity. *Phytother Res* 21(11):1020–1024

- Xin Y, Zhang S, Gu L, Liu S, Gao H, You Z, Zhou G, Wen L, Yu J, Xuan Y (2011a) Electrocardiographic and biochemical evidence for the cardioprotective effect of antioxidants in acute doxorubicin-induced cardiotoxicity in the beagle dogs. *Biol Pharm Bull* 34(10):1523–1526
- Xin YF, Wan LL, Peng JL, Guo C (2011b) Alleviation of the acute doxorubicin-induced cardiotoxicity by *Lycium barbarum* polysaccharides through the suppression of oxidative stress. *Food Chem Toxicol* 49(1):259–264
- Xin YF, You ZQ, Gao HY, Zhou GL, Chen YX, Yu J, Xuan YX (2012) Protective effect of *Lycium barbarum* polysaccharides against doxorubicin-induced testicular toxicity in rats. *Phytother Res* 26(5):716–721
- Xu M, Zhang H, Wang Y (2002) The protective effects of *Lycium barbarum* polysaccharide on alloxan-induced isolated islet cells damage in rats. *Zhong Yao Cai* 25(9):649–651 (In Chinese)
- Yahara S, Shigeyama C, Ura T, Wakamatsu K, Yasuhara T, Nohara T (1993) Cyclic peptides, acyclic diterpene glycosides and other compounds from *Lycium chinense* Mill. *Chem Pharm Bull(Tokyo)* 41(4):703–709
- Yang M, Gao N, Zhao Y, Liu LX, Lu XJ (2011) Protective effect of *Lycium barbarum* polysaccharide on retinal ganglion cells in vitro. *Int J Ophthalmol* 4(4):377–379
- Yang D, Li SY, Yeung CM, Chang RC, So KF, Wong D, Lo AC (2012) *Lycium barbarum* extracts protect the brain from blood–brain barrier disruption and cerebral edema in experimental stroke. *PLoS One* 7(3):e33596
- Yao XL, Wu WL, Zheng MY, Li W, Ye CH, Lu XL (2011) Protective effects of *Lycium barbarum* extract against MPP(+)-induced neurotoxicity in *Caenorhabditis elegans* and PC12 cells. *Zhong Yao Cai* 34(8):1241–1246 (In Chinese)
- Ye F, Yan X, Xu J, Chen H (2006) Determination of aldoses and ketoses by GC-MS using differential derivatization. *Phytochem Anal* 17(6):379–383
- Yu MS, Leung SK, Lai SW, Che CM, Zee SY, So KF, Yuen WH, Chang RC (2005) Neuroprotective effects of anti-aging oriental medicine *Lycium barbarum* against beta-amyloid peptide neurotoxicity. *Exp Gerontol* 40(8–9):716–727
- Yu MS, Ho YS, So KF, Yuen WH, Chang RC (2006) Cytoprotective effects of *Lycium barbarum* against reducing stress on endoplasmic reticulum. *Int J Mol Med* 17(6):1157–1161
- Yu MS, Lai CS, Ho YS, Zee SY, So KF, Yuen WH, Chang RC (2007) Characterization of the effects of anti-aging medicine *Fructus lycii* on beta-amyloid peptide neurotoxicity. *Int J Mol Med* 20(2):261–268
- Zhang M, Wang J, Zhang S (2002) Study on the composition of *Lycium barbarum* polysaccharides and its effects on the growth of weanling mice. *Wei Sheng Yan Jiu* 31(2):118–119 (In Chinese)
- Zhang M, Chen H, Huang J, Li Z, Zhu C, Zhang S (2005) Effect of *Lycium barbarum* polysaccharide on human hepatoma QGY7703 cells: inhibition of proliferation and induction of apoptosis. *Life Sci* 76(18):2115–2124
- Zhang XR, Zhou WX, Zhang YX, Qi CH, Yan H, Wang ZF, Wang B (2011a) Macrophages, rather than T and B cells are principal immunostimulatory target cells of *Lycium barbarum* L. polysaccharide LBPF4-OL. *J Ethnopharmacol* 136(3):465–472
- Zhang Z, Liu X, Wu T, Liu J, Zhang X, Yang X, Goodheart MJ, Engelhardt JF, Wang Y (2011b) Selective suppression of cervical cancer Hela cells by 2-O- β -D-glucopyranosyl-L-ascorbic acid isolated from the fruit of *Lycium barbarum* L. *Cell Biol Toxicol* 27(2):107–121
- Zhang Z, Liu X, Zhang X, Liu J, Hao Y, Yang X, Wang Y (2011c) Comparative evaluation of the antioxidant effects of the natural vitamin C analog 2-O- β -D-glucopyranosyl-L-ascorbic acid isolated from Goji berry fruit. *Arch Pharm Res* 34(5):801–810
- Zhao Q, Li C, Zhou D (1987) Chemical constituents of Gouqi (*Lycium barbarum*) leaf. *Zhongcaoyao* 18:104–133
- Zhao CJ, He YQ, Li RZ, Chui GH (1996) Chemistry and pharmacological activity of peptidoglycan from *Lycium barbarum*. *Chin Chem Lett* 11:1009–1010 (In Chinese)
- Zhao CJ, Li RZ, He YY, Chui GH (1997) Studies on chemistry of Gouqi polysaccharides. *Yie Daxue Xuebao* 29:231–232, 240
- Zhao H, Alexeev A, Chang E, Greenburg G, Bojanowski K (2005a) *Lycium barbarum* glycoconjugates: effect on human skin and cultured dermal fibroblasts. *Phytomedicine* 12(1–2):131–137
- Zhao R, Li Q, Xiao B (2005b) Effect of *Lycium barbarum* polysaccharide on the improvement of insulin resistance in NIDDM rats. *Yakugaku Zasshi* 125(12):981–988
- Zhao R, Li QW, Li J, Zhang T (2009) Protective effect of *Lycium barbarum* polysaccharide 4 on kidneys in streptozotocin-induced diabetic rats. *Can J Physiol Pharmacol* 87(9):711–719
- Zhu CP, Zhang SH (2012) *Lycium barbarum* polysaccharide inhibits the proliferation of HeLa cells by inducing apoptosis. *J Sci Food Agric*. doi:10.1002/jsfa.5743 [Epub ahead of print]
- Zhu J, Zhao LH, Chen Z (2006) Stimulation by *Lycium barbarum* polysaccharides of the maturation of dendritic cells in murine bone marrow. *Zhejiang Da Xue Xue Bao Yi Xue Ban* 35(6):648–652 (In Chinese)
- Zhu J, Zhao LH, Zhao XP, Chen Z (2007) *Lycium barbarum* polysaccharides regulate phenotypic and functional maturation of murine dendritic cells. *Cell Biol Int* 31(6):615–619
- Zou C, Zhao Q, Chen CX, He YN (1999) New dopamine derivative from *Lycium barbarum*. *Chin Chem Lett* 10(2):131–132
- Zou S, Zhang X, Yao W, Niu Y, Gao X (2010) Structure characterization and hypoglycemic activity of a polysaccharide isolated from the fruit of *Lycium barbarum* L. *Carbohydr Polym* 80(4):1161–1167

Lycium chinense

Scientific Name

Lycium chinense Miller.

Synonyms

No synonyms recorded.

Family

Solanaceae

Common/English Names

Common Boxthorn, Chinese Boxthorn, Chinese Desert-Thorn, Chinese Tea Plant, Chinese Wolfberry, Duke Of Argyll Tea Tree, Goji Berry, Go Qi Zi, Gow Kee, Matrimony Vine, Wolfberry.

Vernacular Names

Chinese: Dì Gǔ Pí, Gǒuqǐ, Gǒu Qǐ Zǐ, Kei-Chi, Kau Kei;

Czech: Kustovnice Čínská;

Danish: Bredbladet Bukketorn;

Dutch: Chinese Boksdoorn, Gaugee;

French: Lyciet, Lyciet De Chine;

German: Bocksdoornbeere, Chinesischer Bocksdoorn;

Hungarian: Kínai Ördögcérna;

Icelandic: Kínaflétta;

Indonesia: Daun Koki;

Italian: Spina-Santa Cinese;

Japanese: Kuko, Kuko No Mi, Kuko No Kajitsu, Kukoshi;

Korean: Bulro Kugi, Gu Gi Ja, Kukija, Kujijanamu;

Malaysia: Kaukichai, Kaukichoy, Keichi;

Norwegian: Kinabukketorn;

Polish: Kolcowój Chiński;

Slovenčina: Kustovnica Čínska;

Spanish: Cambrona De Ningxia, Cambronero Chino;

Swedish: Bredbladigt Bocktörne;

Thai: Gǎo Gèe, Kaokichai, Kaochichai;

Tibetan: Dretsherma (Plant), Dretshermā Dräwu (Fruit);

Vietnam: Cẩu Kỳ, Cẩu Kỳ Tử, Cù Khởi, Rau Khoi, Khu Khoi, Dia Coy Bi, Khoi Tu, Kỳ Tử, Phjác Khau Khi (Tây).

Origin/Distribution

The species is native to China (Anhui, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Hebei, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Nei Mongol, Ningxia, Qinghai, Shaanxi, Shanxi, Sichuan, Yunnan, Zhejiang), Taiwan and Japan and widely cultivated in South east and north Asia. Wolfberry is also naturalised in Europe, eastern United States, Japan, Korea, Mongolia, Nepal, Pakistan,

and south-west Asia. The plant is widely cultivated in China as a medicinal and food plant.

Agroecology

In its native range, it occurs in thickets in lowlands, on slopes, wastelands, saline places, roadsides and house backyards. It grows well in many climatic regimes from sea level to 2,000 m elevation. It can be grown in higher elevations in the tropics. It tolerates poor soils but grows well in full sun.

Edible Plant Parts and Uses

The fresh or dried ripe berries are eaten raw and without cooking in herbal teas, processed into juice or cooked. As food, the dried ripe berries are used in special herbal chicken dishes, in rice congee, or in combination with other vegetables and herbs such as wild Chinese yam (*Dioscorea opposita*), *Astragalus membranaceus*, *Codonopsis pilosula*, liquorice root and Chinese red jujubes in herbal tonic soup that is taken with rice. In North America, Europe and Australia the dried ripe berries are also eaten hand-to-mouth as a dried fruit snack for health diet reasons. The ripe berries are also boiled as herbal tea often in combination with dried chrysanthemum flowers, red jujubes or processed as packaged teas. The ripe berries are also used for making wine called *gouqi jui* or wolfberry beer in China or in flavouring ale (Belgium). The roasted seed is also used as a coffee substitute. Young leaves can be eaten raw but are usually eaten cooked as potherb in soups with pork, chicken, meat or eggs. The leaves also make a good tonic tea.

Botany

Deciduous woody perennial shrub erect or sprawling, usually 0.5–1.2 m tall. Stems much branched; branches pale grey, slender, arching, with thorns (0.5–1.5 cm). Leaves alternate, solitary or in whorls of 2–4; leaf blade ovate, rhombic, or oblong-lanceolate, (linear lanceolate in var. *potaninii*) 1.5–5×0.5–2.5 cm (to 10×4 cm in



Plate 1 Leaves and axillary, solitary flowers



Plate 2 Whorled ovate leaves and flower

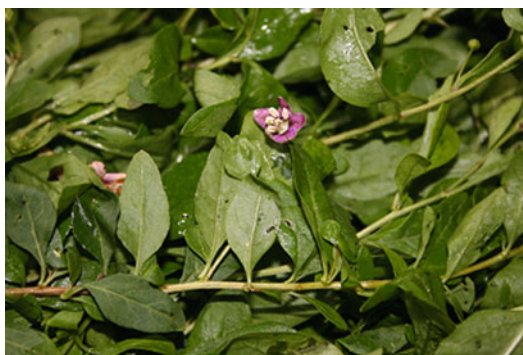


Plate 3 Close-up of ovate leaves and flower

cultivation) entire, usually greyish-green, margin wavy (Plates 1–3). Inflorescences solitary or paired flowers on long shoots or fasciculate among



Plate 4 Ripe fruits



Plate 5 Dried goji berries

leaves on short shoots. Pedicel 1–2 cm. Calyx campanulate, 3–4 mm, 3–5-toothed, lobes densely ciliate. Corolla purple, 0.9–1.2 cm; tube funnel-shaped, lobes pubescent at margin with distinct basal auricles (Plates 1–3). Stamens 5 inserted

to upper part of corolla tube, slightly shorter than corolla, with a villous ring slightly above filament base and adjacent corolla tube. Ovary – two locules. Berry red or orange-red, ovoid or ellipsoid, 0.7–1.5 cm × 5–8 mm (ca. 2.2 × 1 cm in cultivation) (Plates 4 and 5). Seeds numerous, yellow, 2.5–3 mm with curved embryo.

Nutritive/Medicinal Properties

Fruit Nutrients and Phytochemicals

Polysaccharides comprised quantitatively the most important groups of compounds in *L. chinense* fruit (Potterat 2010). Two additional kinds of arabinogalactan-protein (Cp-1-C, and Cp-1-D) were obtained from *Lycium chinense* fruit (Qin et al. 2000). In Cp-1-C, the carbohydrate content was 92.4% and composed of arabinose and galactose at a ratio of 3:1, and O-glycosidically linked to both the serine and threonine residues of protein. Its molecular weight was 42,000. In Cp-1-D, the ratio of arabinose to galactose was 1:1, and the O-glycosidical junction between the carbohydrate and protein was composed of serine residue. The molecular weight was 23,000 and the carbohydrate content was 90.7%. The arabinogalactan-protein Cp-1-A with molecular weight 10,000, had a carbohydrate content of 87.8% and composed of arabinose and xylose in the ratio of 1:1. Two additional arabinogalactan-protein (Cp-2-B and Hp-2-C) were obtained from *L. chinense* fruit (Qin et al. 2001). The ratio of arabinose to galactose was approximately 1:1 in both samples, and the carbohydrate was linked O-glycosidically to serine in Cp-2-B, and to both serine and threonine residues of the protein in Hp-2-C. The weight-average molecular weight was 71,000 for Cp-2-B and 120,000 for Hp-2-C. Both samples also contained non-reducing terminal 3-O- and 4-O-substituted galacturonic acids. Two arabinans Cp-1-B and Hp-O-A were also isolated from the fruit (Qin and Lin 2003). The arabinogalactan-protein Cp-1-B with molecular weight 11,000, had a carbohydrate content of 89.4% and composed of only arabinose. Hp-O-A had a molecular weight of 23,000 and comprised only arabinose.

L. chinense fruit was found to be rich in carotenoids (10), containing 2,952 µg/g of total carotenoids, but 98.6% of carotenoids existed as esterified forms; zeaxanthin dipalmitate predominated, accounting for 77.5% of the total carotenoids (Li et al. 1998). Total carotenoid content found in *L. barabrum* fruit amounted to 0.444% of which zeaxanthin dipalmitate predominated with 0.219%, constituting 49.35% of the total carotenoids (Peng et al. 2005). The fruit had been reported to contain carotenoids: β-carotene (Noculak-Palczewska et al. 2004), and zeaxanthin (Kim et al. 1997d). Betaine (0.2 ng/mL) was detected in *L. chinense* fruit by liquid chromatography-electrospray ionization mass spectrometry (Shin et al. 1999). Bunghez et al. (2012) found goji berries (*L. chinense*) to be a rich source of vitamin E (tocopherols) and carotenoids (neoxanthin, lutein, zeaxanthin, lycopene, β-carotene and α-carotene).

One hundred and thirty volatile components including acids (8), alcohols (21), aldehydes (23), alkanes (10), aromatics (5), esters (15), furans (7), ketones (21), miscellaneous compounds (3), naphthalenes (2), phenols (3), pyrazines (2) and terpenes (10) were identified from dried *L. chinense* fruits (Kim and Chung 2009). Some volatile compounds found in the dried boxthorn fruit might account for its major odorous property, particularly at relatively high concentration, eg, hexadecanoic acid (1,351.57 µg/g), (Z,Z)-9,12-octadecadienoic acid (451.14 µg/g), 3-methyl butanal (304.57 µg/g), 2-furancarboxaldehyde (282.08 µg/g), 2-methyl butanal (280.51 µg/g), trimethylsilyl hexadecanoate (240.78 µg/g), phenylacetaldehyde (223.40 µg/g), 2,3-butanedione (188.33 µg/g) and 3-(methylthio)-propanal (111.67 µg/g). However, traces of undesirable compounds were also found in the boxthorn fruit including hexanal (20.89 µg/g), 1-octen-3-ol (15.38 µg/g), 3-octanol (0.33 µg/g), 3-hydroxy-2-butanone (39.16 µg/g), and 2,6,6-trimethyl-1,3-cyclohexadien-1-carboxaldehyde (0.82 µg/g) (safranal). These were likely produced by lipid or enzymatic oxidation. Thirty-three odor compounds were isolated from kukijas (*L. chinense*) fruit (Lee et al. 2008).

The major odour contributing compounds were (E)-2-heptenal (green, mushroomy), 1-heptanol (planty, oily), hexanal (planty), 3-octanol (mushroomy, planty), 1-octen-3-ol (mushroomy), and 2-methyl-2-butenic acid (pungent, planty), which might be produced by enzymatic oxidation and/or oxidation of lipids and carotenes, resulting in undesirable aromas.

Park et al. (1997) identified 54 compounds in the essential oil of dried *L. chinense* fruits which mainly consisted of esters, aldehydes and alcohols. The main constituents were ethyl hexadecanoate, 1-octadecanone, tetrahydropyridine, 2-furanocarboxaldehyde, and ethyl linoleate.

Forty two components, representing 99.81% of the total oil were identified in the essential oil of *L. chinense* fruits (Chung et al. 2011). The oil was dominated by acids and esters which accounted for 66.61 and 22.25% of the oil, respectively. The major components were hexadecanoic acid (62.89%), hexadecanoic acid ethyl ester (9.92%), hexadecanoic acid methyl ester (4.92%), tetradecanoic acid (3.72%), ethyl linoleate (3.45%), 6-isopropenyl-4,8α-dimethyl-1,2,3,5,6,7,8α-octahydronaphthalen-2-ol (2.19%), 9,12-octadecadienoic acid, methyl ester (1.56%), ethyl oleate (1.23%), 9-octadecenoic acid (1.19%) and dodecyl acrylate (1.17%). Two volatile sesquiterpene components (–)-1,2-dehydro-α-cyperone and solavetivone were isolated from *Lycium chinense* essential oil (Sannai et al. 1980). Other volatile constituents identified from the fruit were megastigmatrienone, β-ionone and 3-hydroxy-β-ionone the main ketones, hydrocarbons β-elemene and δ-cadinene, phenethyl alcohol and benzyl alcohol and smaller amounts of linalool and terpinen-4-ol (Sannai et al. 1983).

Forty components, representing 99.50% of the total extract were identified from the petroleum ether extract of *L. chinense* fruits (Chung et al. 2011). The extract was dominated by acids, esters and higher alkanes which accounted 23.76, 31.77 and 9.52%, respectively. The major components of petroleum ether extract were hexadecanoic acid (17.43%), hexadecanoic acid ethyl ester (9.51%), ethyl linoleate (10.26%), hexadecanoic acid methyl ester (3.72%), phytol (3.58%),

heptyl *p*-toluenesulphonate (3.37%), 2-amino-4,7-pteridinedione (3.24%), ethyl oleate (3.04%), 5-bromo-3-methylidene-1-methoxycyclohexane (3.02%), tetradecane (2.79%), 8,11-octadecadienoic acid, methyl ester (2.60%), (–)-sphathulenol (2.60%), (*E,E*)-2,4-decadienal (2.34%), 2-benzofuranone, 5,6,7,7 α -trimethyl (2.30%), oleic acid (2.16%) and (*Z,Z,Z*)-9,12,15-octadecatrienoic acid (2.01).

Two cerebrosides isolated from *Lycium chinense* fruits were characterized as 1-O- β -D-glucopyranosyl-(2S, 3R,4E,8Z)-2-N-palmitoyloctadecasphinga-4,8-dienine+ ++ and 1-O- β -D-glucopyranosyl -(2S,3R,4E,8Z)-2-N-(2'-hydroxypalmitoyl)octadecasphinga-4,8-dienine (Kim et al. 1997b). A hepatoprotective cerebroside, 1-O-(β -D-glucopyranosyl)-(2S,3R,4E,8Z)-2-N-2'-hydroxy-(palmitoyl)-4,8-sphingadiene was purified from suspension cultures of *Lycium chinense* (Jang et al. 1998). The content of the compound in cultured cell was tenfold higher than that of the fruit of *L. chinense*. The following constituents were isolated from *L. chinense* fruit: (6'-O-palmitoyl)- and (6'-O-stearoyl)- β -sitosterol-3-O- β -D-glucopyranoside and two glycolipids, 1-O-(9Z,12Z, 15Z-octadecatrienoyl)-2-O-(9Z, 12Z, 15Z-octadecatrienoyl)-3-O- β -D-galactopyranosyl glycerol and 1-O-(9Z, 12Z-octadecadienoyl)-2-O-(9Z, 12Z, 15Z-octadecatrienoyl)-3-O- β -D-galactopyranosyl glycerol (Jung et al. 2005). Chin et al. (2003) isolated three pyrrole derivatives from *L. chinense* fruit, and recently Jeon et al. (2011) isolated another pyrrole compound, 5-methoxymethyl-1 H-pyrrole-2-carbaldehyde from the fruit. The following flavonoids were isolated from *L. chinense* fruit: rutin, cholorogenic acid and procatechuic acid (Qian et al. 2004).

Two new compounds stigmast-5-en-3 β -ol-3-O- β -D-(2'-n-triacontanoyl) glucopyranoside (1) and 19,21-dimethyl triacont-17,22,24,26,28-pentaene-1-oic acid (2), along with the three known compounds n-tetracosanyl octadec-9-enoate (3), β -sitosterol, and β -sitosterol-3-O- β -D-glucoside, were isolated from the methanol extract of *Lycium chinense* fruits (Jung et al. 2012). Yamada et al. (2011) isolated 5-(hydroxymethyl)furfural from *Lycium chinense* fruit.

The seeds were reported to contain sterols as part of studies on sterols of Solanaceous plants: cycloartenol, cycloartanol, and 24-methylenecycloartanol (Itoh et al. 1977b), gramisterol and citrostadienol (Itoh et al. 1978), and 24-ethylcholesterol, 24-methylcholesta-5,24-dienol, and 28-isofucosterol (Itoh et al. 1977a) were found to be the major constituents of the 4,4-dimethyl, 4-methyl, 4-desmethyl sterol fractions, respectively.

Plant Phytochemicals

Total phenolic contents of Bulro Kugi (*Lycium chinense*) fruit, leaf, and root were 1,078.4, 939.9, and 3,792.2 mg/l, and their flavonoid contents were 396.7, 1,952.9, and 425.3 mg/l, respectively (Kim et al. 2005a). Citrate was the highest among organic acids in fruits, and malate in leaf and root of Bulro Kugi (*Lycium chinense*) (Kim et al. 2005b). Capsaicin was detected in leaf and root. One hundred and twenty-eight volatile flavor compounds were extracted and included 22 acids, 15 alcohols, 12 aldehydes, 8 esters, 10 furans, 26 hydrocarbons, 4 phenols, 2 pyrroles, 1 pyrazine, and 28 miscellaneous components. The main polyphenolic compounds in the fruit were *p*-coumaric and syringic acids, in the leaf *p*-coumaric, syringic, and procatechuic acids, and in the root *p*-coumaric, syringic, caffeic, and procatechuic acids.

Leaf Nutrients and Phytochemicals

Nutrient composition of the leaves per 100 g edible portion was reported as: 34 kcal, water 89.6 g, protein 4.3 g, fat 0.6 g, carbohydrate 2.9 g, fibre 0.9 g, ash 1.7 g, Ca 120 mg, P 5 mg, Fe 2.7 mg, Na 6 mg, K 656 mg, carotenes 4,170 μ g vitamin A 695 μ g RE, vitamin B1 0.13 mg, vitamin B2 0.28 mg, niacin 0.5 mg, vitamin C 42 mg, lutein 7,591 μ g, β -carotene 5,867 μ g, total carotenes 13,458 μ g, and total RE 978 μ g (Tee et al. 1997). Boxthorn (*L. chinense*) leaves contained fructose (0.58–1.54%), glucose (0.33–1.33%), sucrose (0.23–0.68%) and maltose (0.60–0.98%) (Kim et al. 1997d). Non-volatile organic acids

identified were citric acid (162.3–361.3 mg%), oxalic acid (61.1–130.9 mg%), malonic acid (44.9–59.4 mg%), malic acid (15.6–34.3 mg%), succinic acid (3.7–5.1 mg%), fumaric acid (1.3–2.9 mg%), and lactic acid (0.0–1.1 mg%). Eighteen free amino acids were found in the leaves and their contents varied greatly with season. Proline (52.6–267 mg%), histidine (162–244 mg%), alanine (99.5–198 mg%), leucine (51.4–149 mg%), valine (54.5–125 mg%), isoleucine (37.0–119 mg%) and aspartic acid (46.7–111 mg%) were major amino acids in the leaves. Total tannin contents were 0.90–2.10%, showing the highest amount in October. Forty-five volatile flavor components were identified in the leaves for the first time. These included four acids, 15 alcohols, seven aldehydes, two esters, three furans, nine hydrocarbons, two ionones, and three other compounds. Seasonal variation of vitamin C and rutin in the leaves were reported by Mizobuchi et al. (1969). Fu et al. (2011) reported the presence of mannitol, sucrose, glucose and fructose in the leaves. *L. chinense* leaf was found to contain 94.4 mg/kg of α -tocopherol (Ching and Mohamed 2001) and rutin (Aubert and Kapetanidis 1989). β -sitosterol- β -D-glucoside was isolated from *L. chinense* leaves (Imai et al. 1963).

Nitrogenous compounds nicotianamine (Noma and Noguchi 1976); hypoxanthine, and the nucleosides inosine, cytidine 5'-monophosphate and uridin-5'-monophosphate (Yoshimura et al. 1969) were reported in the leaves. Fresh leaf of *L. chinense* was reported to contain antioxidative components: 0.006–0.015% rutin, 10–17% chlorogenic acid, 0.95–1.5% quercetin-3-O-sophoroside, 0.12–0.18% kaempferol-3-O-sophoroside (Terauchi et al. 1997). Five flavonoids were identified in the leaves of *L. chinense* namely: 5,7,3-trihydroxy-6,4',5'-trimethoxy flavones (1), acacetin (2), acacetin-7-O- α -L-rhamnopyranosyl-(1-6)- β -D-glucopyranside (3), luteolin (4) and quercetin-3-O- α -L-rhamnopyranosyl-(1-6)- β -D-glucopyranside (5) (Zou 2000).

Four volatile flavor compounds from *L. chinense* leaves were identified as 3-hydroxy-7, 8-dihydro- β -ionone, 3-hydroxy-7, 8-dihydro- β -ionol, 3-hydroxy- β -ionone and 3-hydroxy- β -ionol (Sannai et al. 1984).

L. chinense leaves were found to contain scopoletin, vanillic acid (Hänsel and Huang 1977b); withanolides, lycium withanolide A (5 α ,20 α (R)-dihydroxy-6 α ,7 α -epoxy-1-oxo-5 α -witha-2,24-dienolide) and the 20-deoxy derivative (lycium withanolide B) (Hänsel et al. 1975; Hänsel and Huang 1977a). The leaves were found to contain acyclic diterpene glycosides: lyciumoside-I (0.034–0.33%), lyciumoside-II (0.008–0.36%), and lyciumoside-III (0.021–0.22%) (Terauchi et al. 1995). Six new acyclic diterpene glycosides, lyciumosides IV-IX were found in *L. chinense* leaves (Terauchi et al. 1998b).

The main polyphenols identified in *L. chinense* leaves were: rutin, chlorogenic acid, quercetin, kaempferol and apigenin-7-O-(6'-O-acetyl) glucose-rhamnose (Dong et al. 2012). Chlorogenic acid showed the highest average content of 78.36 g/kg. Rutin, quercetin and kaempferol were determined at low contents from 3.85 to 7.08 g/kg. Correlation coefficients between selenium and chlorogenic acid, chlorophyll a, chlorophyll b and carotenoids were: $R^2=0.963, 0.943, 0.957$ and 0.943 respectively. Selenium (0.01–0.05 g/kg) significantly increased chlorogenic acid, chlorophyll and carotenoids by 200–400% and reduced rutin by 400–900%.

Stem, Root Phytochemicals

Fresh stem of *L. chinense* was reported to contain antioxidative components: 0.003–0.011% rutin, 2.1–3.1 chlorogenic acid, 0.045–0.10% quercetin-3-O-sophoroside, <0.005–0.008% kaempferol-3-O-sophoroside while root bark was reported to contain 0.002–0.007% rutin, 0.06–0.18% chlorogenic acid, <0.005% quercetin-3-O-sophoroside, and <0.005% kaempferol-3-O-sophoroside (Terauchi et al. 1997).

Spermine alkaloids, kukoamine A (Funayama et al. 1980) and kukoamine B, were isolated from *L. chinense* root bark (Funayama et al. 1995). Four compounds isolated from *Lycium chinense* roots were identified as β -sitosterol, betaine hydrochloride, scopoletin and E-ferulic acid octacosyl ester (Zhou et al. 1996). Fourteen

calystegines, a cycloheptane bearing an amino group and three hydroxyl groups, and two polyhydroxylated piperidine alkaloids were isolated from *L. chinense* roots (Asano et al. 1997). Calystegines A7 and B5, in addition to the previously known calystegines A3, A5, A6, B1, B2, B3, B4, C1, C2 and N1, were isolated and determined as 1 α ,2 β , 4 α -trihydroxy-nortropane and 1 α ,2 α ,4 α ,7 α -tetrahydroxy-nortropane, respectively. Two polyhydroxytropans bearing a methyl group on the nitrogen atom were also found and established as N-methylcalystegines B2 and C1. 1 β -amino-3 β ,4 β ,5 α -trihydroxycycloheptane was also present and may be a biosynthetic precursor of the calystegines that occur in this plant. Two polyhydroxypiperidine alkaloids, fagomine and 6-deoxyfagomine, were also isolated. Morota et al. (1987) reported the isolation of the following from root bark: scopletin, auran-tiamide acetate, (S)-9-hydroxy-E-10,Z-12-octadecadienoic acid (α -dimorphecolic acid) and (S)-9-hydroxy-E-10,Z-12,Z-15-octadecatrienoic acid. Several compounds, betaine, linoleic acid, linolenic acid, melissic acid, β -sitosterol, cinnamic acid and kukoamine had been previously reported from the crude bark (Noguchi et al. 1985). They reported the isolation of a new dipeptide lyciumamide (Noguchi et al. 1984), sugiol and 5 α -stigmastane-3,6-dione from ti-ku-pi (Noguchi et al. 1985).

A new phenolic amide, dihydro-N-caffeoyltyramine (1) was isolated from *Lycium chinense* root bark along with known compounds, *trans*-N-caffeoyltyramine (2), *cis*-N-caffeoyltyramine (3), and lyoniresinol 3 α -O- β -D-glucopyranoside (4) (Han et al. 2002). A NBT superoxide scavenging assay revealed that three phenolic amides showed potent antioxidative activity. Wei and Liang (2002) isolated the coumarin scopoletin, and its glycosides scopolin and fabiatriin (7-O- β -xylopyranosyl-(1 $\rightarrow$ 6)- β -glucopyranosylscopoletin) from the roots and also five additional compounds: vanillic acid, apigenin, linarin, glucosyringic acid and digupigan A (Wei and Liang 2003). Chu et al. (2005) isolated the following from the roots: acacetin, scopoletin, kaempferol, *p*-coumaric acid, vanillic acid, luteolin and quercetin. Anthraquinones

namely physcion, emodin, 1,3,6-trihydroxy-2-methylantraquinone, and a glycoside were also isolated from the roots (Wei and Liang 2002; Li et al. 2004).

Four phenolic amides, dihydro-N-caffeoyltyramine, *trans*-N-feruloyloctopamine, *trans*-N-caffeoyltyramine, and *cis*-N-caffeoyltyramine were isolated from an ethyl acetate extract of *L. chinense* root bark (Lee et al. 2004b). (+)-lyoniresinol-3 α -O- β -D-glucopyranoside was isolated from an ethyl acetate extract of *L. chinense* root bark (Lee et al. 2005). Two new long-chain hydroxyalkyl ferulates, (E)-22-hydroxydocosyl 3-(4-hydroxy-3-methoxyphenyl)acrylate (lyciumol A, 1) and (E)-20-hydroxyeicosyl 3-(4-hydroxy-3-methoxyphenyl)acrylate (lyciumol B, 2), together with eight known compounds, were isolated from the root bark of *L. chinense* (Pan and Hou 2009).

Four cyclic peptides, lyciumins A–D (1–4), three acyclic diterpene glycosides, lyciumosides I–III (5–7) and other three compounds, a tryptophan derivative glycoside (8), a monoterpene glycoside (9) and a steroidal glycoside (10) were isolated from *Lycium chinense* roots (Yahara et al. 1993). Li et al. (2012) isolated a new furo-lactone-type lignan, lyciumin (1) from *L. chinense* root bark.

Antioxidant Activity

The extracts of *L. chinense* roots, aerial parts and fruit exhibited antioxidant effects in FeCl₂-ascorbic acid — induced lipid peroxidation in rat liver homogenates. Moreover, the free radical scavenger effect of *L. chinense* was demonstrated using electron spin resonance (ESR) and a spin-trapping technique (Lin et al. 1997).

Chung et al. (2011) found that different extracts from *L. chinense* fruits showed remarkable antioxidant activity and suggested one of the possible mechanisms was polyphenolic associated compounds (formation of non-extractable complex between high molecular weight phenolics and polysaccharides). These kinds of phenolic compounds showed antioxidant activity due to their redox properties, which played an important

role in absorbing and neutralizing free radicals, quenching singlet and triple oxygen or decomposing peroxide. They found that the different extracts exhibited remarkable free radical scavenging activities above 90%. Of the different extracts, butanol, ethyl acetate and methanol extract exhibited the highest activity of more than 90%. The DPPH activity of tocopherol showed higher degree of free radical-scavenging activity than that of the extracts at each concentration points. The reducing power of the different extracts of *Lycium* increased with increasing concentration from 25 to 500 µg. Reducing power of the *Lycium* extracts followed the order- ethyl acetate < water < butanol < methanol < hexane.

The flavonoid content in aqueous, and 50% ethanol extracts of *L. chinense* fruit were quite similar $1,154 \pm 89$ and $1,207 \pm 66$ mg/kg respectively, while 95% ethanol had higher content of 1,497 mg/kg (Qian et al. 2004). All extracts showed slow kinetics in DPPH antiradical reaction system. The antiradical efficiency of the extracts tended to become stronger as the polarity of the solvents decreased.

Hepatoprotective Activity

In-Vitro Studies

A CHCl₃: MeOH extract of *L. chinense* fruit exhibited significant protection against carbon tetrachloride-induced toxicity in primary cultures of rat hepatocytes (Kim et al. 1997c). Zeaxanthin and zeaxanthin dipalmitate were isolated as anti-hepatotoxic components. Incubation of injured hepatocytes with zeaxanthin dipalmitate reduced the levels of glutamic pyruvic transaminase (GPT) and sorbitol dehydrogenase (SDH) released from damaged cells to 60.5 and 76.3% of those released from untreated controls, respectively. Zeaxanthin also reduced the levels of GPT and SDH to 68.5 and 61.3% of the levels of those released from the untreated control. Zeaxanthin dipalmitate from *L. chinense* fruit showed a significant hepatoprotective activity against carbon tetrachloride toxicity in hepatic parenchymal and nonparenchymal cells in-vitro (Kim et al. 1997a). Cellular malondialdehyde (MDA) levels

declined significantly with zeaxanthin dipalmitate treatment in a concentration dependent fashion. Zeaxanthin dipalmitate significantly inhibited the uptake of [3 H]thymidine by Ito cells and also reduced collagen synthesis in Ito cells by 65.1% as compared to untreated controls. The formation of NO in either Kupffer cells or in peritoneal macrophages was significantly decreased by zeaxanthin dipalmitate in a concentration dependent manner. The authors concluded that zeaxanthin dipalmitate exerted a potent hepatoprotective activity by inhibiting Ito cell proliferation, collagen synthesis and by inhibiting certain biochemical functions of Kupffer cells. The cerebroside, 1-O-(β-D-glucopyranosyl)-(2S,3R,4E,8Z)-2-N-2'-hydroxy-(palmitoyl)-4,8-sphingadiene s purified from suspension cultures of *Lycium chinense* exhibited hepatoprotective activity comparable to that shown by silymarin (Jang et al. 1998). Two pyrrole compounds isolated from the fruit exhibited hepatoprotective effects comparable to silybin at the concentration of 0.1 µM (64.4 and 65.8%, respectively) (Chin et al. 2003).

Lycium fruit extract scavenged the DPPH free radicals, intracellular ROS, hydroxyl radicals, and superoxide (Zhang et al. 2010). *Lycium* fruit extract restored activities of catalase (CAT), superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) decreased by H₂O₂ and decreased DNA damage, lipid peroxidation and protein carbonyl values increased by H₂O₂ exposure. Furthermore, *Lycium* fruit extract increased the cell viability of Chang liver cells exposed to H₂O₂ via inhibition of apoptosis. The results demonstrated that *Lycium* extract protected Chang liver cells against oxidative stressed cell damage by H₂O₂ via scavenging ROS and enhancing antioxidant enzyme activity.

Two cerebroside isolated from *Lycium chinense* fruits were characterized as 1-O-β-D-glucopyranosyl-(2S, 3R,4E,8Z)-2-N-palmitoyloctadecasphinga-4,8-dienine, (LCC) and 1-O-β-D-glucopyranosyl -(2S,3R,4E,8Z)-2-N-(2'-hydroxypalmitoyl)octadecasphinga-4,8-dienine (Kim et al. 1997b). Incubation of CCl₄-intoxicated hepatocytes with both cerebroside, significantly reduced the levels of glutamic pyruvic transaminase (GPT) and sorbitol

dehydrogenase (SDH) released by injured cells. They found that the decreased activities of glutathione reductase and glutathione peroxidase in CCl₄-injured rat hepatocytes were significantly enhanced by the treatment of LCC (Kim et al. 1999). Additionally, the elevated levels of MDA in CCl₄-injured rat hepatocytes were reduced after treatment with LCC in a concentration dependent manner over a range of 1–10 μ M. The results suggested that LCC may preserve the hepatic mitochondrial level of GSH by scavenging reactive oxygen species produced during CCl₄-induced toxicity and thereby reduce lipid peroxidation and cellular damage. They also found that treatment of galactosamine-injured primary hepatocyte cultures with LCC markedly suppressed the release of both GPT and SDH in a dose-dependent manner over concentrations of LCC ranging from 1 to 10 μ M (Kim et al. 2000). Also, LCC significantly restored the decreased incorporation of [(3)H]-uridine into RNA in a dose-dependent manner and prevented the suppression of RNA synthesis caused by actinomycin D in a dose-dependent manner. The results further confirmed the prominent hepatoprotective activity of LCC cerebroside.

In-Vivo Animal Studies

L. chinense fresh fruit extracts exhibited hepatoprotective in CCl₄-administered rats (Kang et al. 2006). The extract decreased the elevated plasma glutamic oxalacetic transaminase (GOT), glutamic pyruvic transaminase (GPT), and lactate dehydrogenase (LDH) activities, malondialdehyde (MDA) level and lipid peroxidation induced by CCl₄.

Treatment of hepatic fibrosis rats (induced by bile duct ligation/scission (BDL)) with zeaxanthin dipalmitate (ZD) at a dose of 25 mg/kg body weight significantly reduced the activities of serum aspartate transaminase and alkaline phosphatase (Kim et al. 2002). Further, collagen deposition was significantly reduced in BDL rats administered ZD at the dose of 25 mg/kg body weight. Additionally, the levels of thiobarbituric acid-reactive substances and 4-hydroxyproline were reduced when BDL rats received ZD at the dose of 25 mg/kg body weight. The results

showed that ZD effectively inhibited hepatic fibrosis in BDL rats, at least in part via its anti-oxidative activity. Pre-treatment of rats with *L. chinense* fruit protected rats against carbon tetrachloride-induced hepatotoxicity (Ha et al. 2005). *Lycium* prevented the elevation of hepatic malondialdehyde (MDA) formation and the depletion of reduced glutathione (GSH) content and catalase activity in the liver of CCl₄-injected rats. *Lycium* also displayed hydroxide radical scavenging activity in a dose-dependent manner (IC₅₀ = 83.6 μ g/mL). The expression level of cytochrome P450 2E1 (CYP2E1) mRNA and protein, was significantly decreased in the liver of *Lycium*-pretreated rats when compared with that in the liver of control group.

Hypotensive Activity

The spearmin alkaloid, kukoamine A, isolated from *L. chinense* root bark, was shown to produce hypotension in rats at a dose of 0.5 g/kg i.v. (Funayama et al. 1980). Schmidt and Stabler (1992) reported that cyclopeptides lyciumins A and B to be inhibitors of ACE (angiotensin converting enzyme) and renin activities. These octapeptides were isolated from the roots (Yahara et al. 1989). Morita et al. (1996) also reported that lyciumin A exhibited inhibitory activity on angiotensin-converting enzyme.

Root bark extract of *L. chinense* showed an inhibitory activity on angiotensin I converting enzyme (ACE) (Morota et al. 1987). Two active principles were isolated and identified as (S)-9-hydroxy-E-10,Z-12-octadecadienoic acid (α -dimorphecolic acid) and (S)-9-hydroxy-E-10,Z-12,Z-15-octadecatrienoic acid. An unidentified angiotensin converting enzyme (ACE) inhibitory substance was isolated and purified from crude extract of *Lycium chinense* (Lee and Song 2004).

Antiinflammatory Activity

The extracts of *L. chinense* roots, aerial parts and fruit showed antiinflammatory activity against

carrageenan induced rat paw edema and CCl_4 -induced liver injury (Lin et al. 1997). Treatment of macrophages with dihydro-N-caffeoyltyramine (DHCT), isolated from *L. chinense* root bark, suppressed phorbol 12-myristate 13-acetate (PMA)-mediated induction of COX-2 mRNA and protein (Han et al. 2010). PMA-inducible production of PGE2 was inhibited by DHCT in a dose-dependent manner via CCAAT (cytidine-cytidine-adenosine-adenosine-thymidine)/enhancer-binding protein (C/EBP) and activator protein 1 (AP-1). DHCT reduced PMA-induced C/EBP β protein expression and c-jun/c-fos gene and protein expression. Moreover, DHCT significantly inhibited PMA-induced activation of the mitogen activated protein (MAP) kinases (ERK and JNK). The results suggested DHCT to be an effective antiinflammatory agent to attenuate COX-2 production mediated by the transcription factors C/EBP and AP-1.

Antiallergic Activity

The ethylacetate (EtOAc) layer of the hot water *L. chinense* fruit extract exhibited an inhibitory effect on β -hexosaminidase (β -hexo) release from IgE sensitized BSA stimulated rat basophilic leukemia (RBL-2 H3) at the antigen antibody binding stage (Yamada et al. 2011). The water (H_2O) fraction (EFW) of the chloroform (CHCl_3) extract from the EtOAc layer also inhibited β -hexo release at the same stage in a dose-dependent manner. The active component was determined to be 5-(hydroxymethyl)furfural (5-HMF). In addition, 5-HMF suppressed $[\text{Ca}^{2+}]$ I influx in the IgE-sensitized BSA-stimulated RBL-2 H₃ cells. The results suggested that 5-HMF may be useful for the treatment or prevention of type I allergic diseases.

Expectorant Activity

In-vitro studies using cultured hamster tracheal surface epithelial cells showed that betaine (from *L. chinense* fruit) increased mucin release by directly acting on airway mucin-secreting cells

suggesting its potential use as mild expectorant during the treatment of chronic airway diseases (Lee et al. 2004a).

Radioprotective Activity

Based on the studies of endogenous hematopoietic spleen colony formation (CFUs), and the post-irradiation behavior of hematograms and hematocrits, it was demonstrated that the *L. chinense* root extract protected mice more effectively when given in a dose of 500 mg/kg (Hsu et al. 1999). Enhanced CFUs were found in the irradiation range of 4–8 Gy by various treatments. Recovery of leukocyte, erythrocyte and thrombocyte counts was significantly stimulated by the root extract with 500 mg/kg administration. Stimulated recovery by the extract from the root extract was also noted in hematocrit. In contrast, the extracts of both aerial parts and roots did not markedly affect recovery of leukocyte, erythrocyte, thrombocyte counts and hematocrits at 250 mg/kg administration.

Neuroprotective Activity

Studies demonstrated that *L. chinense* fruit had a protective effect against trimethyltin (TMT)-induced neuronal and cognitive impairments in rats (Park et al. 2011). Rats with TMT injection showed impaired learning and memory of the tasks and treatment with LCF produced a significant improvement in escape latency to find the platform in the Morris water maze. Treatment with *Lycium* fruit also slightly reduced the loss of choline acetyltransferase and cyclic adenosine monophosphate (cAMP) in the hippocampus compared to the control group.

A traditional herbal prescription, Kyung-Ok-Ko, composed of *Rehmannia glutinosa* var. *purpurea*, *Panax ginseng*, *Poria cocos*, *Lycium chinense*, *Aquillaria agallocha* and honey, and used to treat age-related symptoms, such as amnesia or dementia, was found to have neuroprotective activity (Cai et al. 2011). Administration of the herbal preparation after reperfusion to

gerbils with transient cerebral global ischemia significantly attenuated the ischemia-induced cognitive impairments observed in the Y-maze and novel object recognition tasks. Histochemical studies showed that the herbal preparation increased the number of viable neuronal cells and decreased the number of degenerated neuronal cells. The herbal mixture administration attenuated the ischemia-induced activation of microglia and astrocytes and the increase of cytokine IL-1 β .

Antiobesity/Hypolipidemic Activity

The body weight gain of rats given a high fat diet and 10% *L. chinense* leaf powder (FLP10) was significantly lower than that of the control high fat diet group (Kang et al. 2010). Also, the obesity index of the *L. chinense* leaf powder with a high-fat diet (FLP5), and FLP10 group was significantly lower than that of the control group. Serum triglyceride and low-density lipoprotein (LDL)-cholesterol levels in the FLP5 group were significantly lower than those of the control group. The intake of *L. chinense* leaf powder did not seem to significantly affect the levels of serum homocysteine, leptin, and ghrelin compared to the control group without *L. chinense* leaf powder intake. The glutathione content in the liver was significantly higher in the FLP5 group than in the normal diet group, but the glutathione S-transferase activity was significantly lower than in the high fat control group. The thiobarbituric acid-reactive substances levels in the liver and kidney were relatively lower in the FLP5 and FLP10 groups than in the normal diet group. The results suggested intake of *L. chinense* leaf powder in obese rats resulted in a lowering of body weight and levels of serum triglyceride and LDL-cholesterol via antioxidative effects.

Antimicrobial Activity

The methanol extract of *L. chinense* was found to have antimicrobial activity against *Helicobacter pylori* and one of the active compounds was

identified as lyciumoside I (Terauchi et al. 1998a). Four phenolic amides, dihydro-N-caffeoyltyramine (1), *trans*-N-feruloyloctopamine (2), *trans*-N-caffeoyltyramine (3), and *cis*-N-caffeoyltyramine (4), isolated from an ethyl acetate extract of *L. chinense* root bark exhibited antifungal activity (Lee et al. 2004b). Compounds 1–3 were potent at 5–10 μ g/mL and were without hemolytic activity against human erythrocyte cells. Compound 4 was active at 40 μ g/mL. All four compounds impeded the dimorphic transition of pathogen, *Candida albicans*. (+)-lyoniresinol-3 α -O- β -D-glucopyranoside isolated from *L. chinense* root bark exhibited potent antimicrobial activity against antibiotic-resistant bacterial strains, methicillin-resistant *Staphylococcus aureus* (MRSA) isolated from patients, and human pathogenic fungi without having any hemolytic effect on human erythrocytes (Lee et al. 2005). The compound induced the accumulation of intracellular trehalose on *Candida albicans* as stress response to the drug, and disrupted the dimorphic transition that forms pseudo-hyphae caused by the pathogenesis.

Antidiabetic Activity

Alloxan-diabetic mice administered *L. chinense* root (LCR) extract daily for 28 days, registered significant decreases of fasting blood glucose (FBG), total cholesterol (TC) and triglycerides (TG) (Gao et al. 2007). The rates of decreasing blood glucose were 36.72% (LCR 100 mg/kg) and 41.89% (LCR 200 mg/kg). LCR also improved body weight gain of diabetic mice. The results suggested that Cortex Lycii Radicis had hypoglycemic potential and could be useful in diabetes therapy.

Anti-fatigue Activity

The results of in-vivo studies showed that feeding mice with *L. chinense* fruit (gou qi zi) extracts significantly increased the survival time of mice under the condition of limited oxygen supply in sealed containers and the swimming time of mice

(Xu 2002). The results suggested that *Lycium* fruit could effectively increase the endurance of mice under hypoxia and fatigue.

Fertility Enhancement Activity

In animal fertility studies, Hojyo (1971) found that *L. chinense* leaf extracts increased luteinizing hormone (LH) activity in rats and rabbits. Suzuki et al. (1972) reported that intravenous injection of *L. chinense* leaf water extract induced ovulation in the adult female rabbit but the active principle still needs to be investigated.

Probiotic Activity

Nishiyama (1965) first demonstrated the growth stimulating effects of *L. chinense* leaves on *Lactobacillus acidophilus* cells, the most commonly used probiotic in today's food industry. In subsequent studies, Nishiyama and Kaya (1969a) reported the growth stimulating effect of *L. chinense* aqueous leaf extract on lactic acid bacteria and identified a high concentration of a suite of amino acids in the extract. However, in a further study, they found that addition of a mixture of 22 amino acids to the growth medium for lactic acid bacteria resulted in no significant growth stimulating effect despite a marked increase in acid production (Nishiyama and Kaya 1969b).

Leaf hydrolysates from *L. chinense* leaves were found to have notable growth stimulating effect on the probiotic bacterium *Pediococcus acidilactici* in MRS both culture (Yeh et al. 2008).

Beta-Glucosidase and Alpha-Galactosidase Inhibitory Activity

Calystegine B2 (from *L. chinense* roots) was found to be a potent competitive inhibitor of almond β -glucosidase ($K_i=1.9 \mu\text{M}$) and coffee bean α -galactosidase ($K_i=0.86 \mu\text{M}$), while N-methylcalystegine B2 was a more potent competitive inhibitor of the latter enzyme

($K_i=0.47 \mu\text{M}$) than the parent compound but showed a marked lack of inhibitory activities towards most other glycosidases (Asano et al. 1997). This compound being a very specific inhibitor of α -galactosidase and inhibited rat liver lysosomal α -galactosidase with a K_i of $1.8 \mu\text{M}$, may provide a useful experimental model for the lysosomal storage disorder, Fabry's disease. The addition of a hydroxyl group at C6exo, as in calystegines B1 and C1, enhanced the inhibitory potential towards β -glucosidase and β -galactosidase but markedly lowered or abolished inhibition towards α -galactosidase. Hence, the N-methylation of calystegine C1 did not enhance its inhibition of α -galactosidase. The chemical N-methylation of calystegines A3 and B4 markedly enhanced inhibition of coffee bean α -galactosidase, with K_i values of 5.2 and $36 \mu\text{M}$, respectively, but almost eliminated their inhibitory potential towards β -glucosidase and trehalase, respectively.

Traditional Medicine Uses

The fruit and root bark and less so the leaf of both *Lycium barbarum* and *L. chinense*, are widely used in traditional medicine in China, Korea, Japan and Vietnam for more than 2000 years ago (Duke and Ayensu 1985; Yeung 1985; Yahara et al. 1993; Chevallier 1996; National Institute of Materia Medica 1999; Burke et al. 2005; Peng et al. 2005; Potterat 2010). Both the berries and the root are considered to promote good health and longevity, tonifying the liver and kidneys, moistening the lungs, nourishing the blood and enriching yin. *L. chinense* has been used especially in traditional medicine for its emmenagogue, diuretic, antipyretic, hepatoprotective effects and reducing the risk of certain disease as arteriosclerosis, essential arterial hypertension, diabetes and night blindness. The leaves have been used as tea in the orient for more than 2000 years due primarily to the stamina-improving, tranquillizing, and thirst-quenching activities (Kim et al. 1997d; Yeh et al. 2008); as an energy restoring tonic drink; as a digestive aid for persons

with insufficient production of acid in the stomach, as the leaves contain anti-aging vitamins ascorbic acid and tocopherols (Park et al. 1997), and antioxidative compounds. The leaves are also used as a tonic to reduce the risk of arteriosclerosis and essential arterial hypertension (Mizobuchi et al. 1969). Goji berries are used as energy restoring tonic, to cure a wide range of ailments from skin rashes and to treat and prevent diseases such as insomnia, nocturnal emissions, fatigue, liver dysfunction, exhaustive coughing, dry cough, debility, abdominal pain, aching back and limbs, arteriosclerosis, arterial hypertension, hypotension, headache, aging, nightblindness and eyesight problems to diabetes mellitus, high blood pressure, vertigo, lumbago, cancer, infertility, impotence and menopausal complaints (Wee and Keng 1990; Yahara et al. 1993; Kim et al. 1997d; Zhang et al. 2010; Lee et al. 2008; Bunghez et al. 2012). The seed is used as a haemostat for the control of bleeding, acting on the kidneys and sex organs (aphrodisiac) and a remedy for various skin rashes and eyesight problems (Duke and Ayensu 1985). The roots are used as an antifebrile, antibacterial, antipyretic, antirheumatic, cooling agent and tonic; and to treat consumptive fever (cough and asthma), fever, pneumonia, night sweats, hypertension, oedema, tuberculosis, haemorrhagic inflammation, bloody stranguria, ulcers, diabetes mellitus, back ache, vertigo, pneumonia, sore-throat, rheumatism, hemoptysis and hematuria (Yeung 1985; Noguchi et al. 1985; Wee and Keng 1990; Pan and Hou 2009; Potterat 2010).

Other Uses

The plant is used as ornamental and often as a bonsai plant and also for hedging. The species is also grown for controlling erosion. The seed oil is used as a lubricant and for cooking.

Na et al. (1997) reported that *L. chinense* leaves increased the amino acids content of broiler meat while improving its flavour, taste, and tenderness, indicating their potential application as feed supplement.

Comments

The trade names for wolfberries “Himalayan Goji berry” and “Tibetan Goji Berry” that are being used to market the fruit in the global health food market are very misleading and a misnomer as the products are not cultivated on any commercial scale in the Himalayas or Tibet and is actually sourced from Inner Mongolia, Ningxia and the Tian Shan mountains of western Xinjiang, China.

Selected References

- Asano N, Kato A, Miyauchi M, Kizu H, Tomimori T, Matsui K, Nash RJ, Molyneux RJ (1997) Specific alpha-galactosidase inhibitors, N-methylcalystegines–structure/activity relationships of calystegines from *Lycium chinense*. *Eur J Biochem* 248(2):296–303
- Aubert C, Kapetanidis I (1989) New flavonoids from *Lycium chinense*. *Planta Med* 55:612
- Backer CA, Bakhuizen van den Brink RC Jr (1965) *Flora of Java (Spermatophytes only)*, vol 2. Wolters-Noordhoff, Groningen, 641 pp
- Bunghez IR, Marius AS, Marian N, Gerogeta R, Rodica-Mariana I (2012) Obtaining of carotenoid extract from *Lycium chinense* and characterization using spectrometric analysis. *Digest J Nanomat Biometr* 7(2):523–528
- Burke DS, Smidt CR, Vuong LT (2005) *Momordica cochinchinensis*, *Rosa roxburghii*, wolfberry, and sea buckthorn – highly nutritional fruits supported by tradition and science. *Curr Top Nutraceut Res* 3(4):259–266
- Cai M, Shin BY, Kim DH, Kim JM, Park SJ, Park CS, Won do H, Hong ND, Kang DH, Yutaka Y, Yutaka Y, Ryu JH (2011) Neuroprotective effects of a traditional herbal prescription on transient cerebral global ischemia in gerbils. *J Ethnopharmacol* 138(3):723–730
- Chevallier A (1996) *The encyclopedia of medicinal plants*. Dorling Kindersley, London, 336 pp
- Chin YW, Lim SW, Kim SH, Shin DY, Suh YG, Kim YB, Kim YC, Kim J (2003) Hepatoprotective pyrrole derivatives of *Lycium chinense* fruits. *Bioorg Med Chem Lett* 13(1):79–81
- Ching LS, Mohamed S (2001) Alpha-tocopherol content in 62 edible tropical plants. *J Agric Food Chem* 49(6):3101–3105
- Chu Q, Fu L, Lin M, Ye J (2005) Study on bioactive ingredients in Cortex lycii by capillary zone electrophoresis with amperometric detector. *Fenxi Huaxue (Chinese J Anal Chem)* 33:1611–1614
- Chung IM, Nagella P, Ahn YS, Kim SJ, Ahmad A (2011) Composition of the essential oil and petroleum ether

- extract of *Lycium chinense* Miller fruits and antioxidant activity of its several extracts. *J Med Plant Res* 5(25):5973–5981
- Dong JZ, Wang Y, Wang SH, Yin LP, Xu GJ, Zheng C, Lei C, Zhang MZ (2012) Selenium increases chlorogenic acid, chlorophyll and carotenoids of *Lycium chinense* leaves. *J Sci Food Agric*. doi:10.1002/jsfa.5758
- Duke JA, Ayensu ES (1985) Medicinal plants of China, vol 1 & 2. Reference Publications, Inc, Algonac, 705 pp
- Fu Y, Zhang L, Chen G (2011) Determination of carbohydrates in *Folium Lycium chinensis* using capillary electrophoresis combined with far-infrared light irradiation-assisted extraction. *J Sep Sci* 34:3272–3278
- Funayama S, Yoshida SK, Konno C, Hikino H (1980) Structure of kukoamine A, a hypotensive principle of *Lycium chinense* root barks. *Tetrahedron Lett* 21:1355–1356
- Funayama S, Zhang GR, Nozoe S (1995) Kukoamine B, a spermine alkaloid from *Lycium chinense*. *Phytochemistry* 38(6):1529–1531
- Gao DW, Liu ZW, Liu ZH, Li Y, Li QW (2007) Hypoglycemic effect of Cortex Lycii Radieis extract and its analysis of compounds. *J Yanshan Univ* 3:269–272 (In Chinese)
- Ha KT, Yoon SJ, Choi DY, Kim DW, Kim JK, Kim CH (2005) Protective effect of *Lycium chinense* fruit on carbon tetrachloride-induced hepatotoxicity. *J Ethnopharmacol* 96(3):529–535
- Han SH, Lee HH, Lee IS, Moon YH, Woo ER (2002) A new phenolic amide from *Lycium chinense* Miller. *Arch Pharm Res* 25(4):433–437
- Han EH, Kim JY, Kim HG, Choi JH, Im JH, Woo ER, Jeong HG (2010) Dihydro-N-caffeoyltyramine down-regulates cyclooxygenase-2 expression by inhibiting the activities of C/EBP and AP-1 transcription factors. *Food Chem Toxicol* 48(2):579–586
- Hänsel R, Huang JT (1977a) *Lycium chinense*, II: a semi-quantitative assay of the withanolides. *Arch Pharm (Weinheim)* 310(1):35–38 (In German)
- Hänsel R, Huang JT (1977b) *Lycium chinense*, III: isolation of scopoletin and vanillic acid. *Arch Pharm (Weinheim)* 310(1):38–40 (In German)
- Hänsel R, Huang JT, Rosenberg D (1975) Two withanolides from *Lycium chinense*. *Arch Pharm (Weinheim)* 308(8):653–654 (In German)
- Herklots GAC (1947) Vegetable cultivation in Hong Kong. South China Morning Post, Hong Kong, 208 pp
- Hojyo T (1971) Studies of chemical ovulating agents on luteinizing hormone secretion with special reference to clomid F-6066 and plant extract. *Acta Obstet Gyn Jpn* 18(1):51
- Hsu HY, Yang JJ, Ho YH, Lin CC (1999) Difference in the effects of radioprotection between aerial and root parts of *Lycium chinense*. *J Ethnopharmacol* 64(2):101–108
- Imai S, Murata T, Fujioka S, Goto M (1963) Isolation of beta-sitosterol-beta-D-glucoside from the leaves of *Lycium chinense* Mill. *Yakugaku Zasshi* 83:1092 (In Japanese)
- Itoh T, Tamura T, Matsumoto T (1977a) 4-desmethylsterols in the seeds of Solanaceae. *Steroids* 30:425–433
- Itoh T, Tamura T, Matsumoto T (1977b) Triterpene alcohols in the seeds of Solanaceae. *Phytochemistry* 16:1723–1726
- Itoh T, Ishi T, Tamura T, Matsumoto T (1978) Four new and other 4 α -methylsterols in the seeds of Solanaceae. *Phytochemistry* 17:971–977
- Jang YP, Lee YJ, Kim YC, Huh H (1998) Production of a hepatoprotective cerebroside from suspension cultures of *Lycium chinense*. *Plant Cell Rep* 18(3–4):252–254
- Jeon WS, Kim ER, Chin YW, Kim J (2011) A new pyrrole constituent from the fruits of *Lycium chinense*. *Nat Prod Sci* 17:181–182
- Jung K, Chin YW, Kim YC, Kim J (2005) Potentially hepatoprotective glycolipid constituents of *Lycium chinense* fruits. *Arch Pharm Res* 28(12):1381–1385
- Jung WS, Chung IM, Ali M, Ahmad A (2012) New steroidal glycoside ester and aliphatic acid from the fruits of *Lycium chinense*. *J Asian Nat Prod Res* 14(4):301–307
- Kang KI, Jung JY, Koh KH, Lee CH (2006) Hepatoprotective effects of *Lycium chinense* Mill fruit extracts and fresh fruit juice. *Korean J Food Sci Technol* 38(1):99–103 (In Korean)
- Kang MH, Park WJ, Choi MK (2010) Anti-obesity and hypolipidemic effects of *Lycium chinense* leaf powder in obese rats. *J Med Food* 13(4):801–807
- Kim JS, Chung HY (2009) GC-MS analysis of the volatile components in dried boxthorn (*Lycium chinensis*) fruit. *J Korean Soc Appl Biol Chem* 52(5):516–524
- Kim HP, Kim SY, Lee EJ, Kim YC, Kim YC (1997a) Zeaxanthin dipalmitate from *Lycium chinense* has hepatoprotective activity. *Res Commun Mol Pathol Pharmacol* 97(3):301–314
- Kim SY, Choi YH, Huh H, Kim J, Kim YC, Lee HS (1997b) New antihepatotoxic cerebroside from *Lycium chinense* fruits. *J Nat Prod* 60(3):274–276
- Kim SY, Kim PY, Huh H, Kim YC (1997c) Antihepatotoxic zeaxanthins from the fruit of *Lycium chinense*. *Arch Pharm Res* 20(6):529–532
- Kim SY, Lee KH, Chang KS, Bock JY, Jung MY (1997d) Taste and flavor compounds in box thorn (*Lycium chinense* Miller) leaves. *Food Chem* 58(4):297–303
- Kim SY, Lee EJ, Kim HP, Kim YC, Moon A, Kim YC (1999) A novel cerebroside from lycii fructus preserves the hepatic glutathione redox system in primary cultures of rat hepatocytes. *Biol Pharm Bull* 22(8):873–875
- Kim SY, Lee EJ, Kim HP, Lee HS, Kim YC (2000) LCC, a cerebroside from *Lycium chinense*, protects primary cultured rat hepatocytes exposed to galactosamine. *Phytother Res* 14(6):448–451
- Kim HP, Lee EJ, Kim YC, Kim J, Kim HK, Park JH, Kim SY, Kim YC (2002) Zeaxanthin dipalmitate from *Lycium chinense* fruit reduces experimentally induced hepatic fibrosis in rats. *Biol Pharm Bull* 25(3):390–392
- Kim EH, Kim HW, Kim SD, Lee BH, Lee CH, Koh KH (2005a) Free radicals scavenging activity of bulro kugi (*Lycium chinense* Mill) fruit, leaf and root. *Korean J Food Sci Technol* 37(1):6–10

- Kim EH, Kim HW, Lee CJ, Lee CH, Koh KH (2005b) Analysis of chemical composition of bulro kugi (*Lycium chinense* Mill) fruit, leaf, and root. Korean J Food Sci Technol 37(2):154–163 (In Korean)
- Lee S, Song KB (2004) Isolation of an angiotensin converting enzyme inhibitory substance from *Lycium chinense* Miller. J Food Sci Nutr 9:95–97
- Lee CJ, Lee JH, Seok JH, Hur GM, Park Js J, Bae S, Lim JH, Park YC (2004a) Effects of betaine, coumarin and flavonoids on mucin release from cultured hamster tracheal surface epithelial cells. Phytother Res 18(4):301–305
- Lee DG, Park Y, Kim MR, Jung HJ, Seu YB, Hahm KS, Woo ER (2004b) Anti-fungal effects of phenolic amides isolated from the root bark of *Lycium chinense*. Biotechnol Lett 26(14):1125–1130
- Lee DG, Jung HJ, Woo ER (2005) Antimicrobial property of (+)-lyoniresinol-3 α -D-glucopyranoside isolated from the root bark of *Lycium chinense* Miller against human pathogenic microorganisms. Arch Pharm Res 28(9):1031–1036
- Lee GH, Shin Y, Oh MJ (2008) Aroma active components of *Lycii fructus* (kukija). J Food Sci 73(6):500–505
- Li Z, Peng G, Zhang S (1998) Separation and determination of carotenoids in *Fructus lycii* by isocratic non-aqueous reversed-phase liquid chromatography. Se Pu 16(4):341–343 (In Chinese)
- Li Y, Li P, Tu P, Chang H (2004) Identification of chemical constituents of *Lycium chinense*. Zhongcaoyao 35:1100–1101
- Li XN, Chu C, Tong SQ, Cheng DP, Yan JZ (2012) A new furoactone-type lignan from *Lycium chinense*. Nat Prod Res DOI:10.1080/14786419.2012.698408
- Lin CC, Chuang SC, Lin JM, Yang JJ (1997) Evaluation of the anti-inflammatory hepatoprotective and antioxidant activities of *Lycium chinense* from Taiwan. Phytomedicine 4(3):213–220
- Mizobuchi K, Taniuchi T, Kata T, Masaue H, Kimura K, Higashi J (1969) Studies on kuko. Part 6, Seasonal variation of vitamin C and rutin contents in *Lycium chinense* leaves. Tokushima Daigaku Yakugaku Kenkyu Nempo 18:27–30
- Morita H, Yoshida N, Takeya K, Itokawa H, Shiota O (1996) Configurational and conformational analyses of a cyclic octapeptide, lyciumin A, from *Lycium chinense* Mill. Tetrahedron 52(8):2795–2802
- Morota T, Sasaki H, Chin M, Sato T, Katayama N, Fukuyama K, Mitsuhashi H (1987) Studies on the crude drug containing the angiotensin I-converting enzyme inhibitors (I). The active principles of *Lycium chinense* Miller. Shoyakugaku Zasshi 41:169–173
- Na JC, Kim HK, Sang BD, Oh HK, Chung HK, Lee SJ, Chae HS, Cho IS (1997) The effects of *Lycium chinense* Mill Leaves (LCML) supplementation on the performance of broiler. RDA J Livest Sci 39(2):44–48
- National Institute of Materia Medica (1999) Selected medicinal plants in Vietnam, vol 2. Science and Technology Publishing House, Hanoi, 460 pp
- Nishiyama R (1965) Studies on components of Kuko (*Lycium chinense* Miller). Part III. Growth effect for lactic acid bacteria by the components of Kuko (*Lycium chinense* Miller). J Agric Chem Soc Jpn 12(8):313–319
- Nishiyama R, Kaya T (1969a) Studies on components of Kuko (*Lycium chinensis* Miller). Part IV. Substances in aqueous extract of Kuko leaves effective in stimulating the growth of lactic acid bacteria (1). J Agric Chem Soc Jpn 43(4):197–201
- Nishiyama R, Kaya T (1969b) Studies on components of Kuko (*Lycium chinensis* Miller). Part V. Substances in aqueous extract of Kuko leaves effective in stimulating the growth of lactic acid bacteria (2). J Agric Chem Soc Jpn 43(4):202–210
- Noculak-Palczewska A, Matkowski A, Gasiorowski K, Tabaka H, Oszmianski J, Lamer-Zarawska E (2004) Chemical characterisation of methanolic-water extracts from the fruit of acclimated *Lycium chinense* Mill. Herba Pol 50:47–53
- Noguchi M, Mochida K, Shingu T, Kozuka M, Fujitani K (1984) The constituents of the Chinese drug “ti-ku-pi”. I. Isolation and constitution of lyciumamide, a new dipeptide. Chem Pharm Bull(Tokyo) 32(9):3584–3587 (In German)
- Noguchi M, Mochida K, Shingu T, Fujitani K, Kozuka M (1985) Sugiol and 5 α -stigmastane-3,6-dione from the Chinese drug “Ti-ku-pi” (*Lycii Radicis Cortex*). J Nat Prod 48:342–343
- Noma M, Noguchi M (1976) Occurrence of nicotianamine in higher plants. Phytochemistry 15:1701–1702
- Ochse JJ, Bakhuizen van den Brink RC (1980) Vegetables of the Dutch Indies, 3rd edn. Ascher & Co, Amsterdam, 1016 pp
- Paisooksantivatana Y (1993) *Lycium chinense* Miller. In: Siemonsma JB, Piluek K (eds) Plant resources of south-east Asia no 8: vegetables. Pudoc, Wageningen, pp 197–199
- Pan S, Hou AJ (2009) New long-chain hydroxyalkyl ferulates from the root bark of *Lycium chinense* Mill. J Asian Nat Prod Res 11(7):681–685
- Park WJ, Bock JY, Baik SO, Han SB, Ju HK (1997) Volatile components of *Lycium chinense* Miller. Korean Soc Foods Nutr 10:1–5
- Park HJ, Shim HS, Choi WK, Kim KS, Shim I (2011) Neuroprotective effect of *Lycium chinense* fruit on trimethyltin-induced learning and memory deficits in the rats. Exp Neurobiol 20(3):137–143
- Peng Y, Ma C, Li Y, Leung KS, Jiang ZH, Zhao Z (2005) Quantification of zeaxanthin dipalmitate and total carotenoids in *Lycium* fruits (*Fructus Lycii*). Plant Food Hum Nutr 60(4):161–164
- Porcher MH et al (1995–2020) Searchable world wide web multilingual multiscript plant name database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Potterat O (2010) Goji (*Lycium barbarum* and *L. chinense*): phytochemistry, pharmacology and safety in the perspective of traditional uses and recent popularity. Planta Med 76(1):7–19

- Qian JY, Liu D, Huang AG (2004) The efficiency of flavonoids in polar extracts of *Lycium chinense* Mill fruits as free radical scavenger. *Food Chem* 87(2):283–288
- Qin X, Lin H (2003) Isolation and characteristics of arabin isolated from fruit of *Lycium chinense* Mill. *Shipin Kexue* 24:52–56 (In Chinese)
- Qin X, Yamauchi R, Aizawa K, Inakuma T, Kato K (2000) Isolation and characterization of arabinogalactan-protein from the fruit of *Lycium chinense* Mill. *J Appl Glycosci* 47(2):155–161
- Qin X, Yamauchi R, Aizawa K, Inakuma T, Kato K (2001) Structural features of arabinogalactan-proteins from the fruit of *Lycium chinense* Mill. *Carbohydr Res* 333(1):79–85
- Sannai S, Fujimori T, Katō K (1980) Isolation of (–)-1,2-dehydro- α -cyperone and solavetivone from *Lycium chinense*. *Phytochemistry* 21(12):2986–2987
- Sannai A, Fujimori T, Kato K (1983) Neutral volatile components of kukoshi (*Lycium chinense* M.). *Agric Biol Chem* 47(10):2397–2399
- Sannai A, Fujimori T, Uegaki R, Akaki T (1984) Isolation of 3-hydroxy-7 8-dehydro-beta-ionone from *Lycium chinense*. *Agric Biol Chem* 48:1629–1630
- Schmidt U, Stäbler F (1992) The cyclopeptides lyciumins A and B have been prepared; these compounds are the total synthesis of lyciumins A and B. *J Chem Soc Chem Commun* 1992:1353–1354
- Shin YG, Cho KH, Kim JM, Park MK, Park JH (1999) Determination of betaine in *Lycium chinense* fruits by liquid chromatography-electrospray ionization mass spectrometry. *J Chromatogr A* 857(1–2):331–335
- Suzuki M, Osawa S, Hirano M (1972) A *Lycium chinense* Miller component inducing ovulation in adult female rabbits. *Tohoku J Exp Med* 106(3):219–231
- Tee ES, Noor MI, Azudin MN, Idris K (1997) Nutrient composition of Malaysian foods, 4th edn. Institute for Medical Research, Kuala Lumpur, pp 299
- Terauchi M, Kanamori H, Nobuso M, Sakamoto I, Yahara S, Nohara T, Kohda H (1995) Analysis of acyclic diterpene glycosides in lycii folium. *Nat Med* 49(2):133–136
- Terauchi M, Kanamori H, Nobuso M, Yahara S, Nohara T (1997) Detection and determination of antioxidative components in *Lycium chinense*. *Nat Med* 51(5):387–391
- Terauchi M, Kanamori H, Nobuso M, Fukuda S, Yahara S, Yamasaki K (1998a) Antimicrobial components in leaves of *Lycium chinense* Mill. *J Food Hyg Soc Japan* 39(6):399–405
- Terauchi M, Kanamori H, Nobuso M, Yahara S, Yamasaki K (1998b) New acyclic diterpene glycosides, lyciumosides IV–IX from *Lycium chinense* Mill. *Nat Med* 52:167–171
- Wee YC, Keng H (1990) An illustrated dictionary of Chinese medicinal herbs. Times Editions, Singapore, 184 pp
- Wei XL, Liang JY (2002) Chemical study on the root bark of *Lycium chinense* Mill. *Zhongguo Yaoke Daxue Xueba* 33:271–273
- Wei XL, Liang JY (2003) Chemical studies on the root bark of *Lycium chinense*. *Zhongcaoyao* (Chinese Trad Herbal Drug) 34:580–581
- Xu C (2002) A laboratory investigation on the effects of Chinese wolfberry (*Lycium chinense* Mill) extract on the endurance of mice. *Int J Oriental Med* 27(2):87–90
- Yahara S, Shigeyama C, Nohara T (1989) Structures of anti-ACE and -renin peptides from Lycii radices cortex. *Tetrahedron Lett* 30(44):6041–6042
- Yahara S, Shigeyama C, Ura T, Wakamatsu K, Yasuhara T, Nohara T (1993) Cyclic peptides, acyclic diterpene glycosides and other compounds from *Lycium chinense* Mill. *Chem Pharm Bull*(Tokyo) 41(4):703–709
- Yamada P, Nemoto M, Shigemori H, Yokota S, Isoda H (2011) Isolation of 5-(hydroxymethyl)furfural from *Lycium chinense* and its inhibitory effect on the chemical mediator release by basophilic cells. *Planta Med* 77(5):434–440
- Yeh YC, Hahm TS, Sabliov CM, Lo YM (2008) Effects of Chinese wolfberry (*Lycium chinense* P. Mill.) leaf hydrolysates on the growth of *Pediococcus acidilactici*. *Bioresour Technol* 99(5):1383–1393
- Yeung H-C (1985) Handbook of Chinese herbs and formulas. Institute of Chinese Medicine, Los Angeles
- Yoshimura Y, Take T, Otsuka H, Daigaku N, Niagata J (1969) Taste substances in foods. XIV. Taste substances in the leaves of boxthorn (*Lycium chinense*). *Kaseigaku Zasshi* 20:481–484
- Zhang ZY, Lu A, D'Arcy WG (1994) Solanaceae A. L. Jussieu. In: Wu ZY, Raven PH (eds) *Flora of China*, vol 17, Verbenaceae through Solanaceae. Science Press/Missouri Botanical Garden Press, Beijing/St. Louis, 378 pp
- Zhang R, Kang KA, Piao MJ, Kim KC, Kim AD, Chae SW, Park JS, Youn UJ, Hyun JW (2010) Cytoprotective effect of the fruits of *Lycium chinense* Miller against oxidative stress-induced hepatotoxicity. *J Ethnopharmacol* 130(2):299–306
- Zhou X, Xu G, Wang Q (1996) Chemical constituents in the roots of *Lycium chinense* Mill. *Zhongguo Zhong Yao Za Zhi* 21(11):675–676, 704. (In Chinese)
- Zou Y (2000) Identification on flavonoids in leaves of *Lycium chinense*. *J Changshu College* ISSN:1008-2794.0.2000-02-009

Physalis angulata

Scientific Name

Physalis angulata L.

Synonyms

Boberella angulata (L.) E.H.L. Krause, *Physalis angulata* fo. *ramosissima* (Mill.) Stehlé, *Physalis angulata* var. *capsicifolia* (Dunal) Griseb., *Physalis angulata* var. *ramosissima* (Mill.) O.E. Schulz, *Physalis capsicifolia* Dunal, *Physalis ciliata* Sieb & Zucc., *Physalis esquirolii* H. Lév. & Vaniot, *Physalis lanceifolia* Nees, *Physalis linkiana* Nees, *Physalis minima* L., *Physalis ramosissima* Mill.

Family

Solanaceae

Common/English Names

Angular Winter Cherry, Annual Ground Cherry, Balloon Cherry, Bladder Cherry, Bladderberry, Bolsa Mulaca, Cape Gooseberry, Cherrylance-Leaf Ground Cherry, Cow Pops, Cut-Leaved Ground Cherry, Cutleaf Groundcherry, Dog tomato, Fisalia, Fisalia Tooth-Leaved Bladder, Ground Cherry, Hog Weed, Husked Tomato, Mullaca, Sunberry, Tooth-Leaved Winter Cherry, Wild Cape Gooseberry Wild Gooseberry, Wild Physalis, Wild Tomato, Winter Cherry.

Vernacular Names

Afrikaans: Kalkoengif, Wilde-Appelliefie;
Azores: Tomate Capucho;
Bangladesh: Fotka;
Brazil: Balãozinho, Bucho De Ra, Camapú, Joá-De-Capote;
Chad: B'lito;
Chamorro: Tomate Chaca, Tomates Caputi;
Chinese: Da Tou Pao, Deng Long Cao, Duan Dou, Ku Zhi, Ta Tou P'ao, Teng Ling Ts'ao, Tian Pao Cao, Tien P'ao Ts'ao, Teng Lung Ts'ao;
Columbia: Uchuva, Vejigon;
Cook Islands: Tāmaru, Tāmaru, Tūpera Tāmaru-Ariki, Tūpere (**Maori**);
Czech: Mochyně Drobnoplodá, Mochyně Hranatá;
Dominican Republic: Tope-Tope;
Dutch: Klap;
Fiji: Cevuvevu, Kospeli, Mborosousou, Mborosousou Ni Vavalangi, Mbotembote Yandra, Mburasu, Mokoai, Thevuthevu'
French Alkékenge Du Mexique, Batoto, Caqueret, Coqueret Anguleux, Coqueret Du Mexique, Herbe Á Cloques, Petit Poc Poc, Petite Tomate Du Mexique;
Gambia: Kubumpap (**Manding-Mandinka**);
Guinea: Jam (**Manding-Mandinka**);
Guinea-Bissau: Tau-Tau (**Crioulo**);
Guyana: Monkey-Gun, Pap-Bush, Papoose;
Hungarian: Mullaca;
I-Kiribati: Te Baraki, Te Bin;
India: Kupanti, Budda, Budamma (**Andhra Pradesh**), Kapalphuta (**Assamese**), Ban Tepari,

Ban Tipariya, Handi Khandi (Bengali), parpoti, popti (Gujerat), rasbhary (Himachal Pradesh), Bandapariya, Bandhapariya, Chirphoti, Chirpoti, Cirpoti, Papotan, Patari, Pipat, Tulatipati (Hindu), Bandula, Bondoola Gida, Bonula Gida, Guddehannu, Guppate Gida, Guppatte Gida, Sannabuddi (Kannada), Notinotta, Nottanotiyān, Pee-Inota-Inodien (Malayalam), Chirboti, Chirputi, Dhanmori, Kapparpodi, Lahanpopti, Phopeti, Popti, Tanmori (Marathi), Kela-Sairawphit (Mizoram), Avaguttha, Chirapotha, Chirapotika, Cirapotha, Kakatikta, Mrdukuncika, Parpataki, Parpoti, Parpotika, Sarngasta, Sarngesta, Tankari, Vayasi (Sanskrit), Ciru Takkali, Cirutakkali, Itayakali, Manathakkali, Nattuttakkali, Pillaitakkali, Puritayacceti, Puritayam, Siruthakkali, Sodakku Thakkaali, Sodakku Thakkali, Thakkali, Tottakkali (Tamil), Budama, Budamakaya, Budda, Budda Gachi, Buddha Bhushada, Kupante, Kupanti, Kuppante (Telugu);

Indonesia: Celpukan, (Java), Daun Kopo-Kopi (Moluccas), Cecendet, Cecendetan, Cicendetan-Cecenetan, Cincindit (Sundanese);

Japanese: Hosuki, Sennari Housuki;

Malaysia: Letup, Letup-Letup, Rumpit Meranti (Malay), Gaguntur (Selako, Sarawak);

Managua: Popa O Chimbonba;

Marshall Islands: Kaōrōr, Kaoror;

Mexico: Tomatillo;

Nicaragua: Popa O Chimbonba;

Nigeria: Matsarmama (Huasa), Koropo (Southwest);

Naruan: Oatamo, Watamo;

Niuean: Manini;

Papua New Guinea: Kaipos (Navuapaka, Central Province), Oviovi (Oroi, Central Province), Watosivo (Garara, Central Province);

Peru: Bolsa Mullaca, Capuli, Cimarron;

Philippines: Asisiyu (Bisaya), Amanti-Ti-UgsaKugut (Bontok), Amansit, Taltilaya (Ilocano), Tino, Tono (Ilongo), Pantug-Pantugan, Putokan, Putok-Putokan, Potokan, Sisiu, Tuttullakak, Tutulaka, (Tagalog);

Portuguese: Alquequenje Amarelo, Balão Rajado, Camapú, João De Capote;

Samoan: Vivao;

Senegal: Kalia Diirini (Bambara), Fuhad, Naling (Serer), Nahali (Wolof);

Spanish: Alquequenje, Capuli Cimarron, Jua-De-Capote, Motojobobo Embolsado, Sacabuche, Sapito, Tomate, Tomatillo, Topotopo;

Suriname: Batotobita, Mullaca, Papoose;

Tahitian: Tamanufairi, Tamaru Ha'Ari;

Thailand: Baa Tom Tok (Northern), Pung Ping (Peninsular), Thong Theng (Central), Kam-Po, Pong-Tee (Kanchanaburi), Tom Tok;

Tibetan: Swa Ra Na, Swa Ra Nga;

Tongan: Polo Pa, Polopā;

Tuvaluan: Pini;

Venezuela: Topotopo;

Vietnamese: Lồng Đèn, Lu Lu Cái, Tầm Bóp, Thù Lù Cạnh.

Origin/Distribution

Physalis angulata is possibly a native of tropical America. It is now distributed pantropically as a weed.

Agroecology

P. angulata is found in tropical, subtropical and temperate areas of the worlds. It is found growing as a common and abundant weed in disturbed areas, pastures, plantations, cane-fields, villages, along roadsides, on open slopes and in open forested areas from near sea level to 1,000 m (–1,600 m) elevation. It is found growing in the sub-Himalayas up to 1,650 m altitude. It is frost tolerant and also tolerant to partial shade. It thrives in fertile, moist and well-drained soil rich in organic matter.

Edible Plant Parts and Uses

The fruits are edible, juicy and a good source of vitamin C. The raw fruit can also be used as a vegetable. In tropical Africa, the fruit is eaten as snack or in sauces. In several countries, the raw leaves are consumed as salad although bitter (Rahayu 2002). Its roots and epigeal parts are taken as tea or infusion, as traditional medicine in some countries (Ribeiro et al. 2002).



Plate 1 Young fruits and flower



Plate 2 Ovate leaves with dentate margins



Plate 3 Ribbed stem, entire leaves and ripening fruit

straight style. Fruit 1.2–1.5 cm across, subglobose to ovoid, green turning to yellow, sessile on invaginated base of balloon-like calyx (Plates 1 and 3). Seed flat reniform, yellowish.

Botany

An erect, branched, glabrescent, herbaceous annual, 30–50 cm high. Stems hollow, ribbed, green often tinged purple. Leaves alternate to sub-opposite, on 1–7 cm long petioles; lamina ovate, ovate-oblong to elliptic, 3–6 cm long by 2–4 cm wide, apex acute to acuminate, base cuneate to broadly cuneate, margin entire or coarsely dentate (Plates 1–3). Flowers 1 cm across, solitary, axillary on 5–12 mm pedicels. Sepals 4–5 mm, campanulate mid-way with ribbed, deltoid-lanceolate, ciliate lobes 1–2 mm long. Corolla campanulate with five erect or spreading lobes, pale yellow to greenish-yellow, dark-spotted in the throat. Stamens exserted with filiform filaments and bluish anthers. Ovary subglobose to ovoid with

Nutritive/Medicinal Properties

Physalis minima fruit was found to contain 61.4% extractable juice, 76.7% moisture, 1.216% ash, 5.97% total sugars, 3% reducing sugars, 2.81% non-reducing sugars, P 0.108%, K 0.613%, Ca 0.024%, Mg 0.056% and Fe 0.006%, 0.64% tannins and 0.52% pectin (Parmar and Kaushal 1982).

Other Phytochemicals

Ayanin, an *o*-methylated flavonol, was isolated from *P. angulata* (Lopez et al. 1976).

From the stems and leaves of *Physalis angulata* and *P. lancifolia*, five new physalins E, F, G,

H and I were isolated (Row et al. 1978b). The structures of physalins E and H were established respectively as 5,6-dihydro-5 α ,7 α -dihydroxy and 7 β -hydroxy derivatives of physalin B. The structures of physalins I, G and K from *Physalis angulata* and *Physalis lancifolia* were established respectively as 5,6-dihydro-5 α -methoxy-6 β -hydroxy; 4,5-dehydro-5,6-dihydro-4 β -hydroxy; and 5,6-dihydro-4 α ,5 α -epoxy-6 α -hydroxy derivatives of physalin B (Row et al. 1978a). Presence of acetylcholine in the fruit of *Physalis angulata* was confirmed by gas chromatography (Mello and Afatpour 1985). The average level was 123 μ g/g of fruit.

A withanolide, withangulatin A was isolated from *Physalis angulata* (Chen et al. 1990) and it was found to be an ergostane-type steroidal lactone possessing a characteristic partial structure 14 α -hydroxy-15 α -acetoxy-16-ene system on ring D (Shingu et al. 1992a). A withanolide, physagulin C was isolated from the methanolic extract of the fresh leaves and stems of *Physalis angulata* and its structure was determined to be (20S, 22R)-15 α -acetoxy-5 β (6), 16 β (17)-diepoxy-4 β , 14 β -dihydroxy-1-oxo-witha-2,24-trienolide (Shingu et al. 1991). Three more withanolides, physagulins A (1), B (2) and D (3), were obtained from the methanolic extract of the fresh leaves and stems of *Physalis angulata* and their structures were established as (20S, 22R)-15 α -acetoxy-5 β , 6 β -epoxy-14 α -hydroxy-1-oxowitha-2,16,24-trienolide (1), (20S, 22R)-15 α -acetoxy-5 α -chloro-6 β , 14 α -dihydroxy-1-oxowitha-2,16,24-trienolide (2) and (20S, 22R)-1 α , 3 β , 27-trihydroxywitha-5,24-dienolide 3-O- β -D-glucopyranoside (3) (Shingu et al. 1992a). Three withanolides, physagulins E(1), F(2), and G(3) were isolated from the fresh berries of *Physalis angulata* and their structures were established as (20S, 22R)-15 α -acetoxy-5 α , 6 β , 14 α , 28-tetrahydroxy-1-oxowitha-2,16,24-trienolide-28-O-D-glucopyranoside (1), (20R, 22R)-15 α -acetoxy-16 β , 17 β -epoxy-5 α , 6 β -14 β -trihydroxy-1-oxo-witha-2,24-dienolide (2) and (20R, 22R)-15 α -acetoxy-16 β , 17 β -epoxy-5 α , 6 β , 14 β , 28-tetrahydroxy-1-oxo-witha-2,24-dienolide 28-O- β -D-glucopyranoside (3) (Shingu et al. 1992b).

Four withanolides were isolated from the aerial parts of *Physalis angulata* (Nagafuji et al. 2004). Further study of the methanol extract of the aerial parts of *Physalis angulata* (Solanaceae) resulted in the isolation of new withanolides, designated physagulins L, M and N, together with known withanolide, physagulin D and flavonol glycoside, quercetin 3-O-rhamnosyl-(1 $\rightarrow$ 6)-galactoside (Abe et al. 2006). The chemical structures were elucidated as (20R,22R)-15 α -acetoxy-5 α ,6 β ,14 β ,17 β ,27-pentahydroxy-1-oxo-witha-2, 24-dienolide; (20S,22S)-15 α -acetoxy-5 α ,6 β ,14 α ,23 β -tetrahydroxy-1-oxo-witha-2,16,24-trienolide and (20S,22R)-15 α -acetoxy-5 β ,6 β -epoxy-14 α -hydroxy-3 β -methoxy-1-oxo-witha-16,24-dienolide, respectively. A withasteroid, physanolide A and two new physalin U and V were isolated from *P. angulata* (Kuo et al. 2006). Four new withanolides, physagulins L-O (1–4), were isolated from the methanol extract of the aerial parts of *Physalis angulata* together with seven known withanolides, compounds 5–11 (He et al. 2007). Seven withanolides, withangulatin B–H (1–7), and a new minor physalin, physalin W (8), along with 14 known compounds, including physaprun A, withaphysanolide, dihydrowithanolide E, physanolide A, withaphysalin A, and physalins B, D, F, G, I, J, T, U, and V were isolated from *P. angulata* plant (Damu et al. 2007). A new withanolide, withangulatin I ((20S,22R)-15 α -acetoxy-5 β ,6 β -epoxy-14 α -hydroxy-1,4-dioxo-witha-2,16,24-trienolide), was isolated from the whole plant of *Physalis angulata* (Lee et al. 2008). Three new withanolides, physangulidines A, B and C were isolated from the whole plant (Jin et al. 2012).

An alkaloid, phygrine was found in *P. angulata* and its structure elucidated as bis-hygrine or 1-[1'-methylpyrrolidine-2'-yl]-3-[1"-methyl-2"-(2"-oxopropyl)pyrrolidine-5"-yl]propan-2-one (Basey et al. 1992).

Withanolides isolated from *P. minima* included withaphysalin A, withaphysalin B, withaphysalin C (Glötter et al. 1975); withaphysalin D, withaphysalin A (Sahai and Kirson 1984); withaphysalin E (Oshima et al. 1987); withaminimin (Gottlieb et al. 1987) and withanolide and

(Choudhary et al. 2005). Other steroidal lactones isolated included physalin B, 5 β ,6 β -epoxyphysalin B (Glottter et al. 1975); physalin A physalin B, Physalin C, dihydroxyphysalin B (Alluri et al. 1976); physalin B, epoxyphysalin B, physalin D, physalin L (6 β -ethoxy-5 α ,13,20,22-tetrahydroxy-1,15-dioxo-16,24-cyclo-13,14-secoergost-2-ene 18,24-dioic acid, 18–20,27-22 dilactone) (Sen and Pathak 1995); physalin H, isophysalin B, 5 β ,6 β -epoxyphysalin B, and three new physalins (Choudhary et al. 2005); Two new physalins, 16,24-cyclo-13,14-secoergosta-2-ene-18,26-dioic acid-14: 17,14: 27-diepox-11 β ,13,20,22-tetrahydroxy-5 α -methoxy-1,15-dioxo- γ -lactone δ -lactone (1), and 16,24-cyclo-13,14-secoergosta-2-ene-18,26-dioic acid-14: 17,14: 27-diepox-5 α ,11 β ,13,20,22-pentahydroxy-1,6,15-trioxo- γ -lactone δ -lactone (2) (Choudhary et al. 2007) and two physalindicanols, new biogenetic precursors of C28-steroidal lactones, the structure of which were elucidated as ergosta-5,25-dien-3 β ,24 ζ -diol and ergosta-5,24(28)-dien-3 β ,25-diol (Sinha et al. 1987). A phenolic compound N-*trans*-p-coumaroyltyramine from the plant (Neelam et al. 2010) and solasodine glycoside from the hairy root cultures of *P. minima* (Putalun et al. 2004).

Antihyperlipidemic Activity

Administration of *Physalis angulata* flower extract to rats for 3 weeks caused no significant changes to the superoxide dismutase and catalase activities and levels of triglyceride total- and LDL-cholesterol but the level of HDL-cholesterol was significantly increased (Choi and Hwang 2005). The level of malondialdehyde was decreased and TBARS, a marker of lipid peroxidation was significantly lower which may reduce the risk of inflammatory and heart disease. The ethanolic extract of *Physalis minima* was found to have the ability to suppress the lipid peroxidation in-vitro based on the measurement of malondialdehyde (MDA) content in goat's liver tissue homogenates (Dinakaran et al. 2011).

Anticancer Activity

The stem and fruit capsule fraction of *P. angulata* were found to have anti-neoplastic activity (Ribeiro et al. 2002) The most significant inhibition values were those for fruit capsules fractions such as 97% against mouse lymphoma and 93% for Erlich carcinoma strains. *Physalis angulata* plant extract exhibited antihepatoma activity against human hepatoma Hep G2 cells but its effect was not as potent as *P. peruviana* plant extract (Wu et al. 2004). *P. angulata* extract inhibited cell proliferation and induced G2/M arrest and apoptosis in human breast cancer MAD-MB 231 and MCF-7 cell lines (Hsieh et al. 2006). The results suggested that the anticarcinogenic effect *P. angulata* on the levels of phosphorylated/inactivated Cdc25C were mediated by Chk2 activation, at least in part, via p21(waf1/cip1) and P27(kip1) cyclin-dependent kinase inhibitors pathway to arrest cells at G2/M phase in breast cancer carcinoma cells. Studies by Lee et al. (2009) found that *P. angulata* induced oxidative stress in human oral cancer HSC-3 cells and that reactive oxygen species may play a dominant role in this process. *P. angulata*-initiated apoptosis was caused through oxidative stress-dependent induction of heme oxygenase-1, Cu/Zn superoxide dismutase and heat shock protein 70 (HSP70) proteins expression. They also found that antioxidants inhibited *P. angulata*-induced cell death through inhibition of the proteins expression of HO-1, Cu/Zn superoxide dismutase and HSP70. Hseu et al. (2011) demonstrated that at sub-cytotoxic concentrations, ethyl acetate extracts of *P. angulata* (5–15 μ g/mL) strongly inhibited the migration and invasion of highly metastatic human oral squamous carcinoma HSC-3 cells as shown by wound-healing repair assay and trans-well assay. The extracts suppressed the activity of matrix metalloproteinase (MMP)-9 and -2, and urokinase plasminogen activator (u-PA) in HSC-3 cells. Additionally, the extracts significantly decreased MMP-2 and u-PA protein expression in HSC-3 cells and significantly augmented the expression of their endogenous inhibitors, including tissue inhibitors of MMP (TIMP-1 and -2), and plasminogen activator

inhibitors (PAI-1 and -2). Further investigations revealed that non-cytotoxic concentration of the extracts (5–15 µg/mL) inhibited vascular endothelial growth factor (VEGF)-induced proliferation, and migration/invasion of HUVECs in-vitro. Further, the extracts strongly suppressed neovessel formation in the chorioallantoic membrane of chick embryos in-vivo. The results strongly suggested an anti-metastatic and anti-angiogenic activity of *P. angulata* and its potential as chemopreventive agent for cancer and inflammation.

Physalin F but not physalin D, both isolated and characterized from the ethanol plant extract of *Physalis angulata* exhibited antitumour activity in-vitro and in-vivo (Chiang et al. 1992b). Physalin F showed cytotoxicity in-vitro by DEA and MTT assays on eight cancer cell lines, five human cancer cell lines: HA22T(hepatoma), HeLa(cervix uteri), KB(nasopharynx), Colo-205(colon) and Calu-1(lung); and three animal cancer cell lines: H1477(melanoma), Hep-2(laryngeal) and 8401(glioma). It was found that the anti-hepatoma action was the most potent, followed by the anti-HeLa. Physalin F also had an antitumour effect in-vivo against P388 lymphocytic leukemia in mice whereas physalin D was inactive both in-vitro and in-vivo. They also found that both physalin B and physalin F inhibited the growth of several human leukemia cells: K562 (erythroleukemia), APM1840 (acute T lymphoid leukemia), HL-60 (acute promyelocytic leukemia), KG-1 (acute myeloid leukemia), CTV1 (acute monocytic leukemia) and B cell (acute B lymphoid leukemia) (Chiang et al. 1992a). Physalin F exerted a stronger activity against these leukemia cells than physalin B, especially against acute myeloid leukemia (KG-1) and acute B lymphoid leukemia (B cell). In a separate study, both physalin B and physalin D isolated from the aerial parts of *Physalis angulata* displayed considerable in-vitro cytotoxicity against several cancer cell lines, showing IC_{50} values in the range of 0.58–15.18 µg/mL for physalin B, and 0.28–2.43 µg/mL for physalin D (Magalhães et al. 2006). The antitumour activity of both compounds was confirmed in-vivo using mice bearing sarcoma 180 tumour cells. The

in-vivo antitumour activity was related to the inhibition of tumour proliferation. Soares et al. (2006) reported that addition of physalins B, F or G to concanavalin A-activated splenocyte cultures induced a concentration-dependent inhibition of proliferation. Physalin B also inhibited IL-2 production by Con A-activated spleen cells. The addition of 2 µg/mL physalin B to mixed lymphocyte reaction (MLR) caused a 100% inhibition of proliferation. Additionally, treatment of mice with physalin B, F or G prevented the rejection of allogeneic heterotopic heart transplant. The results demonstrated the suppressive activity of physalins B, F and G in lymphocyte function and indicated the potential use of physalins as immunosuppressive agents for treatments of pathologies that desire inhibition of immune responses. Physalins B, D and F isolated from *P. angulata* showed potent cytotoxicity against multiple tumour cell lines, including KB (human nasopharynx carcinoma), A431 (human epithelial carcinoma cell line), HCT-8 (intestinal adenocarcinoma), PC-3 (human prostate cancer), and ZR751 (human breast cancer), with EC_{50} values less than 4 µg/mL (Kuo et al. 2006).

Eleven withanolide compounds were tested for their antiproliferative activities towards human colorectal-carcinoma (HCT-116) and human non-small-cell lung-cancer (NCI-H460) cells (He et al. 2007). Compound 5 exhibited the highest anticancer activity against the HCT-116 cell line, with an IC_{50} value of 1.64 µM. Compound 9 exhibited the highest cytotoxicity towards the NCI-H460 cell line, with an IC_{50} value of 0.43 µM. Withangulatin A and withangulatin I exhibited inhibitory activities in-vitro against these two human cancer cells colorectal carcinoma COLO 205 and gastric carcinoma AGS, with IC_{50} values of 16.6 and 1.8 and 53.6 and 65.4 µM, respectively (Lee et al. 2008). Biological evaluation of withangulatin B–H (1–7), and a new minor physalin, physalin W, along with 14 known compounds, including physaprun A, withaphysanolide, dihydrowithanolide E, physanolide A, withaphysalin A, and physalins B, D, F, G, I, J, T, U, and V, isolated from *P. angulata* plant against a panel of human cancer cell lines showed

broad cytotoxic activity (Damu et al. 2007). Withangulatin B and physalins D and F displayed potent cytotoxic activity against a range of human cancer cell lines with EC_{50} values ranging from 0.2 to 1.6 $\mu\text{g/mL}$. Structure–activity relationship analysis indicated that withanolides and physalins with 4 β -hydroxy-2-en-1-one and 5 β ,6 β -epoxy moieties were potential cytotoxic agents. Hsu et al. (2012) showed that physalin B exhibited cytotoxicity towards v-raf murine sarcoma viral oncogene homolog B1 (BRAF)-mutated melanoma A375 and A2058 cells with IC_{50} values <4.6 $\mu\text{g/mL}$. Their findings indicated physalin B could induce apoptosis of melanoma cancer cells via the NOXA, caspase-3, and mitochondria-mediated pathways, but not of human skin fibroblast cells and myoblastic cells and had potential to be developed as an effective chemotherapeutic lead compound for the treatment of malignant melanoma. Withanolides physangulidines A, B and C isolated from *P. angulata* plant showed significant antiproliferative activity against DU145 prostate cancer cells (Jin et al. 2012). Physangulidine A also exhibited significant antiproliferative activity against a wide range of additional cancer cell lines.

A new flavonol glycoside, myricetin 3-O-neohesperidoside isolated from methanol extract of *Physalis angulata* leaves, showed notable cytotoxicity in-vitro against murine leukemia cell line P-388, epidermoid carcinoma of the nasopharynx KB-16 cells, and lung adenocarcinoma A-549 with ED_{50} values of 0.048, 0.50 and 0.55 $\mu\text{g/mL}$ respectively (Ismail and Alam 2005).

P. minima was found to have potent anticancer activity (Lee and Houghton 2008). physalin F was found to be the major cytotoxic component of *Physalis minima* with an IC_{50} values (48 h exposure) of 0.4 μM against COR L23 lung cancer cells and 0.59 μM against MCF7 breast cancer cells. The chloroform extract of *Physalis minima* plant produced a significant growth inhibition against human T-47D breast carcinoma cells as compared with other extracts with an EC_{50} value of 3.8 $\mu\text{g/mL}$ (Ooi et al. 2010a). the results from their study strongly suggested that the chloroform extract of *P. minima* induced

apoptotic cell death via p53-, caspase-3-, and c-myc-dependent pathways. They also found that the chloroform extract of *Physalis minima* plant exerted anticancer effect due to a combination of apoptotic and autophagic cell death mechanisms on human ovarian Caov-3 cells (Ooi et al. 2010b). The induction of these programmed cell deaths was mediated via c-myc, p53 and caspase-3 dependent pathway. The chloroform extract of *Physalis minima* plant exhibited potent cytotoxic activities on NCI-H23 (human lung adenocarcinoma) cell line at dose- and time-dependent manners (after 24, 48 and 72 h of incubation) (Ooi et al. 2011). The extract was found to exert apoptotic programmed cell death in NCI-H23 cells via modulation of -myc, caspase-3 and p53 mRNA expression pathways.

Antimicrobial Activity

Crude *Physalis angulata* chloroform extracts and physalin-containing fractions displayed antimycobacterial activity in-vitro against *Mycobacterium tuberculosis*, *Mycobacterium avium*, *Mycobacterium kansasii*, *Mycobacterium malmoense* and *Mycobacterium intracellulare* (Pietro et al. 2000). In subsequent studies, crude extracts and fractions from aerial parts of *Physalis angulata* were also bioassayed for antimycobacterial activity (Januário et al. 2002). Fraction A1-29-12 containing physalins B, F and D exhibited MIC value of 32 $\mu\text{g/mL}$ against *Mycobacterium tuberculosis* H(37) Rv strain. Purified physalin B and physalin D exhibited MIC values >128 and 32 $\mu\text{g/mL}$ respectively against *Mycobacterium tuberculosis* H(37) Rv strain of suggesting that physalin D played a relevant role in the antimycobacterial activity displayed. A mixture of physalins (pool) containing physalins B, D, F, G from *P. angulata* fruit was found to inhibit different strains of *Staphylococcus aureus* and *Neisseria gonorrhoeae* at a concentration of 200 $\mu\text{g/mL}$, using agar dilution assays (Silva et al. 2005). The mixture was inactive against *Pseudomonas aeruginosa*, *Escherichia coli* and *Candida*

albicans. Physalin B (200 µg/mL) by the agar diffusion assay inhibited *S. aureus* by about 85%; and may be considered responsible for the antimicrobial activity.

Candida torulopsis, *Candida stellatoidea* and *Candida albicans* were susceptible to the essential oils from the aerial and root part of *Physalis angulata* (Osho et al. 2010). The minimum inhibitory concentrations ranging between 3.75 and 4.0 mg/mL were recorded for *Bacillus subtilis*, *Klebsiella pneumoniae* by the aerial and the root extracts, but *Pseudomonas aeruginosa* and *Staphylococcus aureus* were not susceptible to the aerial and root extracts. The observed inhibition of selected bacteria and fungi by oils of *Physalis angulata* makes it a promising antimicrobial agent. This study justified its uses for treatment of sores, cuts, intestinal and digestive problems and some skin-diseases often reported in folkloric medicine.

Absolute alcohol and chloroform extracts of *P. minima* leaf and callus showed antimicrobial activity with MIC values of 2–4 mg/mL against *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas solanacearum*, *Xanthomonas axonopodis* and *Xanthomonas vesicatoria* (Shariff et al. 2006). The chloroform callus and leaf extracts showed MIC of 2 and 4 mg/mL against all the tested fungi namely *Aspergillus oryzae*, *A. flavus*, *Fusarium verticilloides* and *Penicillium* sp. But the petroleum ether and benzene extract were weakly active to inactive against all the tested bacteria and fungi. The methanol and chloroform extracts of *P. minima* exhibited potent inhibitory activity against Gram positive and Gram negative bacterial strains tested. (Patel et al. 2011). Minimum inhibitory concentration was 100 µg in both the extracts.

Antigonorrhoeal Activity

Physalis angulata (leaves) was one of nine plants found to be most active in-vitro against five strains of *Neisseria gonorrhoeae* causal agent of gonorrhoea (Cáceres et al. 1995). The results supported the popular use of the plant against gonorrhoea in Guatemalan traditional medicine.

Antiinflammatory Activity

P. angulata flower extract was found to exhibit inhibitory effects against acute and subacute inflammation by oral administration (200 mg/kg) (Choi and Hwang 2003). Also, administration (200 mg/kg, p.o.) of plant extract for 1 week significantly inhibited type IV allergic reaction in mice. In another study, similar to dexamethasone, topically applied physalin E, a seco-steroid isolated from *Physalis angulata*, at doses of 0.125; 0.25 and 0.5 mg/ear potentially inhibited 12-*O*-tetradecanoyl-phorbol-13-acetate (TPA) and oxazolone-induced dermatitis, leading to substantial reductions in ear edema/thickness, pro-inflammatory cytokines, and myeloperoxidase activity (Pinto et al. 2010). The data suggested that physalin E may be a potent and topically effective antiinflammatory agent useful to treat the acute and chronic skin inflammatory conditions.

Sun et al. (2010) reported that withangulatin A (WA), an active component isolated from *Physalis angulata* significantly suppressed mice T lymphocytes proliferation stimulated with LPS in a dose- and time-dependent manner and inhibited pro-inflammation cytokines (IL-2, IFN-gamma, and IL-6) dramatically. They found that administration of WA inhibited mice ear swelling and decreased pro-inflammatory cytokines production in mice blood serum. They concluded that WA modulated mice T lymphocytes function through targeted inhibiting COX-2 expression via MAPKs and NF-kappaB nuclear translocation signaling pathways, indicating its potential as an anti-inflammatory agent. In a subsequent study they demonstrated that WA might improve the life quality, as well as reduced the accumulation of proteinuria symptoms and levels of anti-double-stranded DNA antibodies in MRL/lpr mice (Sun et al. 2011). Their findings indicated that WA might have a pleiotropic therapeutic effect through their immunosuppression via inhibiting B cell-activating factor signalling. They suggested a potential application of this active constituent in the treatment of systemic lupus erythematosus.

Methanol leaf extract of *P. angulata* was found to possess antiasthmatic activity (Rathore et al. 2011). In smooth muscle models, the extract exhibited inhibitory efficacy by 100% (1 µg), 133% (2 µg) and 126% (4 µg) in guinea pig ileum preparation against 1 µg histamine; 86% (1 µg), 100% (2 µg) and 106% (4 µg) in guinea pig tracheal chain preparation against 1 µg histamine and 50% (1 µg), 75% (2 µg) and 100% (4 µg) in fundus strip preparation against 1 µg 5HT (serotonin).

Both crude extract and chloroform fraction of *P. minima* plant showed marked antiinflammatory and analgesic activities as compared to a control at tested doses 200 and 400 mg/kg, in NMRI mice and Wistar rats (Khan et al. 2009). The antipyretic potential of the crude extract and chloroform were insignificant in the Brewer's yeast fever model.

Immunomodulatory Activities

Various fractions derived from *Physalis angulata* extract showed immunomodulatory activity (Lin et al. 1992). Fractions PA-VII and PA-VII-C strongly enhanced blastogenesis response, PA-VII-B had moderate activity, and PA-VII-A exerted only slight effect on cell proliferation. A synergistic effect was observed when the suboptimal dosage of phytohemagglutinin (PHA) or lipopolysaccharide (LPS) was added to the culture. Further, PA-VII and PA-VII-C possessed stimulatory activity on B cells and less effect on T cells. The antibody responses were also augmented by fraction PA-VII, PA-VII-B and PA-VII-C, but not by PA-VII-A. The enhancement of antibody response could be observed both in BALB/c and C3H/HeJ mice.

Physalins, seco-steroids purified from *P. angulata* extracts were found to have immunomodulatory activity (Soares et al. 2003). Addition of physalins B, F or G, but not D, caused a reduction in nitric oxide production by macrophages stimulated with lipopolysaccharide and interferon-gamma. In the presence of physalin B, macrophages stimulated with lipopolysaccharide, alone or in combination with interferon-gamma,

produced lower levels of tumour necrosis factor (TNF)-alpha, interleukin-6 and interleukin-12. Physalin B-treated mice had lower levels of serum TNF-alpha than control mice after lipopolysaccharide challenge. Additionally, mice injected with physalins B, F or G survived after a lethal lipopolysaccharide challenge. These results demonstrated *P. angulata* seco-steroids to be potent immunomodulatory substances, acting through a mechanism distinct from that of dexamethasone.

Injection of rats with 1 mg/kg aqueous root extract of *P. angulata* (but not 0.5 mg/kg) 1 h before carrageenan administration exerted significant antiinflammatory effects, decreasing exudate volume, total number of inflammatory cells, ADA activity, nitrite level, and PGE(2) level in 50, 41, 20, 60, and 41%, respectively (Bastos et al. 2008). In addition, tumour growth factor-beta was upregulated to 9,700 pg/mL after 5 mg/kg extract, in comparison with 160 pg/mL in the vehicle-treated group, and 137 pg/mL in the indomethacin-treated group. The results indicated that the extract exerted potent anti-inflammatory and immunomodulatory activities, interfering with the cyclooxygenase pathway, lymphocyte proliferation, NO, and TGF-beta production. Yu et al. (2010) demonstrated the immunosuppressive effect of Physalin H isolated from *P. angulata* on T lymphocytes both in-vitro and in-vivo. Physalin H in a dose-dependent manner significantly inhibited the proliferation of T lymphocytes induced by concanavalin A (ConA) and by the mixed lymphocyte culture reaction (MLR). They also showed in in-vivo experiments that immunosuppressive activity might be attributed to the suppression of T cell activation and proliferation, the modulation of Th1/Th2 cytokine balance and the induction of HO-1 in T cells.

Oral treatment with physalin F, a steroid derivative purified from *Physalis angulata*, or dexamethasone caused a marked decrease in paw edema and joint inflammation when compared to vehicle-treated arthritic mice (Brustolim et al. 2010). In contrast, treatment with physalin F had no effect in mice with allergic airway inflammation caused by ovalbumin immunization, whereas

dexamethasone significantly reduced the number of inflammatory cells and eosinophils in the bronchoalveolar lavage fluid and in lung sections of challenged mice. Further it was demonstrated that the mechanism of the immunosuppressive activity of physalin F was distinct from that of the glucocorticoid. Earlier studies using intestinal ischaemia and reperfusion (I/R) mice by Vieira et al. (2005) found that in-vivo antiinflammatory actions of physalins appeared to be mainly due to the activation of glucocorticoid receptors. They found that dexamethasone or physalins effectively suppressed the increase in tissue (intestine and lungs) and serum concentrations of TNF- α but enhanced expression of interleukin-10 (IL-10). The IL-10-enhancing effects of both drugs were not altered by RU486.

Antinociceptive Activity

Bastos et al. (2006) demonstrated that the aqueous root extract of *Physalis angulata* induced notable antinociception against the acetic acid-induced visceral pain and inflammatory pain responses induced by formalin in mice. The antinociceptive action demonstrated supported, at least partly, the ethnomedical uses of this plant.

Trypanocidal Activity

Physalis angulata was one of three plants out of 32 African traditional medicinal plant extracts that exhibited marked trypanocidal activity with $IC_{50} < 1 \mu\text{g/mL}$ with (Freiburghaus et al. 1996). Withanolides, physagulins L, M and N isolated from the methanol extract of the aerial parts of *Physalis angulata* showed weak trypanocidal activity against trypomastigotes, an infectious form of *Trypanosoma cruzi*, the etiologic agent for Chagas' disease (Abe et al. 2006). Withanolides obtained in an earlier study showed considerable trypanocidal activity (Nagafuji et al. 2004), suggesting the structure-activity relationships.

In uninfected *Rhodnius prolixus* insect, the effective concentration of physalin B from *P.*

angulata, which inhibited 50% of the blood ingested (ED_{50}) volume, was $15.2 \mu\text{g/mL}$ of the meal (Garcia et al. 2006). Ecdysis processes and mortality in uninfected larvae, treated orally with physalin B in concentrations ranging from 1 to $10 \mu\text{g/mL}$, was similar to that observed in insects not treated with physalin B. However, *R. prolixus* larvae previously fed on blood containing 1.0, 0.1, and $0.01 \mu\text{g}$ of physalin B/mL exhibited mortality rates of 78.1, 54.3, and 12.7%, respectively, 6 days after inoculation of *Trypanosoma rangeli* strain protozoan. In uninfected *Rhodnius prolixus* insects, the effective concentration of physalins (1×10^3 parasites/insect), whereas only 7.2% mortality was observed in the control group, injected with sterile culture medium. physalin B treatment caused a reduction in hemocyte micro-aggregation and nitric oxide production and enhanced the parasitemia in the hemolymph. The results demonstrated physalin B from *P. angulata* to be a potent immunomodulatory substance for the bloodsucking insect, *R. prolixus*. *Rhodnius prolixus* is a vector of Chagas's disease. Physalin B, a natural secosteroidal chemical from *Physalis angulata* inhibited *Rhodnius prolixus* fifth instar larval hemocyte phagocytosis and microaggregation by the activation of the insect endogenous platelet-activating factor-acetyl hydrolase activities (Castro et al. 2009).

Antileishmanial Activity

Three new physalins (1–3), physalin H, isophysalin B, and $5\beta,6\beta$ -epoxyphysalin B isolated from *P. minima* plant exhibited in-vitro leishmanicidal activities (0.92 – $19.4 \mu\text{g/mL}$) against promastigotes of *Leishmania major* (Choudhary et al. 2005). Two new physalins, 16,24-cyclo-13,14-secoergosta-2-ene-18,26-dioic acid-14: 17,14: 27-diepoxy-11 β ,13,20,22-tetrahydroxy-5 α -methoxy-1,15-dioxo- γ -lactone δ -lactone (1), and 16,24-cyclo-13,14-secoergosta-2-ene-18,26-dioic acid-14: 17,14: 27-diepoxy-5 α ,11 β ,13,20,22-pentahydroxy-1,6,15-trioxo- γ -lactone δ -lactone (2) showed potent leishmanicidal activity against the promastigotes of *Leishmania major* (Choudhary et al. 2007). Physalins, secosteroids

purified from *Physalis angulata* were found to exhibit in-vitro and in-vivo antileishmanial activity (Guimarães et al. 2009). Physalins B and F were able to reduce the percentage of *Leishmania*-infected macrophages and the intracellular parasite number in-vitro at concentrations non-cytotoxic to macrophages. Additionally, topical treatment with physalin F significantly reduced the lesion size, the parasite load and histopathological alterations in BALB/c mice infected with *L. amazonensis*.

Antimalarial Activity

The dichloromethane extract of *P. angulata* leaves exerted potent antiplasmodial activity against *Plasmodium falciparum* with $IC_{50} < 3 \mu\text{g/mL}$ (Lusakibanza et al. 2010). *P. angulata* was one of nine Amazonian plants that displayed an interesting antiplasmodial activity ($IC_{50} < 10 \mu\text{g/mL}$) against *Plasmodium falciparum* chloroquine resistant strain (FCR-3) (Ruiz et al. 2011).

Physalis angulata showed also a good inhibition of parasitemia in-vivo. Flavonoids, phenolic acids and terpenes were identified in the plant. The antimalarial activity of physalins B, D, F, and G, isolated from *Physalis angulata*, were shown using an in vitro assay against *Plasmodium falciparum* (Sá et al. 2011). However, treatment of *Plasmodium berghei*-infected mice with physalin F increased parasitemia levels and mortality, whereas treatment with physalin D was protective, causing a parasitemia reduction and a delay in mortality in *P. berghei*-infected mice. The exacerbation of in-vivo infection by treatment with physalin F was probably due to its potent immunosuppressive activity, which was not evident for physalin D.

Molluscicidal Activity

The ethyl acetate and acetone extracts from the whole plant of *P. angulata*, the ethanolic extracts of the roots and the physalins pool from stems and leaves exhibited molluscicidal activity against *Biomphalaria tenagophila* in the laboratory

(Dos Santos et al. 2003). The snail is a vector of intestinal schistosomiasis.

Topoisomerase-Mediated Activity

Withangulatin A, from *Physalis angulata*, was found to act on topoisomerase II to induce topoisomerase II-mediated DNA damage in-vitro (Juang et al. 1989). It has two effective dosage ranges of approximate 0.5 and 20 μM , with about one-third the activity of 20 μM VM-26. Withangulatin A was reported as a newly identified in-vitro topoisomerase II inhibitor isolated from the *Physalis angulata* (Lee et al. 1991). In-vivo, it was found to be cytotoxic, capable of suppressing general protein synthesis and of inducing the synthesis of a small set of proteins including those generated by heat-shock treatment. The 70 kDa protein generated by withangulatin A was unequivocally identified as the heat-shock protein 70 (HSP70). Other cellular effect of withangulatin A was alterations of protein phosphorylation including an enhancement of phosphorylation of a 65 kDa protein which was also detected in the heat-shocked cells. Increased phosphorylation of the 65 kDa protein may represent one of the earliest signals generated by both heat-shock and withangulatin A and may be involved in the upstream regulation of heat-shock response in cells.

Other Pharmacological Activity

N-trans-p-coumaroyltyramine (CT), a phenolic compound isolated from *Physalis minima* exhibited many pharmacological activities like potent inhibition of acetyl cholinesterase, cell proliferation, platelet aggregation, and also antioxidant activity (Neelam et al. 2010). The binding of CT with human serum albumin was found to occur at physiological pH 7.2 at two binding sites. Molecular docking studies revealed that CT bound with human serum albumin at subdomain IIA with hydrophobic interactions and also by hydrogen-bond interactions.

Antiviral Activity

Preliminary studies conducted in Japan in the early 90s reported *P. angulata* extracts to be active in-vitro against polio virus I, herpes simplex virus I, the measles virus, and human immunodeficiency virus—type 1 (HIV-I) demonstrating reverse transcriptase inhibitory and HIV-1 protease inhibitory effects (Kusumoto et al. 1992a, b; Kurokawa et al. 1993; Otake et al. 1995).

Genotoxic Activity

Alves dos Santos et al. (2008) demonstrated the genotoxic effects of *P. angulata* extract on human lymphocytes in-vitro. Treatments with *P. angulata* at 0.5, 1.0, 2.0, 3.0 and 6.0 µg/mL in culture medium were genotoxic. Lymphocytes treated with *P. angulata* at the concentrations of 3.0 and 6.0 µg/mL in culture medium showed a statistically significant increase in the frequency of micronucleus, however, the cytokinesis blocked proliferation index (CBPI) was not decreased after *P. angulata* treatment.

Traditional Medicinal Uses

In Central, South America and the Caribbean, *Physalis angulata* is widely used as a medicinal plant in traditional medicine (Waterfall 1967; Branch and da Silva 1983; Rutter 1990; Cáceres et al. 1995; Mejia and Rengifo 1995; DeFilipps et al. 2004; Alves dos Santos et al. 2008). In Curaçao and Jamaica, the herb infusion is taken for gonorrhoea, and in Trinidad for indigestion, nephritis and fever; and for toothache in Puerto Rico. The leaves are popularly used in Guatemala for the treatment of gonorrhoea. In Guyana and Surinam, the plant decoction is used to treat upset stomach and Bright's disease; the leaves mixed with other plant ingredients (*Cercopia* sp. and *Carica papaya*) in rum as a preservative is used in treatment of skin diseases; the seeds are cooked with *Phyllanthus amara* seeds in a preparation administered to women to facilitate

labour. In Brazil, different extracts and infusions of *Physalis angulata* fruit and plant parts are commonly used in traditional medicine for the treatment of malaria, asthma, hepatitis, dermatitis and rheumatism and as an antimutagenic, anticoagulant, antispasmodic and anti-leukemia agents. In Brazil, the roots are boiled with roots of uruca and acai and drank as herbal tea for jaundice and inflamed liver. In Peruvian herbal medicine, the sliced and macerated root decoction in rum is used for treating diabetes; a root infusion is employed for hepatitis; leaf infusion used as a diuretic; decoction of leaf and fruit is applied onto inflamed areas as antiinflammatory and disinfectant; leaf infusion is administered for asthma and postpartum infections; leaf decoction used for malaria and crushed green fruit paste is used for scabies. Also in Peru various parts of the plant have been used as a febrifuge anthelmintic, antirheumatic, diuretic, analgesic and for treating gonorrhoea, haemorrhoids, otitis, hepatitis and malaria.

In tropical Africa, leaves used as abortifacient, ebolic antiemetic, rheumatism, arthritis, diuretic, analgesic, anhelminthic, febrifuge, and to treat cutaneous and subcutaneous parasitic infection, whitlow lesions, wounds, diarrhoea, dysentery, eye disorders, stomach disorders, asthma, lithiasis, anuria, African trypanosomiasis, measles, small pox and chicken pox (Dalziel 1955; Adegoke et al. 1968; Irvin 1965; Mairura 2008). In Côte d'Ivoire African trypanosomiasis is treated with a mixture of leaves of *Physalis angulata* and *Anchomanes difformis*. A leaf lotion is applied to treat ophthalmia in children. Leaves are eaten or applied as an enema to cure stomach-upset, colic, lithiasis and anuria, and are added to palm wine to cure fever and to calm attacks of asthma, vomiting and diarrhoea. The leaves are applied to infected scarification wounds and Guinea worm sores and used externally for rheumatic pain.

In Indian folkloric medicine the plant (leaves and shoots) is regarded as bitter, appetizing, tonic, diuretic, laxative, expectorant, febrifuge, useful in inflammations, enlargement of the spleen, ear-ache, and abdominal disorders (Kirtikar and Basu 1975; Parmar and Kaushal 1982; Chopra

et al. 1986). The fruit is considered to be a tonic, diuretic and purgative in the Punjab. The *mundas* (a tribe) of Chhota Nagpur mix the juice of the leaves with water and mustard oil and use it as a remedy against earache.

The plant is also widely used for various ailments in traditional medicine in southeast Asia and Papua New Guinea (Heyne 1950; Burkill 1966; Rahayu 2002; Chai 2006). In Peninsular Malaysia, the Malays are reported to poultice the plant for headache and an infusion taken for intestinal pains. Leaves smeared with oil and heated were applied to ulcers. A decoction of the plant and *Plantago major* leaves were used for gonorrhoea and as diuretic. In Sarawak, the Malays use a poultice of the plant for headaches; the Selako bolid the plant with salt and the solution is used as gargle for toothache. In Sabah, a decoction of the roots is drunk to treat hypertension and diabetes. In Brunei, chewed roots are applied to the lower abdomen to reduce stomach pain. Pounded leaves are used for headache and itches. In Indonesia, the leaves had been used as vermifuge and an extract for fever. The fruits are regarded as diuretic, purgative and aperients, and used for treating epilepsy, dysuria, jaundice, bleeding gums, dropsy, urinary disorders and gout. In Sulawesi, the herb infusion is used as a remedy for hepatitis, influenza, bronchitis, throat infections and orchitis. In Papua New Guinea, a leaf decoction is drunk to treat constipation; leaf sap aqueous solution is taken as an abortifacient. In the Solomon Islands, the seeds are recorded as a remedy for sterility. In Thailand, the herb is used as a diuretic, antidiarrhoeal and antipyretic. An aqueous solution of the crushed plant is drunk for oral abscesses or topically applied to them. In the Philippines, the root decoction is used to treat diabetes and hypoglycaemia.

Other Uses

The plant has been fed to cattle and sheep in tropical Africa but in larger quantities the plant is poisonous (Mairura 2008).

Comments

Raju et al. (2007) provided evidence that indicated the name "*Physalis minima* L." was misapplied to two different elements, viz., *P. angulata* L. and *P. lagascae* Roem. & Schult. The recommended name *Physalis minima* L. may be rejected as nomen confusum, for which their paper provided the primary information. They submerged *P. minima* under the synonymy of *P. angulata* L. The correct name for the widely known *P. minima* is *P. lagascae*.

Selected References

- Abe F, Nagafuji S, Okawa M, Kinjo J (2006) Trypanocidal constituents in plants 6. 1) Minor withanolides from the aerial parts of *Physalis angulata*. Chem Pharm Bull(Tokyo) 54(8):1226–1228
- Adegoke EA, Akinsaya A, Naqui SHZ (1968) Studies of Nigerian medicinal plants I. A preliminary survey of plant alkaloids. J W Africa Sci Assoc 13:13–33
- Alluri RR, Miller RJ, Shelver WH, Khalil SK (1976) Dihydroxyphysalin B: a new physalin from *Physalis minima* leaves. Lloydia 39(6):405–408
- Alves dos Santos R, Cabral TR, Cabral IR, Antunes LM, Pontes Andrade C, Cerqueira dos Santos Cardoso P, de Oliveira Bahia M, Pessoa C, Martins do Nascimento JL, Rodríguez Burbano R, Takahashi CS (2008) Genotoxic effect of *Physalis angulata* L. (Solanaceae) extract on human lymphocytes treated in vitro. Biocell 32(2):195–200
- Ayala Flores F (1984) Notes on some medicinal and poisonous plants of Amazonian Peru. In: Prance GT, Kallunki JA (eds) Ethnobotany in the neotropics, vol 1, Advances in economic botany. New York Botanical Garden, New York, pp 1–8
- Basey K, McGaw BA, Woolley JG (1992) Phygrine, an alkaloid from *Physalis* species. Phytochemistry 31(12):4173–4176
- Bastos GN, Santos AR, Ferreira VM, Costa AM, Bispo CI, Silveira AJ, Do Nascimento JL (2006) Antinociceptive effect of the aqueous extract obtained from roots of *Physalis angulata* L. on mice. J Ethnopharmacol 103(2):241–245
- Bastos GN, Silveira AJ, Salgado CG, Picanço-Diniz DL, do Nascimento JL (2008) *Physalis angulata* extract exerts anti-inflammatory effects in rats by inhibiting different pathways. J Ethnopharmacol 118(2):246–251
- Branch L, da Silva I (1983) Folk medicine of Alter do Chao, Para, Brazil. Acta Amazonica 13(5–6):737–797
- Brustolim D, Vasconcelos JF, Freitas LA, Teixeira MM, Farias MT, Ribeiro YM, Tomassini TC, Oliveira GG,

- Pontes-de-Carvalho LC, Ribeiro-dos-Santos R, Soares MB (2010) Activity of physalin F in a collagen-induced arthritis model. *J Nat Prod* 73(8):1323–1326
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula, Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Burkill HM (2000) The useful plants of west tropical Africa, 2nd edn, vol 5, Families S–Z, Addenda. Royal Botanic Gardens, Kew, 686 pp
- Cáceres A, Menéndez H, Méndez E, Cohobón E, Samayoa BE, Jauregui E, Peralta E, Carrillo G (1995) Antigonorrhoeal activity of plants used in Guatemala for the treatment of sexually transmitted diseases. *J Ethnopharmacol* 48(2):85–88
- Castro DP, Figueiredo MB, Genta FA, Ribeiro IM, Tomassini TC, Azambuja P, Garcia ES (2009) Physalin B inhibits *Rhodnius prolixus* hemocyte phagocytosis and microaggregation by the activation of endogenous PAF-acetyl hydrolase activities. *J Insect Physiol* 55(6):532–537
- Chai PPK (2006) Medicinal plants of Sarawak. Lee Ming Press, Kuching, 212 pp
- Chen CM, Chen Z, Hsieh C, Zin W, Wen S (1990) Withangulatin A, a new withanolide from *Physalis angulata*. *Heterocycles* 31(7):1371–1375
- Chiang HC, Jaw SM, Chen PM (1992a) Inhibitory effects of physalin B and physalin F on various human leukemia cells in vitro. *Anticancer Res* 12(4):1155–1162
- Chiang HC, Jaw SM, Chen CF, Kan WS (1992b) Antitumor agent, physalin F from *Physalis angulata* L. *Anticancer Res* 12(3):837–843
- Chiramongkolgarn U, Paisooksantivatana Y (2002) Medicinal plants in Tao Dam Forest, Wangkrajae Village, Sai Yok District, Kanchanaburi Province. *Thai J Phytopharm* 9(2):47–56
- Choi EM, Hwang JK (2003) Investigations of anti-inflammatory and antinociceptive activities of *Piper cubeba*, *Physalis angulata* and *Rosa* hybrid. *J Ethnopharmacol* 89(1):171–175
- Choi EM, Hwang JK (2005) Effect of some medicinal plants on plasma antioxidant system and lipid levels in rats. *Phytother Res* 19(5):382–386
- Chopra RN, Nayar SL, Chopra IC (1986) Glossary of Indian medicinal plants (Including the Supplement). Council Scientific Industrial Research, New Delhi, 330 pp
- Choudhary MI, Yousaf S, Ahmed S, Yasmeen K (2005) Antileishmanial physalins from *Physalis minima*. *Chem Biodivers* 2(9):1164–1173
- Choudhary MI, Yousuf S, Samreen AS, Atta-Ur-Rahman (2007) New leishmanicidal physalins from *Physalis minima*. *Nat Prod Res* 21(10):877–883
- Dalziel JM (1955) The useful plants of west tropical Africa (Reprint of 1937 edn.) Crown Agents for Overseas Governments and Administrations, London, 612 pp
- Damu AG, Kuo PC, Su CR, Kuo TH, Chen TH, Bastow KF, Lee KH, Wu TS (2007) Structures, and structure–cytotoxic activity relationships of withanolides and physalins from *Physalis angulata*. *J Nat Prod* 70(7):1146–1152
- DeFilipps RA, Maina SL, Crepin J (2004) Medicinal plants of Guianas (Guyana, Surinam, French Guiana). Department of Botany, National Museum of Natural History, Smithsonian Institution, Washington, DC
- Dinakaran SK, Saraswathi NR, Nalini VR, Srisudharson, Bodanapu VR, Avasarala H, Banji D (2011) Anti lipid peroxidation activity of *Piper trioicum* Roxb. and *Physalis minima* L. extracts. *Pak J Pharm Sci* 24(3):411–413
- dos Santos JA, Tomassini TC, Xavier DC, Ribeiro IM, da Silva MT, de Moraes Filho ZB (2003) Molluscicidal activity of *Physalis angulata* L. extracts and fractions on *Biomphalaria tenagophila* (d'Orbigny, 1835) under laboratory conditions. *Mem Inst Oswaldo Cruz* 98(3):425–428
- Duke JA, Martinez RV (1994) Amazonian ethnobotanical dictionary. CRC Press, Boca Raton, 224 pp
- Foundation for Revitalisation of Local Health Traditions (2008) FRLHT database. <http://envis.frlht.org>
- Freiburghaus F, Kaminsky R, Nkunya MHH, Brun R (1996) Evaluation of African medicinal plants for their in vitro trypanocidal activity. *J Ethnopharmacol* 55:1–11
- Freitas TA, Rodrigues ACC, Osuna JTA (2006) Cultivation of *Physalis angulata* L. and *Anadenanthera colubrina* [(Vell.) Brenan] species of the Brazilian semi-arid. *Rev Bras Pl Med Botucatu* 8:201–204
- Garcia ES, Castro DP, Ribeiro IM, Tomassini TC, Azambuja P (2006) *Trypanosoma rangeli*: effects of physalin B on the immune reactions of the infected larvae of *Rhodnius prolixus*. *Exp Parasitol* 112(1):37–43
- Glottier E, Kirson I, Abraham A, Sethi PD, Subramanian SS (1975) Steroidal constituents of *Physalis minima* (Solanaceae). *J Chem Soc Perkin I*(14):1370–1374
- Gonçalves AE (2005) Solanaceae. In: Pope GV, Polhill RM, Martins ES (eds) *Flora Zambesiaca*, vol 8, part 4. Royal Botanic Gardens, Kew, 124 pp
- Gottlieb HE, Cojocar M, Sinha SC, Saha M, Bagchi A, Ali A, Ray AB (1987) Withaminimin, a withanolide from *Physalis minima*. *Phytochemistry* 26(6):1801–1804
- Guimarães ET, Lima MS, Santos LA, Ribeiro IM, Tomassini TB, Ribeiro dos Santos R, dos Santos WL, Soares MB (2009) Activity of physalins purified from *Physalis angulata* in in vitro and in vivo models of cutaneous leishmaniasis. *J Antimicrob Chemother* 64(1):84–87
- He QP, Ma L, Luo JY, He FY, Lou LG, Hu LH (2007) Cytotoxic withanolides from *Physalis angulata* L. *Chem Biodivers* 4(3):443–449
- Heyne K (1950) *De Nuttige Planten van Indonesië* [The useful plants of Indonesia], 3rd edn, 2 vols. W. van Hoeve, 's-Gravenhage, the Netherlands/Bandung, 1660 pp
- Hseu YC, Wu CR, Chang HW, Kumar KJ, Lin MK, Chen CS, Cho HJ, Huang CY, Huang CY, Lee HZ, Hsieh

- WT, Chung JG, Wang HM, Yang HL (2011) Inhibitory effects of *Physalis angulata* on tumor metastasis and angiogenesis. *J Ethnopharmacol* 135(3):762–771
- Hsieh WT, Huang KY, Lin HY, Chung JG (2006) *Physalis angulata* induced G2/M phase arrest in human breast cancer cells. *Food Chem Toxicol* 44(7):974–983
- Hsu CC, Wu YC, Farh L, Du YC, Tseng WK, Wu CC, Chang FR (2012) Physalin B from *Physalis angulata* triggers the NOXA-related apoptosis pathway of human melanoma A375 cells. *Food Chem Toxicol* 50(3–4):619–624
- Hu SY (2005) Food plants of China. The Chinese University Press, Hong Kong, 844 pp
- Irvin FR (1965) Botany and medicine in West Africa. Ibadan University Press, Ibadan, pp 102–130
- Ismail N, Alam M (2005) A novel cytotoxic flavonoid glycoside from *Physalis angulata*. *Fitoterapia* 72(6):676–679
- Januário AH, Filho ER, Pietro RC, Kashima S, Sato DN, França SC (2002) Antimycobacterial physalins from *Physalis angulata* L. (Solanaceae). *Phytother Res* 16(5):445–448
- Jin Z, Mashuta MS, Stollowich NJ, Vaisberg AJ, Stivers NS, Bates PJ, Lewis WH, Hammond GB (2012) Physangulidines A, B, and C: three new antiproliferative withanolides from *Physalis angulata* L. *Org Lett* 14(5):1230–1233
- Juang K, Huang HW, Chen CM, Liu HJ (1989) A new compound, withangulatin A, promotes type II DNA topoisomerase-mediated DNA damage. *Biochem Biophys Res Commun* 159(3):1128–1134
- Khan MA, Khan H, Khan S, Mahmood T, Khan PM, Jabbar A (2009) Anti-inflammatory, analgesic and antipyretic activities of *Physalis minima* Linn. *J Enzyme Inhib Med Chem* 24(3):632–637
- Kirtikar KR, Basu BD (1975) Indian medicinal plants, 4 vols, 2nd edn. Jayyed Press, New Delhi
- Kuo PC, Kuo TH, Damu AG, Su CR, Lee EJ, Wu TS, Shu R, Chen CM, Bastow KF, Chen TH, Lee KH (2006) Physanolide A, a novel skeleton steroid, and other cytotoxic principles from *Physalis angulata*. *Org Lett* 8(14):2953–2956
- Kurokawa M, Ochiai H, Nagasaka K, Neki M, Xu H, Kadota S, Sutardjo S, Matsumoto T, Namba T, Shiraki K (1993) Antiviral traditional medicines against herpes simplex virus (HSV-1), poliovirus, and measles virus in vitro and their therapeutic efficacies for HSV-1 infection in mice. *Antiviral Res* 22(2–3):175–188
- Kusumoto IT, Kakiuchi N, Hattori M, Namba T, Sutardjo S, Shimotohno K (1992a) Screening of some Indonesian medicinal plants for inhibitory effects on HIV-1 protease. *Shoyahugaku Zasshi* 46(2):190–193
- Kusumoto IT, Shimada I, Kakiuchi N, Hattori M, Namba T, Supriyatna S (1992b) Inhibitory effects of Indonesian plant extracts on reverse transcriptase of an RNA Tumour Virus (I). *Phytother Res* 6:241–244
- Lee CC, Houghton P (2008) Cytotoxicity of plants from Malaysia and Thailand used traditionally to treat cancer. *J Ethnopharmacol* 100(3):237–243
- Lee WC, Lin KY, Chen CM, Chen ZT, Liu HJ, Lai YK (1991) Induction of heat-shock response and alterations of protein phosphorylation by a novel topoisomerase II inhibitor, withangulatin A, in 9L rat brain tumor cells. *J Cell Physiol* 149(1):66–76
- Lee SW, Pan MH, Chen CM, Chen ZT (2008) Withangulatin I, a new cytotoxic withanolide from *Physalis angulata*. *Chem Pharm Bull(Tokyo)* 56(2):234–236
- Lee HZ, Liu WZ, Hsieh WT, Tang FY, Chung JG, Leung HW (2009) Oxidative stress involvement in *Physalis angulata*-induced apoptosis in human oral cancer cells. *Food Chem Toxicol* 47(3):561–570
- Leong OK, Muhammad TS, Sulaiman SF (2011) Cytotoxic activities of *Physalis minima* L. chloroform extract on human lung adenocarcinoma NCI-H23 cell lines by induction of apoptosis. *Evid Based Complement Alternat Med Vol* 2011: Article ID 185064
- Lin YS, Chiang HC, Kan WS, Hone E, Shih SJ, Won MH (1992) Immunomodulatory activity of various fractions derived from *Physalis angulata* L. extract. *Am J Chin Med* 20(3–4):233–243
- Lopez JA, Saenz JA, Slatkin DJ, Knapp JE, Schiff PL Jr (1976) Flavonoid and lipid constituents of *Hymenaea courbaril* and *Physalis angulata*. *Phytochemistry* 15(12):2028
- Lusakibanza M, Mesia G, Tona G, Karemere S, Lukuka A, Tits M, Angenot L, Frédéric M (2010) In vitro and in vivo antimalarial and cytotoxic activity of five plants used in Congolese traditional medicine. *J Ethnopharmacol* 129(3):398–402
- Magalhães HI, Veras ML, Torres MR, Alves AP, Pessoa OD, Silveira ER, Costa-Lotufo LV, de Moraes MO, Pessoa C (2006) In-vitro and in-vivo antitumour activity of physalins B and D from *Physalis angulata*. *J Pharm Pharmacol* 58(2):235–241
- Mairura FS (2008) *Physalis angulata* L. In: Schmelzer GH, Gurib-Fakim A (eds) *Prota 11(1): Medicinal plants/Plantes Médicinales 1*. [CD-Rom]. PROTA, Wageningen
- Mejia K, Rengifo E (1995) Plantas Medicinales de Uso Popular en la Amazonia Peruana. AECI and IIAP, Lima, 286 pp
- Mello AC, Afatpour P (1985) Presence of acetylcholine in the fruit of *Physalis angulata* (Solanaceae). *Ciênc Cult (São Paulo)* 37(5):799–805
- Nagafuji S, Okabe H, Akahane H, Abe F (2004) Trypanocidal constituents in plants 4. Withanolides from the aerial parts of *Physalis angulata*. *Biol Pharm Bull* 27(2):193–197
- Neelam S, Gokara M, Sudhamalla B, Amooru DG, Subramanyam R (2010) Interaction studies of coumaroyltyramine with human serum albumin and its biological importance. *J Phys Chem B* 114(8):3005–3012
- Ooi KL, Tengku Muhammad TS, Lim CH, Sulaiman SF (2010a) Apoptotic effects of *Physalis minima* L. chloroform extract in human breast carcinoma T-47D cells mediated by c-myc-, p53-, and caspase-3-dependent pathways. *Integr Cancer Ther* 9(1):73–83

- Ooi KL, Tengku Muhammad TS, Sulaiman SF (2010b) Growth arrest and induction of apoptotic and non-apoptotic programmed cell death by, *Physalis minima* L. chloroform extract in human ovarian carcinoma Caov-3 cells. *J Ethnopharmacol* 128(1):92–99
- Ooi KL, Tengku Muhammad TS, Sulaiman SF (2011) Cytotoxic activities of *Physalis minima* L. chloroform extract on human lung adenocarcinoma NCI-H23 cell lines by induction of apoptosis. *Evid Based Complement Alternat Med* Vol 2011:Article ID 185064
- Oshima Y, Bagchi A, Hikino H, Sinha SC, Ray AB (1987) Withaphysalin E, a withanolide of *Physalis minima* var. *indica*. *Phytochemistry* 26(7):2115–2117
- Osho A, Adetunji T, Fayemi SO, Moronkola DO (2010) Antimicrobial activity of essential oils of *Physalis angulata* L. *Afr J Tradit Complement Altern Med* 7(4):303–306
- Otake T, Mori H, Morimoto M, Ueba N, Sutardjo S, Kusumoto IT, Hattori M, Namba T (1995) Screening of Indonesian plant extracts for anti-human immunodeficiency virus—type 1 (HIV-1) activity. *Phytother Res* 9:6–10
- Pacific Island Ecosystems at Risk (PIER) (2007) *Physalis angulata* L. Solanaceae. http://www.hear.org/pier/species/physalis_angulata.htm
- Parmar C, Kaushal MK (1982) Wild fruits of the sub-Himalayan region. Kalyani Publishers, Ludhiana, pp 136
- Patel T, Shah K, Jiwan K, Shrivastava N (2011) Study on the antibacterial potential of *Physalis minima* Linn. *Indian J Pharm Sci* 73(1):111–115
- Pietro RC, Kashima S, Sato DN, Januário AH, França SC (2000) In vitro antimycobacterial activities of *Physalis angulata* L. *Phytomedicine* 7(4):335–338
- Pinto NB, Morais TC, Carvalho KM, Silva CR, Andrade GM, Brito GA, Veras ML, Pessoa OD, Rao VS, Santos FA (2010) Topical anti-inflammatory potential of Physalin E from *Physalis angulata* on experimental dermatitis in mice. *Phytomedicine* 17(10):740–743
- Porcher MH et al (1995–2020) Searchable world wide web multilingual multiscript plant name database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Putalun W, Prasamsiwamai P, Tanaka H, Shoyama Y (2004) Solasodine glycoside production by hairy root cultures of *Physalis minima* Linn. *Biotechnol Lett* 26(7):545–548
- Quisumbing E (1978) Medicinal plants of the Philippines. Katha Publishing Co., Quezon, 1262 pp
- Rahayu SSB (2002) *Physalis* L. In: van Valkenburg JLCH, Bunyapraphatsara N (eds) Plant resources of south-east Asia no 12(2): medicinal and poisonous plants 2. Prosea Foundation, Bogor, pp 423–426
- Raju VS, Reddy CS, Rajarao KG (2007) The myth of ‘minima’ and ‘maxima’, the species of *Physalis* in the Indian subcontinent. *Acta Phytotaxon Sin* 45(2):239–245
- Rathore C, Dutt KR, Sahu S, Deb L (2011) Antiasthmatic activity of the methanolic extract of *Physalis angulata* Linn. *J Med Plant Res* 5(22):5351–5355
- Ribeiro IM, Silva MTG, Soares RDA, Stutz CM, Bozza M, Tomassini TCB (2002) *Physalis angulata* L. anti-neoplastic activity, in vitro, evaluation from its stems and fruit capsules. *Rev Bras Farmacogn* 12:21–23
- Row LR, Reddy KS, Sarma NS, Matsuura T, Nakashima R (1978a) New physalins from *Physalis angulata* and *Physalis lancifolia*. Structure and reactions of physalins D, I, G and K. *Phytochemistry* 19(6):1175–1181
- Row LR, Saito N, Matsuura T, Nakashima R (1978b) Physalins E and H, new physalins from *Physalis angulata* and *P. lancifolia*. *Phytochemistry* 17(9):1641–1645
- Ruiz L, Ruiz L, Maco M, Cobos M, Gutierrez-Choquevilca AL, Roumy V (2011) Plants used by native Amazonian groups from the Nanay River (Peru) for the treatment of malaria. *J Ethnopharmacol* 133(2):917–921
- Rutter RA (1990) *Catalogo de Plantas Utiles de la Amazonia Peruana*. Instituto Linguistico de Verano, Yarinacocha, 349 pp
- Sá MS, de Menezes MN, Krettli AU, Ribeiro IM, Tomassini TC, Ribeiro dos Santos R, de Azevedo WF, Jr SMB (2011) Antimalarial activity of physalins B, D, F, and G. *J Nat Prod* 74(10):2269–2272
- Sahai M, Kirson I (1984) Withaphysalin D, a new withaphysalin from *Physalis minima* Linn. var. *indica*. *J Nat Prod* 47(3):527–529
- Sen G, Pathak HD (1995) Physalin L, a 13,14-seco-16,24 cyclosteroid from *Physalis minima*. *Phytochemistry* 93(5):1245–1246
- Shariff N, Sudarshana MS, Umesha S, Hariprasad P (2006) Antimicrobial activity of *Rauvolfia tetraphylla* and *Physalis minima* leaf and callus extracts. *Afr J Biotechnol* 5(10):946–950
- Shingu K, Marubayashi N, Ueda I, Yahara S, Nohara T (1991) Physagulin C, a new withanolide from *Physalis angulata* L. *Chem Pharm Bull* 39(6):1591–1593
- Shingu K, Yahara S, Nohara T, Okabe H (1992a) Three new withanolides, physagulins A, B and D from *Physalis angulata* L. *Chem Pharm Bull* 40(8):2088–2091
- Shingu K, Yahara S, Okabe H, Nohara T (1992b) Three new withanolides, physagulins E, F and G from *Physalis angulata* L. *Chem Pharm Bull* 40(9):2448–2451
- Silva MT, Simas SM, Batista TG, Cardarelli P, Tomassini TC (2005) Studies on antimicrobial activity, in vitro, of *Physalis angulata* L. (Solanaceae) fraction and physalin B bringing out the importance of assay determination. *Mem Inst Oswaldo Cruz* 100(7):779–782
- Sinha SC, Ali A, Bagchi A, Sahai M, Ray AB (1987) Physalindicanols, new biogenetic precursors of C28-steroidal lactones from *Physalis minima* var. *indica*. *Planta Med* 53(1):55–57
- Soares MB, Bellintani MC, Ribeiro IM, Tomassini TC, Ribeiro dos Santos R (2003) Inhibition of macrophage activation and lipopolysaccharide-induced death by seco-steroids purified from *Physalis angulata* L. *Eur J Pharmacol* 459(1):107–112
- Soares MB, Brustolim D, Santos LA, Bellintani MC, Paiva FP, Ribeiro YM, Tomassini TC, Ribeiro Dos

- Santos R (2006) Physalins B, F and G, seco-steroids purified from *Physalis angulata* L., inhibit lymphocyte function and allogeneic transplant rejection. *Int Immunopharmacol* 6(3):408–414
- Stone BC (1970) The flora of Guam. *Micronesica* 6:1–659
- Sun L, Liu J, Cui D, Li J, Yu Y, Ma L, Hu L (2010) Anti-inflammatory function of Withangulatin A by targeted inhibiting COX-2 expression via MAPK and NF-kappaB pathways. *J Cell Biochem* 109(3):532–541
- Sun L, Zhou L, Chen M, Zhong R, Liu J (2011) Amelioration of systemic lupus erythematosus by Withangulatin A in MRL/lpr mice. *J Cell Biochem* 112(9):2376–2382
- Vieira AT, Pinho V, Lepsch LB, Scavone C, Ribeiro IM, Tomassini T, Ribeiro-dos-Santos R, Soares MB, Teixeira MM, Souza DG (2005) Mechanisms of the anti-inflammatory effects of the natural secosteroids physalins in a model of intestinal ischaemia and reperfusion injury. *Br J Pharmacol* 146(2):244–251
- Waterfall UT (1967) *Physalis* in Mexico, Central America and the West Indies. *Rhodora* 69(778):203–240
- Wu SJ, Ng LT, Chen CH, Lin DL, Wang SS, Lin CC (2004) Antihepatoma activity of *Physalis angulata* and *P. peruviana* extracts and their effects on apoptosis in human Hep G2 cells. *Life Sci* 74(16):2061–2073
- Yu Y, Sun L, Ma L, Li J, Hu L, Liu J (2010) Investigation of the immunosuppressive activity of Physalin H on T lymphocytes. *Int Immunopharmacol* 10(3):290–297
- Zhang ZY, Lu A, D’Arcy WG (2008) Solanaceae A. L. Jussieu. In: Wu ZY, Raven PH, Hong DY (eds) *Flora of China*, vol 11, Oxalidaceae through Aceraceae. Science Press/Missouri Botanical Garden Press, Beijing/St. Louis

Physalis peruviana

Scientific Name

Physalis peruviana L.

Peruvian Ground Cherry, Poha, Poha Berry, Strawberry Tomato, Winter Cherry.

Synonyms

Alkekengi pubescens Moench, *Boberella peruviana* (L.) E.H.L. Krause, *Boberella pubescens* (L.) E. H. L. Krause in Sturm, *Herschelia edulis* (Sims) Bowdich, *Physalis chenopodifolia* Lam., *Physalis edulis* Sims, *Physalis esculenta* Salisbury, *Physalis latifolia* Lam., *Physalis peruviana* var. *latifolia* (Lam.) Dunal, *Physalis puberula* Fernald, *Physalis tomentosa* Medik.

Family

Solanaceae

Common/English Names

Aztec Berry, Barbados Gooseberry, bladderberry, Cape Gooseberry, Cherry Tomato Goldenberry, Gooseberry-Tomato, goldenberry, Husk Cherry, Inca Berry, obra cabbage, Peruvian Cherry,

Vernacular Names

Arabic: Hhabwah, Hhashîsh Sakrân;
Bolivia: Capuli, Motojobobo Embolsado;
Brazil: Alquequenje Amarelo, Bate-Testa, Camapú, Erva-Noiva-Do-Peru, Groselha Do Perú, Herva Noiva Do Perú (Portuguese);
Chile: Capuli, Amor En Bolsa, Bolsa De Amor;
Chinese: Deng Long Cao, Deng Long Guo, Gu Niao, Mao, suan Jiang, Suan Jiang Cao, Xiao Guo Suan Jiang;
Columbia: Uvilla, Uchuva, Vejigón, Guchavo;
Cook Islands: Tupera, Tūpere, Tūpere (Maori);
Czech: Mochyně Peruánská;
Danish: Ananaskirsebaer, Kapstikkelsbaer;
Dutch: Ananaskers, Goudbes, Kaapsche Kruisbes, Kaapse Kruisbes, Lampion, Peruaansche Ananaskers, Peruviaanse Aardkers;
Eastonian: Peruu Füüsal;
Ecuador: Uvilla (Spanish);
Egypt: Harankash, Is-Sitt Il-Mistahiya;
Fijian: Botebote Yadra, Kospeli, Maulanggua, Mbotembote Yandra, Tukiyandra;

Finnish: Ananaskirsikka, Kapinmarja, Kapinkarviainen, Karviaiskoiso;

French: Alkékange Jaune Doux, Alkékange Du Pérou, Capuli, Coqueret Comestible, Coqueret Du Pérou, Coquerelle, Groseille Du Cap, Groseiller Canaque, Poc Poc;

Gabon: Alkekengi, Coqueret;

German: Ananaskirsche, Kap-Stachelbeere, Capische Stachelberre, Essbare Judaskirsche, Judenkirsche, Kapstachelbeere, Peruanische Schlutte;

Hawaiian: Pa'Ina, Poha;

I-Kiribati: Te Baraki, Te Bin;

India: Macao, Makowi, Rasbhari, Teparee, Tipriyo, Tiparee (Hindu), Budde Hannu, Doddabudd (Kannada), Chirbot, Popti, Phopati (Marathi), Kuntali, Tankari, Tankasi (Sanskrit), Milkau Takkali, Pottipallam (Tamil), Buddabusara, Busarataya (Telugu);

Italian: Alchechenge Giallo, Alchechengi Giallo, Alchechenge Grosso Comestibile, Capulé, Fisalis, Vescicaria;

Japanese: Ke Hôzuki;

Malawi: Jamu, Peruvian Cherry;

Mangarevan: Maru;

Mexico: Cereza Del Peru;

Nauruan: Oatamo, Watamo;

Nepalese: Ishmagol, Jangalii Mevaa, Jangali Meva, Rasabarii, Rasbari;

Niuean: Manini, Manini Fua Lalahi;

Peru: Capulí, Pasa Capulí, Aguaymanto, Tomate Sylvestre, Motojobobo Embolsado, Uchuba;

Philippines: Lobolobohan (Tagalog);

Polish: Miechunka Peruwianska;

Portuguese: Groselha-Do-Peru Tomateiro Inglês, Tomatinho-De-Capucho;

Quecha: Aguaymanto, Topotopo;

Slovenian: Perujsko Volčje Jabolko;

South Africa: Cape Gooseberry, Golden Berry, Pomelmoes, Apelliefie;

Spanish: Alquequenje, Capuli, Uvilla, Yuyo De Ojas;

Sri Lanka: Thol Thakkali (Sinhalese);

Sudan: Habwa (Arabic);

Swedish: Ananaskörsbär, Kapkrusbär;

Tahitian: Tupere;

Tongan: Ku'Usi;

Turkish: Altın Çilek, Sarhosh Out;

Venezuela: Topotopo, Chuchuva, Alquequenje Amarillo, Alchechengi Del Perú, Amor En Bolsa, Cereza Del Perú.

Origin/Distribution

Cape gooseberry is indigenous to South America in the high altitude tropical Colombia, Chile, Ecuador and Peru where the fruit grows wild. It is cultivated in Central and South America, tropical Africa, India, SE Asia, Australia, also in some parts of Europe and East Asia, and has also naturalized in many of these areas.

Agroecology

The cape gooseberry behaves as an annual in temperate regions and a perennial in the tropics from near sea level to 3,000 m elevations. The plant is grown from sea level in New Zealand, for instance, to 3,000 m near the equator in the Andes. In Venezuela, it grows wild in the Andes and the coastal range between 800 and 3,000 m. It has naturalised and grows wild in Hawaii at 300–2,400 m. In northern India, it is not possible to cultivate it above 1,200 m, but in South India it thrives up to 1,800 m. It thrives best in frost free areas with temperatures of 15–30°C. Plants are frost tender and are killed at sub-zero temperatures. In South Africa, plants have been killed to the ground and failed to recover after a temperature drop to –0.75°C. In temperate areas, The plant need frost protection and are easily grown in pots and adapt well to greenhouse culture. Heat apparently does not inhibit fruit setting; in Hawaii, the plant produces fruit where day temperatures are in the range of 27–32°C. The plant needs full sun but protection from strong winds; plenty of rain throughout its growing season, very little when the fruits are maturing. A mean annual rainfall of 800 mm is adequate but it will also grown in areas with heavy rainfall above 3,000 mm where drainage is good. The plant abhors waterlogged conditions and will grown in any free draining soils from pH 4.5–8.2. It prefers highly weathered, free draining tropical latosols, gravelly soils and fertile, well-drained, sandy soils.

Edible Plant Parts and Uses

The acid-sweet aromatic fruits are eaten raw on its own, in fruit salads, fruit cocktails, in cooked dishes or canned whole in syrup or processed into jams. The fruit is ideal for snacks and for making pies, puddings, chutneys, jams, jellies, preserves, ice cream and sauces and glazes for meat and seafood. In Colombia, the fruits are stewed with honey and eaten as dessert. The British use the husk as a handle for dipping the fruit in icing.

Botany

Cape gooseberry is herbaceous or soft-wooded, perennial plant, 45–90 cm high, sparingly branched, with densely pubescent and ribbed, often purplish branches. Leaves are sub-opposite, on 2–5 cm long petioles, lamina is broadly ovate to cordate, 6–15 × 4–10 cm, densely pubescent, base cordate, margin entire or with a few irregular indistinct teeth, apex short acuminate (Plate 1). Flowers occur in leaf axils on 1.5 cm pedicel with campanulate (bell-shaped) purplish-green pubescent calyx, 7–9 mm with five pointed lobes, corolla yellow and purple spotted in throat, 1.2–1.5 × 1.2–2 cm, stamens with blue purple filaments and anthers (Plates 1 and 2). After fertilisation, the calyx expands, ultimately forming an ovoid, 5–10 weakly ribbed, pubescent straw-coloured parchment-like husk enclosing the fruit (Plate 3). Fruit is a sub-globose berry, 1.25–2 cm diameter, green turning to a glossy, smooth, golden –yellow when ripe (Plate 4), with numerous tiny (2 mm diameter) yellowish, flat seeds embedded in the juicy edible pulp.

Nutritive/Medicinal Properties

Goldenberry fruit was reported to have the following proximate nutrient composition (per 100 g pulp) energy 73 cal, water 78.9 g, protein 0.3 g, fat 0.2 g, carbohydrate 19.6 g, fibre 4.9 g, ash



Plate 1 Leaves and flowers of goldenberry



Plate 2 Close-up of flower



Plate 3 Goldenberry fruits



Plate 4 Goldenberry fruit with parchment-like husk removed



1.0 g, Na 1 mg, K 320 mg, Ca 8 mg, P 55 mg, Fe 1.20 mg, β -carotene 11,460 mg, thiamin 0.10 mg, riboflavin 0.03 mg, niacin 1,70 mg and vitamin C 43 mg (National Research Council 1989). Nutrient composition (per 100 g fruit) was reported by Fischer et al. (2000) as: energy 49 cal, water 85.5 g, protein 1.5 g, fat 0.5 g, carbohydrate 11 g, fibre 0.4 g, and ash 0.7 g. In their ecological study in the Boyaca region of Columbia, they found that



β -carotene content of ripe fruits increased markedly whereas α -carotene and β -cryptoxanthin only slightly increased with decreasing altitude (2,300 versus 2,690 m). Of the analyzed carotenoids, β -carotene had the highest concentration (236 $\mu\text{g}/100$ g FW). Altitude did not show a significant influence on ascorbic acid content (32.2 mg/100 g FW). None of the analyzed organic acids (citric, malic and tartaric acid) was affected by the site factor; citric acid was the dominating acid (2,018 mg/100 g FW). De Carrasco and Zelada (2008) reported the following nutrient composition per 100 g fruit: energy 76.8 kcal, water 79.8 g, ash 1 g, crude protein 1.9 g, crude fibre 3.6 g, carbohydrate 17.3 g, P 37.9 mg, Ca 10.55 g, Fe 1.24 mg, Zn 0.4 mg, K 292.65 mg, brix 13.4° and pH 3.43.

Physalis peruviana was also found to have high contents of ash (0.8 g/100 g) and total lipids (3.16 g/100 g) (Rodrigues et al. 2009). In its mineral composition, K, Mg, Ca and Fe were the main elements, and Fe concentrations were higher than those in the common beans. The lipid fraction was predominated by linoleic acid (72.42%). Its elemental and lipid composition per 100 g edible portion was as follows: moisture 80.97 g, total lipids 3.16 g, total carbohydrates 13.22 g, protein 1.85 g, ash 0.80 g, energy 88.72 kcal/372.62 kJ, Fe 1.47 mg, Mg 34.70 mg, Zn 0.49 mg, Ca 9.00 mg, K 347.00 mg, Na 1.10 mg, Cu 0.28 mg, Mn 0.26 mg, Al 0.33 mg, Ba 0.06 mg, Co 0.01 mg, Cr 0.01 mg, Sr 0.04 mg, Rb 0.42 mg; saturated fatty acids 12.87%, C16:0 (palmitic) 9.38%, C18:0 (stearic) 2.67%, C20:0 (arachidic) 1.36%, C22:0 (behenic) 0.26%, C24:0 (lignoceric) 0.24%; monounsaturated fatty acids

10.71%, C16:1 (palmitoleic) 0.71%, C18:1 (oleic) 10.03%; polyunsaturated fatty acids 73.78%, C18:2 (linoleic) 72.42% and C18:3 (α -linolenic) 0.32% (Rodrigues et al. 2009).

The total lipid contents in the whole berries, seeds, and seedless parts were 2.0, 1.8, and 0.2% (on a fresh weight basis), respectively (Ramadan and Mörsel 2003). In the pulp/peel oil, the fatty acid profile was characterized by higher amounts of saturates, monoenes, and trienes than in whole berry and seed oils. The pulp and peel oil contained 16.10% saturated fatty acids, 27.70% monoenes, 44.4% dienes and 11.70% trienes while the seed oil contained 11.30% saturated fatty acids, 12.20% monoenes, 76.10% dienes and 0.33% trienes. Linoleic acid was the dominating fatty acid followed by oleic acid as the second major fatty acid. Palmitic and stearic acids were the major saturates. Neutral lipids comprised >95% of total lipids in whole berry oil and seed oil, while neutral lipids separated in lower levels in pulp/peel oil. Triacylglycerols were the predominant neutral lipid subclass and constituted ca. 81.6, 86.6, and 65.1% of total neutral lipids in whole berry, seed, and pulp/peel oils, respectively. Nine triacylglycerol molecular species were detected, wherein three species, C54:3, C52:2, and C54:6, were present to the extent of approximately 91% or more.

The highest level of phytosterols was found in pulp/peel oil that contained the highest level of unsaponifiables (Ramadan and Mörsel 2003). In both whole berry and seed oils, campesterol and β -sitosterol were the sterol markers, whereas δ -5-avenasterol and campesterol were the main 4-desmethylsterols in pulp/peel oil. The phytosterol profile (g/kg total lipids) of the pulp/peel oil was total phytosterol 53.20 g comprising campesterol 11.50 g, β -sitosterol 4.99 g, δ -5-avenasterol 11.80 g, lanosterol 7.44 g, stigmasterol 6.17 g, δ -7-avenasterol 2.68 g and ergosterol 8.62 g. The phytosterol composition (g/kg total lipids) of the seed oil was total phytosterol 22.50 g comprising campesterol 6.48 g, β -sitosterol 5.71 g, δ -5-avenasterol 4.57 g, lanosterol 2.27 g, stigmasterol 1.32 g, δ -7-avenasterol 1.11 g and ergosterol 1.04 g.

The tocopherols level was much higher in pulp/peel oil than in whole berry and seed oils (Ramadan and Mörsel 2003). β -tocopherol and γ -tocopherol were the major components in whole berry and seed oils, whereas γ -tocopherol and α -tocopherol were the main constituents in pulp/peel oil. The seed oil (in g/kg of total lipids) had 29.70 g vitamin E comprising 0.88 g α -tocopherol, 11.30 g β -tocopherol, 9.08 g γ -tocopherol and 8.44 g δ -tocopherol. The seed oil (in g/kg of total lipids) had 0.88 g α -tocopherol, 11.30 g β -tocopherol, 9.08 g γ -tocopherol and 8.44 g δ -tocopherol. The pulp and peel oil (in g/kg of total lipids) had 86.30 g vitamin E comprising 22.50 g α -tocopherol, 13.10 g β -tocopherol, 50.40 g γ -tocopherol and 0.30 g δ -tocopherol. β -carotene and vitamin K₁ were also measured in markedly high levels in pulp/peel oil followed by whole berry oil and seed oil, respectively. The vitamin K₁ content in the pulp/peel oil was 2.12 and 0.12 g/kg total lipids respectively.

Goldenberry pomace (seeds and skins) represents a large portion (about 27.4% of fruit weight) of the waste generated during juice processing (Ramadan and Mörsel 2009). The fruit pomace, contained 6.6% moisture, 17.8% protein, 3.10% ash, 28.7% crude fibre and 24.5% carbohydrates. The n-hexane-extractable oil content of the raw by-products was estimated to be 19.3%. Studies showed that enzymatic treatment increased the extraction yield by 42%. Further, application of enzymes, led to juices with higher pulp content, higher macro- and micro-elements, higher acidity and higher total soluble solids (Ramadan and Mörsel 2007). However, enzyme-treated juices were characterised by lower alcohol-soluble solids and pH values. Water- and fat-soluble bioactives were estimated in appreciable amounts in the juice. Antioxidant radical scavenging activity was also satisfactory.

Other Phytochemicals

Forty bound volatiles were identified in the volatile fraction of cape gooseberry fruit (Mayorga et al. 2001) including two new glycosides (1S,2S)-1-phenylpropane-1,2-diol 2-O- β -D-gluc-

pyranoside and *p*-menth-4(8)-ene-1,2-diol 1-O- α -L-arabinopyranosyl-(1-6)- β -D-glucopyranoside. They could be considered as immediate precursors of 1-phenylpropane-1,2-diol and *p*-menth-4(8)-ene-1,2-diol, typical volatiles found in the fruit of cape gooseberry. Several hydroxyester disaccharides were also isolated from the fruit: 3-O- β -D-glucopyranosyl-(1 $\rightarrow$ 6)- β -D-glucopyranoside of ethyl 3-hydroxyoctanoate and the diastereomeric 3-O- α -L-arabinopyranosyl-(1 $\rightarrow$ 6)- β -D-glucopyranosides of (3R) and (3S)-butyl 3-hydroxybutanoate (Mayorga et al. 2002). The three glycoconjugates can be considered as immediate precursors of ethyl 3-hydroxyoctanoate and butyl 3-hydroxybutanoate, which are important aroma volatiles found in the fruit.

Lan et al. (2009) isolated seven new withanolides, phyperunolide A, phyperunolide B, phyperunolide C, phyperunolide D, peruvianoxide, phyperunolide E and phyperunolide F together with ten known withanolides from the plant extracts. Other withanolides isolated in earlier studies from the plant materials, include withaperuvin E (Bagchi et al. 1984), Withaperuvins F and G from the roots (Neogi et al. 1986), physalolactone C (Ali et al. 1984), withaphysanolide, viscosalactone B, (20R,22R)-5 α ,6 β ,14 α ,20,27-pentahydroxy-1-oxowith-24-enolide, and (20S,22R)-5 β ,6 β -epoxy-4 β ,14 β ,15 α -trihydroxy-1-oxowith-2,24-dienolide (Ahmad et al. 1999b), 17 β -hydroxy-14, 20-epoxy-1-oxo-[22R]-3 β -[O- β -D-glucopyranosyl]-witha-5, 24-dienolide (Ahmad et al. 1999a), and 28-hydroxy-withanolide E and 4 β -hydroxywithanolide E, from the fruit calyces of (Dinan et al. 1997). Two new perulactone-type withanolides, named perulactone C and perulactone D, together with four known compounds, perulactone, perulactone B, blumenol A, and (+)-(S)-dehydromifoliol, were isolated from the aerial parts of *Physalis peruviana* (Fang et al. 2009). A novel 1,10-seco withanolide, 1,10-seco withaperuvin C, together with four known withanolides, (4 β -hydroxywithanolide E, visconolide, withanolide F and withaphysanolide), were isolated from the aerial parts of *Physalis peruviana* (Fang et al. 2010). Ten new withanolides, including four perulactone-type withanolides, perulactones E–H, three 28-hydroxy-withanolides, withaperu-

vins I–K, and three other withanolides, withaperuvins L–N, together with six known compounds were isolated from the aerial parts of *Physalis peruviana* (Fang et al. 2012).

Some of the pharmacological activities of the plant reported are highlighted below.

Antioxidant Activity

Physalis peruviana plant extracts were found to possess high antioxidant activity (Wu et al. 2005). Results revealed that at 100 μ g/mL, the extract prepared from 95% ethanol exhibited the most potent inhibition rate (82.3%) on FeCl₂-ascorbic acid induced lipid peroxidation in rat liver homogenate. At concentrations 10–100 μ g/mL, this extract also demonstrated the strongest superoxide anion scavenging and inhibitory effect on xanthine oxidase activities. In general, the ethanol extracts revealed a stronger antioxidant activity than 06 tocopherol and HWEPP. Compared to α -tocopherol, the IC₅₀ value of 95% ethanol *P. peruviana* extract was lower in thiobarbituric acid test (IC₅₀ = 23.74 vs. 26.71 μ g/mL), in cytochrome C test (IC₅₀ = 10.40 vs. 13.39 μ g/mL) and in xanthine oxidase inhibition test (IC₅₀ = 8.97 vs. 20.68 μ g/mL). Golden berry fruit was found to have antioxidant activity as determined in terms of DPPH radical scavenging activity with a value of 729 g trolox equivalent/g pulp and 2,2'-azobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS*) value of 1,066 trolox equivalent/g (De Carrasco and Zelada 2008). The total phenol content was found to be 154 mg gallic acid equivalent/100 g sample, vitamin C 43.3 mg/100 g, β -carotene content of 2.64 mg/100 g.

Supercritical carbon dioxide extract of *Physalis peruviana* exhibited enhanced antioxidant activities (Wu et al. 2006). Among all the extracts tested, supercritical carbon dioxide of *P. peruviana* (SCEPP-5) demonstrated the highest total flavonoid (234.63 mg/g) and phenol (90.80 mg/g) contents. At concentrations 0.1–30 μ g/mL, SCEPP-5 also demonstrated the strongest superoxide anion scavenging activity and xanthine oxidase inhibitory effect.

Anticancer Activity

Physalis peruviana contains withanolides with cytotoxic activities. Lan et al. (2009) isolated seven new withanolides, phyperunolide A (1), phyperunolide B (2), phyperunolide C (3), phyperunolide D (4), peruvianoxide (5), phyperunolide E (16), and phyperunolide F (17) together with ten known withanolides from the plant extracts. Compounds 1, 6, 7, and 9 showed cytotoxicity against lung cancer (A549), breast cancer (MDA-MB-231 and MCF7), and liver cancer (Hep G2 and Hep 3B) cancer cell lines. The presence of 5 β ,6 β -epoxy-2-en-1-ones in withanolides was found to be a key important factor for cytotoxicity; however, interestingly, the unusual 5-chloride withanolide, 9, displayed significant activity.

Studies demonstrated that ethanol extract of *P. peruviana* possessed potent antihepatoma activity and its effect on apoptosis was associated with mitochondrial dysfunction (Wu et al. 2004a). The results showed that ethanol extract of *P. peruviana* (EEPP) possessed the lowest IC₅₀ value against the Hep G2 cells. Interestingly, all extracts showed no cytotoxic effect on normal mouse liver cells. Treatment with carbonyl cyanide *m*-chlorophenyl hydrazone, a protonophore, caused a reduction of membrane potential (Deltapsim) by mitochondrial membrane depolarization. At high concentrations, EEPP was shown to induce cell cycle arrest and apoptosis through mitochondrial dysfunction as demonstrated by the following observations: (i) EEPP induced the collapse of Deltapsim and the depletion of glutathione content in a dose dependent manner; (ii) pretreatment with the antioxidant (1.0 μ g/mL vitamin E) protected cells from EEPP-induced release of ROS; and (iii) at concentrations 10–50 μ g/mL, EEPP displayed a dose-dependent accumulation of the Sub-G1 peak (hypoploid) and caused G0/G1-phase arrest. Apoptosis was elicited when the cells were treated with 50 μ g/mL EEPP as characterized by the appearance of phosphatidylserine on the outer surface of the plasma membrane. Further studies (Wu et al. 2004b) suggested that EEPP-induced Hep G2 cell apoptosis was possibly mediated through the CD95/CD95L system

and the mitochondrial signalling transduction pathway.

P. peruviana ethanolic leaf and stem extracts exhibited cytotoxic activity in colo-205 (colon cancer) and K562 (chronic myeloid leukemia) cell lines with IC₅₀ values of 1.93 and 0.84 μ g/mL in colo-205 and 2.42 and 2.1 μ g/mL for K562 (Zavala et al. 2006). The *P. peruviana* leaf and stem ethanolic extracts were more cytotoxic than 5-FU in the colo-205 and K562 cell lines and were less cytotoxic than 5-FU for 3 T3 (normal mouse fibroblasts) cell line. In another study, *P. peruviana* leaf and stem ethanolic extracts were more cytotoxic than cisplatin and 5-fluorouracil (5-FU) (positive controls), on the cancer cell lines HT-29, PC-3 and K562 (Quispe-Mauricio et al. 2009). *P. peruviana* cytotoxic effects were less than cisplatin and 5-FU for VERO control cells lines. The IC₅₀ in g/mL in leaves and stems were, 0.35 and 0.37 for HT-29; 0.87 and 1.01 for PC-3; 0.02 and 0.03 for K-562; 4.9 and 6.2 for VERO. The leaves and stems extracts selectivity index were between 5.6 and 245 for tumour cell lines evaluated, by contrast, cisplatin and 5-FU, only showed values between 0.11 and 7.3.

Studies showed that supercritical carbon dioxide of *P. peruviana* (SCEPP-5) possessed the highest total flavonoid (226.19 mg/g) and phenol (100.82 mg/g) contents and demonstrated the most potent inhibitory effect on human lung cancer H661 cell proliferation (Wu et al. 2009). Taken together, these results indicated that SCEPP-5 induced cell cycle arrest at S phase, and its apoptotic induction could be mediated through the p53-dependent pathway and modification of Bax and XIAP proteins expression. The results also provided important pharmacological backgrounds for the potential use of *Physalis peruviana* supercritical fluid extract as products for cancer prevention.

Yen et al. (2010) demonstrated that golden berry-derived 4 β HWE to be a potential DNA-damaging and chemotherapeutic agent against lung cancer. DNA damage of lung cancer (H1299) cells was significantly induced by 1, 5, and 10 μ g/mL 4 β HWE for 2 h in a dose-dependent manner. A trypan blue exclusion assay showed that the proliferation of human lung cancer cells was

inhibited by 4βHWE in both dose- and time-dependent manners. The half maximal inhibitory concentrations (IC_{50}) of 4βHWE in H1299 cells for 24 and 48 h were 0.6 and 0.71 μg/mL, respectively, suggesting it could be a potential therapeutic agent against lung cancer. 4βHWE produced cell cycle perturbation in the form of sub-G1 accumulation and slight arrest at the G2/M phase with 1 μg/mL for 12 and 24 h, respectively. These phenomena were proven to be apoptosis and complete G2/M arrest for H1299 cells treated with 5 μg/mL for 24 h.

Antiinflammatory Activity

The antiinflammatory activity attributed to *Physalis peruviana* calyces in hydroalcoholic fractions was using the 12-*O*-tetradecanoylphorbol-13-acetate-induced mouse model of ear edema and validated its use in folk medicine (Franco et al. 2007).

Supercritical carbon dioxide extract of *Physalis peruviana* exhibited enhanced antiinflammatory activities (Wu et al. 2006). At 30 μg/mL, supercritical carbon dioxide of *P. peruviana* (SCEPP-5) significantly prevented lipopolysaccharide (LPS; μg/mL)-induced cell cytotoxicity in murine macrophage (Raw 264.7) cells. At 10–50 μg/mL, it also significantly inhibited LPS-induced NO release and PGE2 formation in a dose-dependent pattern. SCEPP-5 at 30 μg/mL remarkably blocked the LPS induction of inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2) expression. Its protection against LPS-induced inflammation could be through the inhibition of iNOS and COX-2 expression.

P. peruviana fruit juice exhibited a mild antiinflammatory activity compared with methylprednisolone, a known antiinflammatory drug using a rabbit eye inflammatory model (Pardo et al. 2008). An interesting dose-dependent cytostatic effect on cultured fibroblasts was also established. The data suggested that the *P. peruviana* fruit juice anti-ptyerygium effect described in traditional medicine may be related to its inhibiting fibroblast growth.

Physalis peruviana's antiinflammatory activity observed in the in-vitro phagocytosis

model (*Leishmania panamensis* infection of murine macrophages) was related to an immunomodulatory effect exerted on macrophages infected, which directly or indirectly “blocked” their ability to secrete soluble proinflammatory mediators (Martínez et al. 2010).

Hepatoprotective Activity

Water, ethanol and hexane extracts of *Physalis peruviana* (500 mg/kg body weight) showed anti-hepatotoxic activities against CCl₄ induced hepatotoxicity (Arun and Asha 2007). The ethanol and hexane extracts showed moderate activity compared to water extract, which showed activity at a low dose of 125 mg/kg. Histopathological changes induced by CCl₄ were also significantly reduced by the extract. Further, the extract administration to rats resulted in an increase in hepatic GSH and decrease in malondialdehyde. The extract was found to be devoid of any conspicuous acute toxicity in rats.

Miscellaneous Activity

Melatonin (N-acetyl-5-methoxytryptamine), a neurohormone, was detected in the plant (Kolar and Malbeck 2009). Results from animal studies suggested that melatonin administration may help prevent or cure diseases associated with oxidative stress, such as neurodegenerative diseases, which frequently occur during aging.

Traditional Medicinal Uses

Physalis peruviana is a medicinal plant widely used in folk medicine as anticancer, antimycobacterial, antipyretic, and immunomodulatory, diuretic, immunomodulatory and antiinflammatory and also for treating diseases such as malaria, asthma, hepatitis, dermatitis, leukemia, and rheumatism (Wu et al. 2004a, b, 2005; Franco et al. 2007). In Kerala, India, *Physalis peruviana* is a common medicinal herb used by Muthuvan tribes and Tamilian native residing in the Shola forest regions against

jaundice (Arun and Asha 2007). In Colombia, the leaf decoction is taken as a diuretic and antiasthmatic. In South Africa, the heated leaves are applied as poultices on inflammations and the Zulus administer the leaf infusion as an enema to relieve abdominal ailments in children.

Other Uses

Physalis peruviana is used as an ornamental plant.

Comments

The Global Compendium on Weeds lists *Physalis peruviana* as an agricultural weed, cultivation escape and environmental weed (Randall 2007).

Selected References

- Ahmad S, Malik A, Afza N, Yasmin R (1999a) A new withanolide glycoside from *Physalis peruviana*. *J Nat Prod* 62(3):493–494
- Ahmad S, Malik A, Yasmin R, Ullah N, Gul W, Khan PM, Nawaz HR, Afza N (1999b) Withanolides from *Physalis peruviana*. *Phytochemistry* 50(4):647–651
- Ali A, Sahai M, Ray AB, Slatkin DJ (1984) Physalolactone C, a new withanolide from *Physalis peruviana*. *J Nat Prod* 47(4):648–651
- Arun M, Asha VV (2007) Preliminary studies on antihepatotoxic effect of *Physalis peruviana* Linn. (Solanaceae) against carbon tetrachloride induced acute liver injury in rats. *J Ethnopharmacol* 111(1):110–114
- Bagchi A, Neogi P, Sahai M, Ray AB, Oshima Y, Hikino H (1984) Withaperuvins E and nicandrin B, withanolides from *Physalis peruviana* and *Nicandra physaloides*. *Phytochemistry* 23(4):853–855
- Council of Scientific and Industrial Research (CSIR) (1969) The wealth of India. A dictionary of Indian raw materials and industrial products (Raw materials 8). Publications and Information Directorate, New Delhi
- De Carrasco RR, Zelada CRE (2008) Determinación de la capacidad antioxidante y compuestos bioactivos de frutas nativas peruanas. *Rev Soc Quím Perú* 74(2):108–124
- Dinan LN, Sarker SD, Šik V (1997) 28-Hydroxywithanolide E from *Physalis peruviana*. *Phytochemistry* 44(3):509–512
- Facciola S (1990) *Cornucopia*. A source book of edible plants. Kampong Publ., Vista, 677 pp
- Fang ST, Li B, Liu JK (2009) Two new withanolides from *Physalis peruviana*. *Helv Chim Acta* 92(7):1304–1308
- Fang ST, Liu JK, Li B (2010) A novel 1,10-seco withanolide from *Physalis peruviana*. *J Asian Nat Prod Res* 12(7):618–622
- Fang ST, Liu JK, Li B (2012) Ten new withanolides from *Physalis peruviana*. *Steroids* 77(1–2):36–44
- Fischer G, Eber G, Lüdders P (2000) Provitamin A carotenoids, organic acids and ascorbic acid content of cape gooseberry (*Physalis peruviana* L.) ecotypes grown at two tropical altitudes. *Acta Hort (ISHS)* 531:263–268
- Franco LA, Matiz GE, Calle J, Pinzón R, Ospina LF (2007) Antiinflammatory activity of extracts and fractions obtained from *Physalis peruviana* L. calyces. *Biomedica* 1:110–115
- Kolar J, Malbeck J (2009) Levels of the antioxidant melatonin in fruits of edible berry species. *Planta Med* 75:9
- Lan YH, Chang FR, Pan MJ, Wu CC, Wu SJ, Chen SL, Wang SS, Wu MJ, Wu YC (2009) New cytotoxic withanolides from *Physalis peruviana*. *Food Chem* 116(2):462–469
- Martínez W, Ospina LF, Granados D, Delgado G (2010) In vitro studies on the relationship between the anti-inflammatory activity of *Physalis peruviana* extracts and the phagocytic process. *Immunopharmacol Immunotoxicol* 32(1):63–73
- Mayorga H, Knapp H, Winterhalter P, Duque C (2001) Glycosidically bound flavor compounds of cape gooseberry (*Physalis peruviana* L.). *J Agric Food Chem* 49(4):1904–1908
- Mayorga H, Duque C, Knapp H, Winterhalter P (2002) Hydroxyester disaccharides from fruits of cape gooseberry (*Physalis peruviana*). *Phytochemistry* 59(4):439–445
- Morton JF (1987) Cape gooseberry. In: Morton JF (ed) *Fruits of warm climates*. Julia F. Morton, Miami, pp 430–434
- Morton JF, Russell OS (1954) The cape gooseberry and the Mexican husk tomato. *Fla State Hort Soc* 67:261–266
- National Research Council (1989) *Lost crops of the Incas: little-known plants of the Andes with promise for worldwide cultivation*. BOSTID, National Research Council, National Academy Press, Washington, DC, 428 pp
- Neogi P, Sahai M, Ray AB (1986) Withaperuvins F and G, two withanolides of *Physalis peruviana* roots. *Phytochemistry* 26(1):243–247
- Pacific Island Ecosystems at Risk (PIER) (2002) *Physalis peruviana* L. Solanaceae http://www.hear.org/pier/species/physalis_peruviana.htm
- Pardo JM, Fontanilla MR, Ospina LF, Espinosa L (2008) Determining the pharmacological activity of *Physalis peruviana* fruit juice on rabbit eyes and fibroblast primary cultures. *Invest Ophthalmol Vis Sci* 7:3074–3079
- Pinto Mda S, Ranilla LG, Apostolidis E, Lajolo FM, Genovese MI, Shetty K (2009) Evaluation of antihyperglycemia and antihypertension potential of native

- Peruvian fruits using in vitro models. *J Med Food* 12(2):278–291
- Puente LA, Pinto-Munoz CA, Castro ES, Cortes MS (2011) *Physalis peruviana* Linnaeus, the multiple properties of a highly functional fruit: a review. *Food Res Int* 44:1733–1740
- Quispe-Mauricio A, Callacondo D, Rojas J, Zavala D, Posso M, Vaisberg A (2009) Cytotoxic effect of *Physalis peruviana* in cell culture of colorectal and prostate cancer and chronic myeloid leukemia. *Rev Gastroenterol Peru* 29(3):239–246 (In Spanish)
- Ramadan MF, Mörsel JT (2003) Oil goldenberry (*Physalis peruviana* L.). *J Agric Food Chem* 51(4):969–974
- Ramadan MF, Mörsel JT (2007) Impact of enzymatic treatment on chemical composition, physicochemical properties and radical scavenging activity of goldenberry (*Physalis peruviana* L.) juice. *J Sci Food Agric* 87(3):452–460
- Ramadan MF, Mörsel JT (2009) Oil extractability from enzymatically treated goldenberry (*Physalis peruviana* L.) pomace: range of operational variables. *J Food Sci Technol* 44(3):435–444
- Randall R (2007) Biodiversity information projects of the world global compendium of weeds. <http://www.hear.org/gcw/>
- Rodrigues E, Rockenbach II, Cataneo C, Gonzaga LV, Chaves ES, Fett R (2009) Minerals and essential fatty acids of the exotic fruit *Physalis peruviana* L. *Ciênc Tecnol Aliment Campinas* 29(3):642–645
- Wu SJ, Ng LT, Chen CH, Lin DL, Wang SS, Lin CC (2004a) Antihepatoma activity of *Physalis angulata* and *P. peruviana* extracts and their effects on apoptosis in human Hep G2 cells. *Life Sci* 74(16):2061–2073
- Wu SJ, Ng LT, Lin DL, Huang SN, Wang SS, Lin CC (2004b) *Physalis peruviana* extract induces apoptosis in human Hep G2 cells through CD95/CD95L system and the mitochondrial signaling transduction pathway. *Cancer Lett* 215(2):199–208
- Wu SJ, Ng LT, Huang YM, Lin DL, Wang SS, Huang SN, Lin CC (2005) Antioxidant activities of *Physalis peruviana*. *Biol Pharm Bull* 28(6):963–966
- Wu SJ, Tsai JY, Chang SP, Lin DL, Wang SS, Huang SN, Ng LT (2006) Supercritical carbon dioxide extract exhibits enhanced antioxidant and anti-inflammatory activities of *Physalis peruviana*. *J Ethnopharmacol* 108(3):407–413
- Wu SJ, Chang SP, Lin DL, Wang SS, Hou FF, Ng LT (2009) Supercritical carbon dioxide extract of *Physalis peruviana* induced cell cycle arrest and apoptosis in human lung cancer H661 cells. *Food Chem Toxicol* 47(6):1132–1138
- Yen CY, Chiu CC, Chang FR, Chen JY, Hwang CC, Hseu YC, Yang HL, Lee AY, Tsai MT, Guo ZL, Cheng YS, Liu YC, Lan YH, Chang YC, Ko YC, Chang HW, Wu YC (2010) Beta-Hydroxywithanolide E from *Physalis peruviana* (golden berry) inhibits growth of human lung cancer cells through DNA damage, apoptosis and G2/M arrest. *BMC Cancer* 10: Article 46
- Zavala D, Quispe A, Posso M, Rojas J, Vaisberg A (2006) Cytotoxic effect of *Physalis peruviana* (capuli) in colon cancer and chronic myeloid leukemia. *An Fac Med* 67(4):283–289 (In Spanish)
- Zhang ZY, Lu A, D’Arcy WG (2008) Solanaceae A. L. Jussieu. In: Wu ZY, Raven PH, Hong DY (eds) *Flora of China*, vol 11, Oxalidaceae through Aceraceae. Science Press/Missouri Botanical Garden Press, Beijing/St. Louis

Solanum aethiopicum

Scientific Name

Solanum aethiopicum L.

Synonyms

Lycopersicon aethiopicum (L.) Mill., *Pseudocapsicum torulosum* Moench, *Solanum aethiopicum* Jacq., *Solanum aethiopicum* var. *aculeatum* Dunal, *Solanum aethiopicum* var. *armatum* Bitter, *Solanum aethiopicum* var. *giorgii* (De Wild.) Bitter, *Solanum aethiopicum* var. *inermis* Dunal, *Solanum aethiopicum* var. *integrifolium* (Poir.) O. E. Schulz, *Solanum aethiopicum* var. *modicelobatum* Bitter, *Solanum aethiopicum* var. *paaschenianum* (H. J. P. Winkl.) Bitter, *Solanum ambrosiacum* Vell., *Solanum aurantiacum* Sendtn., *Solanum briei* De Wild., *Solanum geminifolium* Thonn., *Solanum gilo* Raddi, *Solanum gilo* var. *ellipsoideum* Bitter, *Solanum gilo* var. *erectifolium* Bitter, *Solanum gilo* var. *pierreanum* (Pailleux & Bois) Bitter, *Solanum gilo* var. *sparseaculeatum* Bitter, *Solanum gilo* subsp. *megalacanthum* Bitter, *Solanum gilo* subsp. *monteiroi* (C. H. Wright) Bitter, *Solanum giorgii* De Wild., *Solanum elsenii* De Wild., *Solanum hybridum* Jacq., *Solanum indicum* subsp. *ambifarium* Bitter, *Solanum integrifolium* Poir., *Solanum kupperi* Markgr., *Solanum lobelii* Ten., *Solanum lusitanicum* Dunal, *Solanum monteiri* C. H. Wright, *Solanum naumannii* Engl., *Solanum obtusifolium* Willd., *Solanum olivare* Pailleux & Bois, *Solanum ovatifolium* De Wild.,

Solanum paaschenianum H. J. P. Winkl., *Solanum pierreanum* Paill. & Bois, *Solanum poggei* Dammer, *Solanum pseudomelongena* Ten., *Solanum racemiflorum* Dunal, *Solanum scabrum* Jacq., *Solanum scabrum* Zuccagni nom. illeg., nom. superfl., *Solanum schroederi* Dammer, *Solanum sparsespinosum* De Wild., *Solanum subsessile* De Wild., *Solanum sudanense* Hammerst., *Solanum texanum* Dunal, *Solanum undatum* var. *violaceum* Dunal, *Solanum wilddenowii* Roem. & Schult. nom. illeg., nom. superfl., *Solanum worsleyi* W. Watson, *Solanum zuccagnianum* Dunal nom. illeg., nom. superfl., *Solanum zuccagnianum* var. *allogonum* Dunal.

Family

Solanaceae

Common/English Names

African Bitter Pea-Aubergine, African Eggplant, Bitter Tomato, Chinese Scarlet Eggplant, Dayak Eggplant, Ethiopian Eggplant, Garden Egg, Gilo, Jamaican Bitter Balls, Kumba, Mock Tomato, Sarawak Wild Eggplant, Scarlet Eggplant, Shum, Terung Asam, Terung Dayak, Terung Dayak Sarawak, Terung Iban, Terung Sarawak, Tomato-Fruit Eggplant, Wild Pea-Aubergine, Wild African Aubergine.

Vernacular Names

Angola: tungo (Kikongo);

Brazil: Jagatú Tunga, Jiló;

Benin: aubergine indigene, tomate amère (French), gboman (Sahouè), assoukoussé (Watchi);

Central African Republic: Sasa;

Chinese: Xiao Gu Qie, Xiao Ku Fan Qie (Cantonese);

Democratic Republic of Congo: ngbagu (Batiabetuwa);

Ethiopia: Bmy (Amharic);

French: Africaine, Aubergine Africaine, Aubergine Amère, Aubergine Écarlate, aubergine indigene, Djakattou, Petite Bringelle Maronne, Tomate Amère;

Malaysia: Dayak Eggplant, Sarawak Wild Eggplant, Sour Brinjal (English), Terong Asam, Terong Iban, Terong Sarawak, Terung Dayak, Terung Dayak Sarawak, Terung Asam;

Nigeria: Osun;

Portuguese: Jiló, Jagatú Tunga;

Senegal: dyahatu (Diola);

Swahili: Ngogwe, Nyanya Chungu;

Swedish: Röd Aubergine;

Uganda: Ekitulatula (fruit), nakatti (Leafy vegetables).

Origin/Distribution

Solanum aethiopicum, one of the leading vegetables in tropical Africa was reported to have been domesticated from the wild *Solanum anguivi* Lam., via the semi-domesticated *Solanum distichum* Schumach. & Thonn. Both these ancestral species occur throughout tropical Africa, *Solanum anguivi* in disturbed vegetation and *Solanum distichum* in gardens. *Solanum aethiopicum* is grown throughout tropical Africa and South America (mainly Brazil), and occasionally elsewhere, e.g. in southernmost France and Italy and in southeast Asia.

Agroecology

Solanum aethiopicum is strictly a tropical crop species, and is intolerant of low cold temperatures and frost or extremely wet conditions. It is intolerant of water-logging and some tolerance of irrigation-induced salinity is reported from Senegal. Members of the Gilo Group grow best at in full sun in woodland savanna on fairly deep and well-drained soils with pH 5.5–6.8, and day temperatures of 25–35°C and night temperatures of 20–27°C. The Kumba Group tolerates hotter conditions (up to 45°C day temperature) with air humidity sometimes as low as 20%, especially if irrigated. The Shum Group prefers warm, humid conditions and will shed its leaves when it gets dry. In Uganda, it is grown in swamps during the dry season.

Edible Plant Parts and Uses

In the humid tropical zone of West Africa *S. aethiopicum* is mainly cultivated for its immature fruit (garden egg), in the savanna area frequently for both its leaves and immature fruits (often called ‘djakattou’), and in East Africa, especially Uganda, mainly as a leaf vegetable (called ‘nakati’).

In Africa, the immature fruits of *Solanum aethiopicum* are used as cooked vegetables in stews, and sometimes eaten raw. The leaves and shoots are used as a cooked vegetable. They are picked from the same plants that provide the fruit vegetable or from special leafy cultivars. The fruits are sour with a pleasant aroma and are used raw or cooked in stews, soups, sauces or relish. In Sarawak the fruit is prepared in many ways. It is cooked with fish, made into *kerabu* (spicy salad) or cooked in coconut milk. One popular recipe with fish is called *sour brinjal asam pedas*.

Botany

Perennial or annual deciduous shrub, up to 2 m tall, often much-branched (Plate 1); root system extending both vertically and laterally; branches

and leaves with or without prickles and stellate hairs. Leaves alternate, simple; stipules absent; petiole up to 11 cm long; blade broadly ovate, 6–30 cm × 4–21 cm, obtuse or cordate at base, acute to obtuse at apex, slightly to deeply lobed at margin, pinnately veined; upper leaves smaller, narrower, less lobed and often subopposite (Plates 1 and 2). Inflorescence a lateral, racemose cyme, 5–12-flowered; peduncle often short or even absent. Flowers bisexual, regular, 4–10-merous; pedicel 2–15 mm long; calyx campanulate, lobes 4–10 mm long; corolla stellate, free not fused, 6–15 mm long, white, sometimes pale purple; stamens inserted near the base of the corolla tube and alternate with corolla lobes, filaments short and thick, anthers connivent, yellow, opening by



Plate 1 Branched shrub of Terung Asam with large, long-petioled, lobed leaves and fruit (A. Salowi, DOA, Sarawak)



Plate 2 Bisexual, pentamerous whiteflowers of Terung asam (A. Salowi, DOA, Sarawak)

terminal pores; ovary superior, 2–6-celled, style as long as or slightly longer than stamens, stigma small, obtuse (Plate 2). Fruit a globose to oblate, 5–15 cm across, ellipsoid, ovoid or fusiform berry 2–12 cm long, smooth (Plates 3–7) to furrowed (Plates 8 and 9), immature green or white turning to red or orange, many-seeded. Seeds lenticular to reniform, flattened, 2–5 mm across, pale brown or yellow (Plate 7).

Nutritive/Medicinal Properties

Fruit Nutrients and Phytochemicals

Solanum aethiopicum fruit was found to contain per 100 g edible portion: water 90.6 g, energy 135 kJ (32 kcal), protein 1.5 g, fat 0.1 g, carbohydrate 7.2 g, fibre 2.0 g, Ca 28 mg, P 47 mg, Fe 1.5 mg, β -carotene 0.35 mg, thiamin 0.07 mg,



Plate 3 Globose glossy orange, smooth Terung asam fruit with purplish blotches and short sepals



Plate 4 Ovoid and subglobose fruits of Terung asam



Plate 5 Terung asam fruits glossy and smooth without coloured purplish blotches/streaks



Plate 6 X-section of Terung asam fruit showing the five locule and yellowish-orangey flesh



Plate 7 Fruit halved to show the orange-yellow flesh and yellow seeds



Plate 8 Large, white, furrowed oblate fruit



Plate 9 Large oblate, furrowed fruits with green stripes

riboflavin 0.06 mg, niacin 0.8 mg, ascorbic acid 8 mg (Leung et al. 1968). The composition was comparable with that of eggplant.

The nutrient composition (per 100 g) of *S. aethiopicum* fruit was reported by AVRDC (2004) as: 8.6 g dry matter, 1.27 protein, 1.42 g fibre, 2.97 g sugar, 0.05 mg lutein, 0.39 mg β -carotene, 12 mg vitamin C, 0.05 mg γ -tocopherol, 0.26 mg α -tocopherol, 0.31 mg total tocopherol, 9 mg Ca, 0.95 mg Fe, and the antioxidant activity in terms of ABTS was 345 μ mol Trolox/100g fresh weight. The fruit (per 1,100 g) also contained 69 mg phenolics, 37 mg oxalate and 9 μ g folate.

Proximate analysis of fresh fruits of *S. aethiopicum* (per 100 g) showed: 89.27 g moisture, 2.24 g protein, 0.52 g fat, 0.87 g ash, 2.96 g crude fibre, 4.14 g carbohydrate and 498.47 mg calcium, 1.98 mg magnesium and 1.02 mg iron (Chinedu et al. 2011). Alkaloids, flavonoids phytoosterols, saponins and vitamin C, moderate presence of cardiac glycosides, steroids and tannins,

and trace amount of terpenoids were also found in the fruits. Edem et al. (2009) reported the fruit to contain 74.8% moisture, 52.13% carbohydrate, 14.87% crude protein, 116% crude fibre, 7% crude fat, 10% ash, 93.7% ascorbic acid, 3.81 ppm Zn, 1.74 ppm Cr, 1.48 ppm Cu, 0.12 ppm Co, 0.16 ppm Cd and 0.01 ppm Hg.

The nutrient composition of ripe terung asam per 100 g edible portion was reported as: energy 36 kcal, moisture 89.46 g, protein 1.1 g, fat 0.9 g, carbohydrate 5.8 g, crude fibre 1.7 g, ash 0.8 g, vitamin C 8 mg, P 28 mg, K 199 mg, Ca 3 mg, Mg 6 mg, Fe 0.6 mg, Mn 0.2 mg, Zn 0.39 mg and Cu 0.06 mg (Voon et al. 1988; Voon and Kueh 1999).

Fruits of *S. aethiopicum* and *S. melongena* contained 0.58–4.56 mg/100 g of α -solamargine and 0.17–1 mg/100 g of α -solasonine, on a wet basis (Sánchez-Mata et al. 2010). The proportion of α -solamargine in *S. aethiopicum* was variable 48–89%. The glycoalkaloid levels of *S. aethiopicum* were similar to those of *S. melongena* (about 14% of values considered as toxic) and could be considered as safe for consumption. Betulin and sterolin (sitosterol glucoside) were isolated from *S. aethiopicum* fruit (Banerjee et al. 1974). Acid hydrolysis of the methanolic extract of the berries afforded solasodine in negligible yield.

Four groups of phenolic acids were found in *S. aethiopicum* fruit. (Stommel and Whitaker 2003). Group 1 comprised chlorogenic acid isomers and four compounds were identified 3-*O*-*trans*, 5-*O*-*trans*, 5-*O*-*cis* isomers of caffeoylquinic acid (3CQA, neochlorogenic acid; 5-CQA, chlorogenic acid; 4-CQA, cryptochlorogenic acid and 5-(*Z*)-CQA, *cis*-chlorogenic acid) respectively. Chlorogenic acid was the predominant compound in Group 1, with average levels 176-, 28.9-, and 92.5-fold higher than levels of neochlorogenic acid, cryptochlorogenic acid and *cis*-chlorogenic acid respectively. Group 2 consisted of two phenolics 3,5-diCQA and 4,5-diCQA. Group 3 comprised four compounds: – N, N"-dicafeoylspermidine (predominated); N-cafeoylputrescine and their isomers; and Group 4 comprised 3-*O*-acetyl-5-*O*-caffeoylquinic acid (3-acetyl-5CQA), 3-*O*-acetyl-4-*O*-caffeoylquinic acid (3-acetyl-4-CQA).

Leaf Nutrients and Phytochemicals

The composition of fresh *S. aethiopicum* leaves per 100 g edible portion was reported as: water 82.1 g, energy 215 kJ (51 kcal), protein 4.8 g, fat 0.3 g, carbohydrate 10.3 g, fibre 2.4 g, Ca 523 mg, P 94 mg, Fe 6.0 mg, β -carotene 6.40 mg, thiamin 0.23 mg, riboflavin 0.44 mg, niacin 1.8 mg, and ascorbic acid 67 mg (Leung et al. 1968). This composition is within the range of other dark-green leafy vegetables. AVRDC (2006) reported nakati leaves to have per 100 g : 14.2 g dry matter, 4.78 g protein, 1.76 g fibre, 0.69 g sugar, 1.49 μ g violaxanthin, 1.68 μ g neoxanthin, 5.85 μ g lutein, 0.08 μ g β -carotene, 5.82 μ g α -carotene, 14.92 μ g total carotenoid, 44 mg vitamin C, 0.05 mg γ -tocopherol, 6.81 mg α -tocopherol, 7.31 mg total tocopherol, 241 mg Ca, 2.52 mg Fe, and 0.81 mg Zn. The antioxidant activity of nakatti leaves in terms of ABTS was 2,430 μ mol Trolox/100g fresh weight. The leaves (per 100 g) also contained 722 mg phenolics, 118 mg oxalate and 9 μ g folate.

The leaves were also reported to contain oxalate and alkaloids, e.g. solasodine, with reported glycocorticoid effects (Lester and Seck 2004). Their concentration could be reduced by cooking. The characteristic bitter taste was attributed to furostanol glycosides.

Other Plant Parts Phytochemicals

15-norlubiminol and 15-norepilubiminol were isolated from *Solanum aethiopicum* as an inseparable 1:1 mixture in a relatively poor yield to that of the major phytoalexins, lubimin and epilubimin (Watanabe et al. 2001). The antifungal activity of 15-norlubiminols were weaker than that of lubimins.

Five sesquiterpenoids, solavetivone, lubimin, lubiminoic acid, aethione and lubiminol were isolated from *Solanum aethiopicum* roots (Nagaoka et al. 2001). Three new sesquiterpenoids, lubiminoic acid, epilubiminoic acid and aethione, and six known sesquiterpenoids, solavetivone, 3 β -hydroxysolavetivone, 13-hydroxysolavetivone,

anhydro- β -rotunol, epilubimin and lubimin, were isolated from *S. aethiopicum* roots (Nagase et al. 2001).

Antiinflammatory Activity

Anosike et al. (2012) showed that *S. aethiopicum* fruit had antiinflammatory property. The fruit extract significantly reduced the fresh egg albumin-induced rat paw oedema and also significantly reduced the granuloma tissue formation in the fruit treated groups when compared to the control.

Hypolipidemic Activity

Odetola et al. (2004) showed that that supplementation of hypercholesterolemic rabbits *Solanum melongena* and *Solanum gilo* significantly reduced serum total cholesterol by 65.40 and 52.69% respectively, triglyceride by 47.7 and 27%, LDL cholesterol by 85 and 83% respectively. They also increased significantly serum HDL by 24.7 and 25% respectively leading to increased HDL/LDL cholesterol ratio (3.37 and 3.25 respectively). This trend was also similar with liver lipid levels. Histopathological examination of the liver and aorta paraffin section showed fewer lesions in the hypercholesterolemic rabbits treated with *Solanum* fruits compared with control hypercholesterolemic rabbits. These observations demonstrated that *Solanum melongena* and *Solanum gilo* had strong hypolipidemic effect and could be useful in the treatment of diseases associated with hyperlipidemia such as ischemic heart diseases and arteriosclerosis.

Antispasmodic Activity

Methanol fruit extract showed a dose-dependent relaxation of the rhythmic contraction of the iso-

lated rabbit jejunum (Hassan et al. 2006). The extract also reduced histamine and barium chloride induced contractions of the isolated rabbit jejunum. The results indicated the fruit to possess antispasmodic activity and supported the traditional use of the plant in alleviating intestinal complaints.

Antiulcerogenic Activity

S. aethiopicum fruit extract was found to have antiulcerogenic property (Chioma et al. 2011). The macerated methanol fruit extract produced higher ulcer inhibition in a dose-dependent manner rats than ranitidine in the indomethacin and acid-ethanol models.

Traditional Medicinal Uses

Fruits of bitter cultivars are used as medicine in many tropical African countries. Roots and fruits have been used as a carminative and sedative, and to treat colic and high blood pressure; crushed and macerated fruit is used as an enema. Leaf juice is used as a sedative to treat uterine complaints; an alcoholic extract of leaves as a sedative, anti-emetic and to treat tetanus after abortion. In Nigeria, a hot leaf infusion is taken to treat diabetes mellitus and a leaf infusion is also taken to treat intestinal worms in southern Uganda.

Other Uses

Solanum aethiopicum is sometimes cultivated as an ornamental. Some cultivars are occasionally used as a rootstock for tomato and eggplant. Studies by Gisbert et al. (2011) showed that interspecific hybrids of eggplant with *Solanum incanum* and *Solanum aethiopicum* can be used as new rootstocks for eggplant. These hybrids have better germination than the currently used rootstock *Solanum torvum* and have full grafting

compatibility with eggplant. Eggplants grafted on interspecific hybrids have higher yield and earliness, and lower plant mortality than other rootstocks.

Comments

Terung Asam or *Terung Iban* as shown in Plates 1–7 above has large shallowly lobed leaves with obtuse apex and obtuse or subcordate based and long petioles 10–12 cm that are covered with hairs but are generally not prickly, the flowers are white and the corolla stellate, free not fused as in *S. macrocarpon*; stamens inserted near the base of the corolla tube and alternate with corolla lobes, filaments short and thick, anthers connivent, yellow; fruit subglobose, globose to ovoid, >6 cm diameter, smooth, glossy orange with or without irregular purple streaks or blotches. Its morphological description fits the Gilo Group of *Solanum aethiopicum*; however definitive molecular studies are needed to affirm this. In Sarawak, it has been erroneously identified as *Solanum lasiocarpum* (previously *S. ferox*) which has smaller, globose orange fruits (2.5–3.5 cm) densely hirsute with stellate hairs and prickly stems, branches and leaves. This species with smaller, densely hairy orange-yellow fruit is also called Dayak Eggplant, Sarawak Wild Eggplant, Sour Brinjal (English), *Terong Asam*, *Terong Iban*, *Terung Dayak*. Also some quarters in Sarawak have erroneously identified this large orange, smooth, globose fruited Solanaceous plant as *S. macrocarpon* which has sessile, lobed, elliptical leaves with acute or cuneate bases, fused (campanulate), mauve or deep purple corolla; large 4–6 cm diameter, globose or depressed-globose fruit, the pericarp thin, smooth, sometimes shiny, glabrous, plain green or with dark green stripes when young, usually yellow or orange at maturity, calyx accrescent, elongating up to 3–6 cm long often becoming broad and foliaceous, covering 1/3–3/4 of the mature fruit.

Solanum aethiopicum is closely related to *S. macrocarpon* and has been classified into four

usage-cultivar groups (Lester 1986; Lester and Seck 2004). The Gilo group has edible fruit of many shapes (globose, oblate) (2.5–8 cm across), to ovoid, elliptic (2.5–12 cm long), smooth (Plates 3–7) or grooved (Plates 8 and 9) fruit. The Shum group is a short much-branched plant with small hairless leaves and shoots that are plucked frequently as a leafy green called *nakati*. However, the small (1–3 cm across) very bitter fruit is not eaten. The Kumba group has stout main stem with large hairless leaves that can be picked as a green vegetable, and also produces very large (5–15 cm diameter) grooved, oblate fruit that is picked green or even red. The Aculeatum Group has prickly stems and leaves, mature leaves covered with stellate hairs; fruit subglobose, furrowed, 3–8 cm in diameter and is not eaten, mainly cultivated as an ornamental or as rootstock for tomato or eggplant, but not cultivated in Africa.

Selected References

- Adjahoun EJ, Adjakidjè V, Ahyi MRA, Aké Assi L, Akoègninou A, d'Almeida J, Apovo F, Boukef K, Chadare M, Cusset G, Dramane K, Eyme J, Gassita JN, Gbaguidi N, Goudote E, Guinko S, Houngnon P, Lo I, Keita A, Kiniffo HV, Kone-Bamba D, Musampa Nseyya A, Saadou M, Sodogandji T, De Souza S, Tchabi A, Zinsou Dossa C, Zohoun T (1989) Contribution aux Études Ethnobotaniques et Floristiques en République Populaire du Bénin. Médecine Traditionnelle et Pharmacopée. Agence de Coopération Culturelle et Technique, Paris, 895 pp
- Anosike CA, Obidoo O, Ezeanyika LU (2012) The anti-inflammatory activity of garden egg (*Solanum aethiopicum*) on egg albumin-induced oedema and granuloma tissue formation in rats. *Asian Pac J Trop Med* 5(1):62–66
- Asian Vegetable Research Development Center (AVRDC) (2004) African scarlet eggplant. The AVRDC Nutrient Database. AVRDC – The World Vegetable Database Center. <http://avrdcnutrition.gtdtestsite.comoj.com/nutrition/about.php>
- Asian Vegetable Research Development Center (AVRDC) (2006) Nakati. The AVRDC Nutrient Database. AVRDC – The World Vegetable Database Center. <http://avrdcnutrition.gtdtestsite.comoj.com/nutrition/about.php>
- Banerjee SK, George V, Kapoor R (1974) Chemical investigation of the berries of *Solanum aethiopicum*. *Planta Med* 25(3):216–218

- Bossard E (1996) Quelques notes sur l'alimentation et les apports nutritionnels occultes en Angola. *Garcia de Orta Sér Bot Lisboa* 13(1):7–41
- Bukenya-Ziraba R, Carasco JF (1999) Ethnobotanical aspects of *Solanum* L. (Solanaceae) in Uganda. In: Nee M, Symon DE, Lester RN, Jessop JP (eds) *Solanaceae 4: advances in biology and utilization*. Royal Botanic Gardens, Kew, pp 345–360
- Burkill HM (2000) Useful plants of west tropical Africa, vol 5, Families S–Z. Royal Botanical Gardens, Kew, 686 pp
- Chinedu SN, Olasumbo AC, Eboji OK, Emiloju OC, Arinola OK, Dania DI (2011) Proximate and phytochemical analyses of *Solanum aethiopicum* L. and *Solanum macrocarpon* L. fruits. *Res J Chem Sci* 13(1):63–71
- Chioma A, Obiora A, Chukwuemeka U (2011) Does the African garden egg offer protection against experimentally induced ulcers? *Asian Pac J Trop Med* 4(2):163–166
- Edem CA, Dosunmu MI, Bassey FI, Wilson C, Umoren P (2009) A comparative assessment of the proximate composition, ascorbic acid and heavy metal content of two species of garden egg (*Solanum gilo* and *Solanum aubergine*). *Pak J Nutr* 8(5):582–584
- Gbile ZO (1979) *Solanum* in Nigeria. In: Hawkes JG, Lester RN, Skelding AD (eds) *The biology and taxonomy of the Solanaceae*. Academic, London, pp 113–120
- Gbolade AA (2009) Inventory of antidiabetic plants in selected districts of Lagos State, Nigeria. *J Ethnopharmacol* 121:135–139
- Gisbert C, Prohens J, Raigón MD, Stommel JR, Nuez F (2011) Eggplant relatives as sources of variation for developing new rootstocks: effects of grafting on eggplant yield and fruit apparent quality and composition. *Sci Hortic* 128(1):14–22
- Grubben GJH (1977) Tropical vegetables and their genetic resources. IBPGR, Rome, 197 pp
- Hassan HS, Haruna AK, Hassan AS, Agunu A, Musa KY (2006) Phytochemical and antispasmodic studies of the fruit of *Solanum gilo*. *Nig J Nat Prod and Med* 10:45–46
- Kawukpa UU, Angoyo MM (1994) Plantes utiles chez les Batiabetuwa de l'île de Mbie, Kisangani, Zaïre. *Afr Stud Monogr* 1(2):49–68
- Lester RN (1986) Taxonomy of scarlet eggplants, *Solanum aethiopicum* L. *Acta Hort* 182:125–132
- Lester RN, Niakan L (1986) Origin and domestication of the scarlet eggplant, *Solanum aethiopicum* L., from *S. anguivi* Lam. In: D'Arcy WG (ed) *Solanaceae: biology and systematics*. Columbia University Press, New York, pp 433–456
- Lester RN, Seck A (2004) *Solanum aethiopicum* L. [Internet] Record from Protabase. In: Grubben GJH, Denton OA (ed) *PROTA (Plant Resources of Tropical Africa/Ressources végétales de l'Afrique tropicale)*, Wageningen, Netherlands. <http://database.prota.org/search.htm>
- Leung W-TW, Busson F, Jardin C (1968) Food composition table for use in Africa. FAO, Rome, 306 pp
- Nagaoka T, Goto K, Watanabe A, Sakata Y, Yoshihara T (2001) Sesquiterpenoids in root exudates of *Solanum aethiopicum*. *Z Naturforsch C* 56(9–10):707–713
- Nagase H, Nagaoka T, Watanabe A, Sakata Y, Yoshihara T (2001) Sesquiterpenoids from the roots of *Solanum aethiopicum*. *Z Naturforsch C* 56(3–4):181–187
- Odetola AA, Iranloye YO, Akinloye O (2004) Hypolipidaemic potentials of *Solanum melongena* and *Solanum gilo* on hypercholesterolemic rabbits. *Pak J Nutr* 3(3):180–187
- Porcher MH et al (1995–2020) Searchable world wide web multilingual multiscript plant name database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Sánchez-Mata MC, Yokoyama WE, Hong YJ, Prohens J (2010) Alpha-solasonine and α -solamargine contents of gboma (*Solanum macrocarpon* L.) and scarlet (*Solanum aethiopicum* L.) eggplants. *J Agric Food Chem* 58(9):5502–5508
- Ssegawa P, Kasenene JM (2007) Medicinal plant diversity and uses in Sango bay area, Southern Uganda. *J Ethnopharmacol* 113:521–540
- Stommel JR, Whitaker BD (2003) Phenolic acid content and composition of eggplant fruit in a germplasm core subset. *J Am Soc Hort Sci* 128(5):704–710
- Thomas L-V (1972) De l'ethnobotanique à la médecine: l'exemple Diola. *Notes Africaines* 134:48–52
- Vergiat A-M (1969) Plantes magiques et médicinales des féticheurs de l'Oubangui (Région de Bangui) *J Agric Trop Bot Appl* 16:84–112, 335–367, 418–456
- Voon BH, Kueh HS (1999) The nutritional value of indigenous fruits and vegetables in Sarawak. *Asia Pac J Clin Nutr* 8(1):24–31
- Voon BH, Chin TH, Sim CY, Sabariah P (1988) Wild fruits and vegetables in Sarawak. Department of Agriculture, Sarawak, 114 pp
- Watanabe A, Toshima H, Nagase H, Nagaoka T, Yoshihara T (2001) Structural confirmation of 15-norlubiminol and 15-norepilubiminol, isolated from *Solanum aethiopicum*, by chemical conversion from lubimin and epilubimin, and their antifungal activity. *Biosci Biotechnol Biochem* 65(8):1805–1811

Solanum americanum

Scientific Name

Solanum americanum Mill.

Synonyms

Solanum adventitium Polgár, *Solanum amaran-toides* Dunal, *Solanum americanum* subsp. *nodiflorum* (Jacq.) R. J. F. Hend., *Solanum americanum* subsp. *nodiflorum* (Jacq.) R. J. F. Hend., *Solanum americanum* var. *nodiflorum* (Jacq.) Edmonds, *Solanum calvum* Bitter, *Solanum caribaeum* Dunal, *Solanum curtipes* Bitter, *Solanum depilatum* Bitter, *Solanum erythrocarpon* G. Mey., *Solanum fauriei* H. Lév., *Solanum fistulosum* Dunal, *Solanum ganchouenense* H. Léveille, *Solanum gollmeri* Bitter, *Solanum imerinense* Bitter, *Solanum inconspicuum* Bitter, *Solanum indecorum* A. Rich., *Solanum inops* Dunal, *Solanum macrotonum* Bitter, *Solanum merrillianum* Liou, *Solanum microtatanthum* Bitter, *Solanum minutibaccatum* Bitter, *Solanum minutibaccatum* subsp. *curtipedunculatum* Bitter, *Solanum nigrum* auct. non L., *Solanum nigrum* forma *nodiflorum* (Jacq.) Miq., *Solanum nigrum* forma *glabrum* Chiov., *Solanum nigrum* forma *violaceum*, *Solanum nigrum* L. var. *americanum* (Mill.) O. E. Schulz, *Solanum nigrum* var. *dillenii* (Schult.) A. Gray, *Solanum nigrum* var. *minor* Hook. f., *Solanum nigrum* var. *nodiflorum* (Jacq.) A. Gray, *Solanum nigrum* var. *pauciflorum* Liou, *Solanum nigrum* var. *virginicum* L., *Solanum*

nodiflorum Jacq., *Solanum nodiflorum* subsp. *nutans* R. J. F. Hend., *Solanum nodiflorum* var. *acuminatum* Dunal, *Solanum nodiflorum* var. *acuminatum* Chodat, *Solanum nodiflorum* var. *fauriei* (H. Lév.) O. Deg. & O. Deg., *Solanum nodiflorum* var. *macrophyllum* Dunal, *Solanum nodiflorum* var. *petiolastrum* Dunal, *Solanum nodiflorum* var. *puberulum* Dunal, *Solanum nodiflorum* var. *sapucayense* Chodat, *Solanum oleraceum* Dunal, *Solanum oleraceum* var. *macrocarpum* Dunal, *Solanum pachystylum* Polg., *Solanum parviflorum* Badarò, *Solanum pauciflorum* (Liou) H. Y. Zhang, *Solanum pentagonocalyx* Bitter, *Solanum photeinocarpum* Nakam. & Odash., *Solanum pterocaulon* Dunal, *Solanum ptychanthum* Dunal, *Solanum purpuratum* Bitter, *Solanum quadrangulare* Thunb. ex L. f., *Solanum rhinozerotheris* Blume, *Solanum sciaphilum* Bitter, *Solanum subspathulatum* Sendtn., *Solanum tenellum* Bitter, *Solanum triangulare* Lam.

Family

Solanaceae

Common/English Names

Black Nightshade, American Black Nightshade, Glossy Nightshade, Large-Fruited Black Nightshade, Small-Flowered Nightshade.

Vernacular Names

Arabic: anab-ul-thalab, anab-us-salab, anab-us-salap, anbulzahalab, enab-ul-thalab, enabus salab, makoh;

Argentina: Arachichu (Misiones);

Assumption: Brede (West Island);

Brazil: Erva-Moura, Maria-Preta, Maria-Pretinha, Pimenta-De-Galinha (Portuguese);

Cameroon: Wosangu-Njika, Wosangu (Bakweri), Legume Verte (French);

Chinese: Bai Hua Cai, Pai Hua Ts'ai, Kou Zi Cao, K'ou Tzu Ts'ao, Gu Niu Cai, Ku Niu Ts'ai, Shao Hua Long Kui;

Cook Islands: Poro, Poro Puaka, Poroporo (Maori);

Czech: Lilek Americký;

Dutch: Zwarte Nachtschade;

Fiji: Malahome, Mboro, Mboro Laukana, Mboro Ni Veiwere, Mboro Ni Yaloka Ni Ngata, Mburosousou Ni Vavalangi, Thevuthevu;

French: Herbe A Calalou;

French Guiana: Alaman;

Ghana: Ebibirba (Fante), Nsusúa (Twi);

Guatemala: Macuy (Alta Verapaz), Hierba More (Chimaltenango, Jutiapa), Quilete (Santa Rosa);

Guyana: Bitter-Gumma, Black-Calalu, Black Nightshade, KuYa-Wick-Yik (Patamona);

Hawaiian: 'Olohua, Polopolo, Pōpolo, Pōpolohua;

India: Indonesia: Kampai, Ranti (Javanese), Ranti (Malay), Leunca Biasa, Leunca Badak, (Sundanese);

Kenya: Managu (Kikuyu), Isoyot (Kipsigis), Ol'momoit (Masai), Ysudza;

Laotian: Kh'eengz Namz;

Madagascar: Brede;

Malaysia: Ranti;

Marquesan: Oupoo;

Mauritius: Brede, Brede Martin (Mapau Island);

Mexico: Ekelite, Quelite, Yerba Mora;

Nigeria: Òdú, O'dú, O'gunmo (Yoruba);

Niuean: Polo Fua, Polo Kai;

Norwegian: Adventivstøtvier;

Panama: Kaburgia;

Papua New Guinea: Karakap;

Persian: angoor-e-shifa, robah turbuk;

Philippines: Kuti, Bolagtab (Bisaya), Anti (Tagalog);

Portuguese: Erva Moura, Erva De Bicho, Maria Pretinha, Pimenta De Galinha;

Samoan: Magālo, Polo;

Seychelles: Brède Martin (Aride Island);

Sierra Leone: Eat-Finish-And-Broke-Plate, Sapota (Creole), Efo-Odu (Creole Ex Yoruba), Kholekoleden-Na (Yalunka);

Spanish: Hierba Mora, Hierba Mora Negra;

Surinam: Agoema Wiwiri, Aguma Wiwiri, Bietagomo, Bietawiwirrie;

Swahili: Mnavu Mchungu;

Tahitian: 'Oporo;

Tanzania: Msogo (Bende), Mnavu (Bondei), Mhaki (Kibena), Mnavu (Shambaa), Mnavu Mchungu;

Thai: Mawaeng-Nok, Ya-Tomtok;

Tibetan: smon sne u dmar po, smon sneu dmar po;

Tongan: Polo Kai;

Trinidad & Tobago: Agouma, Gouma;

Swedish: Amerikansk Nattskatta;

Uganda: Wsuggaenzirugavu;

Vietnamese: Hôt Mít, Lủ Lủ Duc, Thu Lu Du'c Ca Den;

West Indies: Agouma, Bitter Gumma, Black Nightshade.

Origin/Distribution

The plant is probably a native of South America and is widely adventive in Africa, Australia, Melanesia, Caribbean Islands, Central America, Europe (rare casual), Hawaii, New Zealand, North America, East, South and southeast Asia. The taxon *S. americanum* is morphologically variable and is widespread throughout the Old and New Worlds. It is deemed a ubiquitous noxious weed of cane fields and plantation crops.

Agroecology

The plant is adaptable to a wide range of ecological conditions. It is widespread in all tropical and subtropical regions and is found in many types of soil from sea level to 2,300 m elevation under full sun or partial shade. It grows in open disturbed places, roadsides, fields, pastures, cane fields and plantations. It can be found growing among rocks, along sandy beaches and trails, on open gravel banks and waste land, from coastal to wet forest, subalpine woodlands and in the yards of village homes. It can be found in the arid lowlands in the Galápagos Islands. In semi-arid regions it is mostly found near a water source or as a weed in irrigated fields.

Edible Plant Parts and Uses

Leaves and young shoots are eaten as potherb, leafy vegetables (Plates 4 and 5), as spinach or in soups in Cameroon, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Natal (South Africa), Madagascar, Mauritius, Nigeria, Sierra Leon, Seychelles, Uganda, Tanzania, eastern Zimbabwe, Papua New Guinea, Pacific Islands, Guatemala, Peru, Malaysia, Indonesia and Vietnam. In Hawaii, the leaves and tender stems cooked as substitute for poi, berries eaten raw. The berries are also eaten raw or in soups in Kenya, Bolivia, Peru, the Pacific Islands and Asia. To further reduce the bitterness, the leaves are served together with cooked amaranth, either separately or as a mixture. It is held that leaves cooked with milk, groundnut or sesame (*Sesamum indicum* L.) protects children from diseases associated with malnutrition.

Botany

Annual or short-lived perennial erect, small and widely spreading herb, growing to 150 cm high, unarmed (prickles absent) (Plate 1), glabrescent

or puberulent with simple hairs. Stem rounded or narrowly winged, glabrous or sparsely pubescent green or tinted with purple. Leaves arranged spirally to almost opposite, simple, green on 1–9 cm long petiole. Lamina ovate-lanceolate, up to 14–16 cm by 7–12 cm, cuneate to truncate at base and decurrent along the petiole, acute to acuminate at apex, margins entire to sinuate (Plates 1–3), rarely sinuate-dentate, glabrous or sparsely pubescent. Inflorescence an extra-axillary, loose, umbelliform cyme, 3–6-flowered; peduncle 0.5–2.5 cm long, elongating up to 4 cm in fruit. Flowers bisexual, actinomorphic, pentamerous; pedicel 5–10 mm long, becoming noddling; calyx campanulate, 1.5–2 mm long, lobes ovate to oblong, reflexed in fruit; corolla deeply stellate, 5–9 mm in diameter, white or flushed purple with basal yellow-green star, lobes ovate-oblong, 3 mm long; stamens inserted on corolla throat, filaments 0.5–2 mm long, with hairs on inner side, anthers yellow, connivent, 1.5–2 mm long, opening by terminal pores; ovary superior, globose, c. 1 mm in diameter, style 2.5–4 mm long, hairy in the lower part, style exerted beyond anthers, stigma capitate, pale green. Fruit a globose flecked berry, 4–10 mm in diameter, from green turning to glossy purplish black at maturity (Plates 1–3), falling from calyces when ripe with many (24–70) discoid seeds with minutely reticulate testa and 0.8–1.5 mm in diameter.



Plate 1 Small herbaceous plant habit



Plate 2 Sinuate leaves, glossy green and purplish black ripe flecky fruit



Plate 3 Sinuate leaves and dull flecky, pale green fruits



Plate 4 Leafy shoots on sale in a local market in Indonesia



Plate 5 Bunch of leaves sold as vegetables

Nutritive/Medicinal Properties

Fruit of *Solanum* Morellae section including *S. americanum* and *S. nigrum* were found to contain solasonine and solamargine (Briggs et al. 1961). Solasodamine was shown to be solasonine monohydrate and solauricine a mixture of solasonine and solamargine and that solauricidine was probably a mixture of solasodine and its galactoside. Both fruits also contained small amounts of α -solanigrine and β -solanigrine. The ripe fruit of *S. americanum* was reported to contain 0.3–0.45% of solasonine (Watt and Breyer-Brandwijk 1962). Significant amounts of diosgenin (1.2%) and solasodine (0.65%) were found in green berries of the Indian diploid '*S. nigrum*' (= *S. americanum*) with lesser amounts of both chemicals in the Indian tetraploid (= *S. villosum*) and hexaploid (= *S. nigrum*) species (Khanna and Rathore 1977). Máthé et al. (1980) had also found solasodine in all parts of *S. americanum*, but suggested that since the highest concentration occurred in the green berries, these might be a suitable source of solasodine for steroid hormone synthesis. Rao (1978) identified the anthocyanin pigment, "petunidin3-(*p*-coumoryl) rhamnosyl glucoside" in the Indian forms of both *S. nigrum* and *S. americanum*. Leaf-extracts of all species in *Solanum* sect. *Solanum* (= sect. Morella) including *S. americanum* and *S. nigrum* were found to contain diosgenin and tigogenin (Carle 1981). Solasodine was absent in the leaf extracts but was detected in unripe fruits.

Solanum americanum was found to contain the following steroidal glycolalkaloids α -solanargine 1.96 mg/g, solasonine 3.5 mg/g, α -solanine 3.29 mg/g but was devoid of β -solanargine and the following steroidal glycolalkaloid aglycones solanidine 8.85% and solasodine 85.67% (Mohy-Ud-Din et al. 2010). Among the five taxa of *Solanum nigrum* Complex investigated, *S. nigrum* showed highest level of total flavonoids (2.116%) followed by *S. americanum* 1.667%, *S. retroflexum* 1.204%, *S. villosum* 0.891% and *S. chenopodioides* 0.883% the lowest (Mohy-Ud-Din et al. 2009). In terms of quercetin concentration (mg/100 g of plant), *S. americanum* had the highest 6.46 mg, followed by *S. villosum* 4.91 mg, *S. chenopodioides* 3.81 mg, *S. retroflexum* 3.18 mg and *S. nigrum* 3.06 mg the lowest.

Solanum americanum contains glycolalkaloids which have potent pharmacological properties.

Antiviral and Antimicrobial Activity

Solanum americanum was one of 22 plants tested that showed anti-dermatophyte activity against *Epidermophyton floccosum*, *Microsporum canis*, *Microsporum gypseum*, *Trichophyton mentagrophytes* and *Trichophyton rubrum* (Caceres et al. 1991). *Solanum americanum* extracts were active against *Microsporum gypseum*, *Cryptococcus neoformans* and *Artemia salina nauplii* and showed intra-peritoneal subacute toxicity in mice (Cáceres et al. 1998).

Ikeda et al. (2000) found the spirostanol glycosides to be most effective in anti-Herpes simplex virus activity amongst steroidal glycosides obtained from *Solanum* plants. The potency in decreasing order was found to be of spirostane, tomatidane, ergostane, solasodane, nuatigenin type, dimer of ergostane and furostane. It was also suggested that the activity depends on the kind of oligosaccharide moiety. Alpha-solanargine isolated from the fresh fruits of *Solanum americanum* is a glycoalkaloid with biological activity against *Herpes simplex I*, *Herpes zoster* and *genital Herpes* and *Trypanosoma cruzi*. (Al Chami et al. 2003).

Alpha-solanargine isolated from the fresh fruits of *Solanum americanum* is a glycoalkaloid with biological activity against *Herpes simplex I*, *Herpes zoster* and *genital Herpes* (Al Chami et al. 2003).

Chataing et al. (1996) applied topically a cream base made up of a mixture of alkaloids mainly solanargine and solasodine extracted from *Solanum americanum* to 46 patients aged between 13 months and 79 years, 34 of them with *Herpes simplex*, 9 with *Herpes zoster* and 3 with *Herpes genitalis*. *Herpes simplex* patients showed improvement after 3 days of daily application with a substantial decrease in pruritus, erythema and vesicles; patients with *Herpes zoster* showed maximum improvement after 10 days with the appearance of scabs and scarring 5–10 days; patients with *Herpes genitalis* showed improvement after 5 days with disappearance of lesions in treatment of 5 days. No symptoms of disease recurrence were observed after 9 months into treatment. None of the 46 patients experienced adverse event. In another study they found that a mixture of *Solanum americanum* alkaloids containing mainly solanargine and solasonine and a low proportion (<5%) of mono- and diglycosides, applied topically as a cream to 90 patients, 54 of them with *Herpes simplex*, 27 with *Herpes zoster* and 9 with *Herpes genitalis* was effective (Chataing et al. 2001). Symptoms of infection disappeared from all patients in a period of 5–10 days. One year after treatment, 90% of the patients did not show signs of recurrence, in the remaining 10% reappearance of the infection was delayed.

Cardiovascular Activity

Studies showed that administration of α -solanargine isolated from fresh fruits of *Solanum americanum* did not cause any appreciable effect on heart rate in rats at doses below LD₅₀ (Méndez et al. 2007). In contrast, α -solanargine at doses of 10 and 50 mg/kg body weight decreased transiently blood pressure in a concentration-dependent fashion. Histological studies in cardiac tissue did not show any damage at the cellular level. The results obtained suggested that even

though α -solamargine possessed an acetylcholinesterase inhibitory activity, similar in many aspects to the data reported for other *Solanaceae* glycoalkaloids, the effects of the glycoalkaloid on the cardiovascular system of Wistar rats at doses below LD₅₀ was not statistically significant. The transient decrease on the blood pressure upon administration of α -solamargine, which after a short time increased slightly and return to control values, could be in part be due to a possible reduced reversible inhibition caused by α -solamargine on acetylcholinesterase.

Antiinflammatory Activity

The chloroform, methanol and ethanol extract of *S. americanum* plant at 150 and 200 mg/kg exhibited inhibition of carrageenan induce paw oedema of 53.90, 71.80 and 74.93% and minimum inhibition of 15.54, 60.59 and 73.08% respectively in male Wistar albino rats (Pushpalatha et al. 2011). Indomethacin (10 mg/kg) as standard showed 67% inhibition after 3 h treatment. The researchers concluded that *S. americanum* extract may be useful as adjuvant along with standard anti-inflammatory drugs.

Trypanocidal Activity

Solanum americanum extracts were reported active against and *Trypanosoma cruzi* and showed intra-peritoneal subacute toxicity in mice (Cáceres et al. 1998). Chataing et al. (1998) tested the following glycoalkaloids: α -chaconine, α -solamargine, α -solanine, solasonine, sycophantine, and tomatine, as well as the aglycones demissidine, solanidine, solanocapsine, solasodine, tomatidine, and veratrine for inhibitory action on growth of *Trypanosoma cruzi*. They found that glycoalkaloids containing α -chacotriose showed trypanolytic activity against the epimastigote form and trypanocidal activity against the bloodstream and metacyclic trypomastigote form of *Trypanosoma cruzi* in culture medium in micromolar concentration.

Ketoconazole, an antifungal, showed a lower activity, at the same concentrations of α -chaconine and α -solamargine. Internal compartments of the parasites were observed to be affected by the drugs, revealing the dissolution of some organelles like mitochondrias and glycosomes.

Molluscicidal Activity

All parts of the plant were found toxic to the snails *Fossaria (Lymnaea) cubensis*, *Lymnaea columella*, *Biophalaria glabrata* and *Physa cubensis* (Medina and Ritchie 1980). No toxicity was found against *Marisa cornuarietis* and *Tarebia granifera*. The plant being easy to find locally afforded a cheap safe means for controlling both *Schistoma* and *Fasciola* snail hosts in Puerto Rico.

Toxicological Studies

Lethality studies of α -solamargine, isolated from *S. americanum* fresh fruit showed a dose-mortality relationship in rats with a LD₅₀ of 42 mg/kg body weight intraperitoneally (Al Chami et al. 2003). No appreciable toxic effects were observed at doses below 35 mg/kg body weight as indicated by blood parameters, enzyme levels and histological sections of kidney, liver and cardiac muscle. α -solamargine did not affect the weight of the testes and epididymis or the number of spermatozoa but produced a slight irritation and congestion in the epididymis and testis at doses up to 50 mg/kg body weight

Traditional Medicinal Uses

All parts of the Black nightshade plant has been featured in traditional folk medicine throughout the tropics. The stalk, leaves, and root are used in decoction for wounds and cancerous sores, and as an astringent and are regarded to be diuretic. The bruised fresh leaves, used externally, are said to ease pain and abate inflammation, and the Arabs apply them to burns and ulcers. Their juice

has been used for ringworm, gout and earache, and mixed with vinegar, is said to be good as a gargle and mouthwash. In Cameroon, the leaves are pounded and applied on sores. In Kenya, the Masai make infusion from leaves to rub on body for rheumatic pains. In Sierra Leone, the leaves are eaten for heart pains. In Tanzania, the fresh leaves are pounded and juice sprayed into the eye to treat severe conjunctivitis. In Hawaii, juice of leaves is mixed with salt and used as remedy for eye diseases, and the roots chewed as cold cure. In Trinidad and Tobago, the plant is used as bath for children malnutrition. In French Guiana, Guyana and The Surinam, a decoction of the whole plants is used as an antispasmodic, as a blood purifier and vermifuge to expel intestinal worms. It is also used for cardialgia, corroding ulcers, suppurating cancers, deep wound, skin diseases such as darter and in cataplasms for kidney pain. In Guyana, the stem and leaves are used in teas to improve kidney function. The roots are boiled with water, mixed with lime juice and salt and drank as anti-malarial by the Guyana Patomona. In Surinam, parts of the plant are used in a curative herbal bath, for tetanus cramps, stiffness, contractions of limbs and for headache.

Other Uses

The plant is also used as fodder for animals.

Comments

S. americanum is one of 30 odd species in the *S. nigrum* complex, more formally *Solanum* L. section *Solanum*, also called section *Maurella* (Dun.) Dumort. or section *Morella* (Dun.) Bitter. The taxonomy of *S. nigrum* complex needs more work.

Selected References

- Al Chami L, Mendez R, Chataing B, O'Callaghan J, Usubilliga A, Lacruz L (2003) Toxicological effects of α -solanargine in experimental animals. *Phyto Res* 17(3):254–258
- Briggs LH, Cambie RC, Hoare JL (1961) *Solanum* alkaloids. Part XV. The constituents of some *Solanum* species and a reassessment of solasodamine and solauricine. *J Chem Soc* 1961:4645–4649
- Bukenya-Ziraba R, Carasco JF (1999) Ethnobotanical aspects of *Solanum* L. (Solanaceae) in Uganda. In: Nee M, Symon DE, Lester RN, Jessop JP (eds) *Solanaceae 4: advances in biology and utilization*. Royal Botanic Gardens, Kew, pp 345–360
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula, Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A—H), pp 1–1240, vol 2 (I—Z), pp 1241–2444
- Caceres A, Lopez BR, Giron MA, Logemann H (1991) Plants used in Guatemala for the treatment of dermatophytic infections. 1. Screening for antimycotic activity of 44 plant extracts. *J Ethnopharmacol* 31(3): 263–276
- Cáceres A, López B, González S, Berger I, Tada I, Maki J (1998) Plants used in Guatemala for the treatment of protozoal infections. I. Screening of activity to bacteria, fungi and American trypanosomes of 13 native plants. *J Ethnopharmacol* 62(3):195–202
- Carle R (1981) Investigations on the content of steroidal alkaloids and sapogenins within *Solanum* sect. *Solanum* (= sect. *Morella*) (Solanaceae). *Plant Syst Evol* 138(1–2):61–71
- Chataing B, Concepcion JL, de Cristancho NB, Usubillaga A (1996) Estudio clinico de la efectividad de extractos alcaloides obtenidos de los frutos *Solanum americanum* Miller so berel Herpes simplex, Herpes zoster, and Herpes genitalis. *Rev Fac Farm (Merida)* 32:18–25
- Chataing B, Concepcion JL, Lobaton R, Usubillaga A (1998) Inhibition of *Trypanosoma cruzi* growth in vitro by *Solanum* alkaloids: a comparison with ketoconazole. *Planta Med* 64(1):31–36
- Chataing B, Cristancho NB, Usubillaga A (2001) Topical treatment of herpes simplex, herpes zoster and genital herpes with a mixture of solanaceous glycoalkaloids. *MedULA* 7:30–35
- Chweya JA, Eyzaguirre PB (1999) Conclusion: managing the diversity of African leafy vegetables. In: Chweya JA, Eyzaguirre PB (eds) *The biodiversity of traditional leafy vegetables*. IPGRI, Rome, pp 173–182
- De Padua LS, Lugod GC, Pancho JV (1977–1983) *Handbook on Philippine medicinal plants*, 4 vols. Documentation and Information Section, Office of the Director of Research, University of the Philippines at Los Banos, The Philippines
- DeFilipps RA, Maina SL, Crepin J (2004) Medicinal plants of Guianas (Guyana, Surinam, French Guiana). Department of Botany, National Museum of Natural History, Smithsonian Institution, Washington, DC
- Edmonds JM, Chweya JA (1997) Black nightshades, *Solanum nigrum* L., and related species. Promoting the conservation and use of underutilized and neglected crops 15. IPGRI/IPK, Rome/Gatersleben, 113 pp

- Henderson RJF (1974) *Solanum nigrum* L. (Solanaceae) and related species in Australia. Contr Queensland Herb 16:1–78
- Holm LG, Plucknett DL, Pancho JV, Herberger JP (1977) The world's worst weeds: distribution and biology. East-West Center, University Press of Hawaii, Honolulu, 609 pp
- Hu SY (2005) Food plants of China. The Chinese University Press, Hong Kong, 844 pp
- Ikeda T, Ando J, Miyazono A, Zhu X-H, Tsumagari H, Nohara T, Yokomizo K, Uyeda M (2000) Anti-herpes virus activity of *Solanum* steroidal glycosides. Biol Pharm Bull 23(3):363–364
- Khanna P, Rathore AK (1977) Diosgenin and solasodine from *Solanum nigrum* L. complex. Indian J Exp Biol 15:808–809
- Lans C (2007) Comparison of plants used for skin and stomach problems in Trinidad and Tobago with Asian ethnomedicine. J Ethnobiol Ethnomedicine 3:3
- Máthé I, Hoang VM, Máthé I (1980) Studies on the Morella section of the *Solanum* genus. V. Evaluation of the alkaloid production of *Solanum americanum* Mill. Acta Agron Acad Sci Hungaricae 29(1–2):227–230
- Medina FR, Ritchie LS (1980) Molluscicidal activity of the Puerto Rican weed, *Solanum nodiflorum*. Econ Bot 34(4):368–375
- Méndez R, Usabillaga A, Chataing B (2007) Cardiovascular effects of α -*Solamargine* in wistar rats. Salud Desarrollo Social 3:1–7
- Mohy-Ud-Din A, Khan Z-U-D, Ahmad M, Kashmiri MA, Yasmin S, Mazhar H (2009) Chemotaxonomic significance of flavonoids in the *Solanum nigrum* complex. J Chil Chem Soc 54(4):486–490
- Mohy-Ud-Din A, Khan Z-U-D, Ahmad M, Kashmiri MA (2010) Chemotaxonomic value of alkaloids in *Solanum nigrum* complex. Pak J Bot 42(1):653–660
- Ochse JJ, Bakhuizen van den Brink RC (1980) Vegetables of the Dutch Indies, 3rd edn. Ascher & Co., Amsterdam, 1016 pp
- PBI Solanum Project (2011) Solanaceae Source. 10 Nov 2011. <http://www.nhm.ac.uk/solanaceaesource/>
- Porcher MH et al (1995–2020) Searchable world wide web multilingual multiscript plant name database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Pushpalatha KN, Ramachandran VS, Arumugasamy K (2011) Evaluation of anti-inflammatory activity of the whole plant extracts of *Solanum americanum* Miller (Solanaceae) in albino male rats. South Asian J Biol Sci 1(1):16–20
- Rao GR (1978) Role of fruit pigments in understanding the inter-relationships and mechanism of evolution of higher chromosomal forms of the species of the *Solanum nigrum* L. complex. Acta Bot Indica 6(Suppl):41–47
- Siemonsma JS, Jansen PCM (1994) *Solanum americanum* Miller. In: Siemonsma JS, Piluek K (eds) Plant resources of south-east Asia, no. 8. vegetables. Prosea Foundation, Bogor, pp 252–255
- Tropicos Org (2012) Nomenclatural and Specimen Database of the Missouri Botanical Garden. <http://www.tropicos.org/Home.aspx>
- Watt JM, Breyer-Brandwijk MG (1962) *Solanum nigrum* L. In: The medicinal and poisonous plants of southern and eastern Africa. E. and S. Livingstone Ltd. Edinburgh/London, pp 996–1000
- Zhang ZY, Lu AM, D'Arcy WG (1994) Solanaceae A. L. Jussieu. In: Wu ZY, Raven PH, Hong DY (eds) Flora of China, vol 17, Verbenaceae through Solanaceae. Science Press/Missouri Botanical Garden Press, Beijing/St. Louis

Solanum betaceam

Scientific Name

Solanum betaceum Cav.

Synonyms

Cyphomandrabetacea (Cav.) Sendtn., *Cyphomandra crassifolia* (Ortega) Kuntze, *Cyphomandra crassifolia* (Ortega) J. F. Macbr. nom. illeg., *Cyphomandra procera* Wawra, *Pionandra betacea* (Cav.) Miers, *Solanum betacea* Cav., *Solanum crassifolium* Ortega nom. illeg., *Solanum insigne* Lowe.

Family

Solanaceae

Common/English Names

Cape Tomato, Tamarillo, Tomatillo, Tree Tomato, Yellow Tree Tomato.

Vernacular Names

Argentina: Limatolate, Tomate De Monte, Tomate De La Paz;
Bolivia: Limatolate, Tomate De Monte, Tomate De La Paz;
Chinese: Shu-Fan-Qie, Shu-Fan-Ch'ieh;

Czech: Rajčenka Řepovitá;

Danish: Trætomat;

Dutch: Boom-Tomatie, Struiktomaat;

French: Tamarille, Tomate D'arbre, Arbre À Tomates, Tomate De La Paz, Tomate En Arbre;

German: Tamarillo, Baumtomate;

India: Ookhamen (Manipuri), Marattakkali (Tamil);

Indonesia: Terong Belanda, Terong Menen;

Italian: Pomodora Arboreo;

Malaysia: Pokok Tomato;

Peru: Tomate De Árbol, Berenjena, Sachatolate, Yuncatolate;

Portuguese: Tomate Francês, Tomato De Árvore;

Spanish: Palo DE Tomate, Tamarillo, Tomate Serrano, Tomate Silvestre, Tomate De Arbol, Tomate Dulce, Tomate Granadillo, Tomate Pimiento, Caxlan Pix;

Slovenian: Tamarilo;

Swahili: Mgogwe;

Swedish: Trätomat, Tamarillo;

Thailand: Makhua-Thetton (Chiang Mai);

Uganda: Munyanya (Luganda).

Origin/Distribution

The species is indigenous to the Andes of Bolivia, Chile, Ecuador, Argentina and Peru. It is cultivated in Argentina, Australia, Brazil, Colombia, Kenya, the United States, Venezuela and New Zealand where it is grown as a commercial export crop. In the tropics, it is cultivated in the highlands

in Indonesia, Philippines, Malaysia, Thailand, Vietnam and Papua New Guinea.

Agroecology

Tamarillo is a subtropical species and flourishes at elevations of 1,000–3,000 m in the tropics and subtropics, and in lower elevations of 300–1,000 m in the cooler areas in the subtropics. It is frost susceptible, and temperatures of -2.2°C will kill the young foliage, juvenile branches and seedlings; it tolerates low temperatures above 10°C . Tamarillo grows best in regions with temperatures between 18 and 22°C and annual precipitation of 600–800 mm. Cool temperatures promote flowering. High temperatures affect flowering and fruiting, as do prolonged droughts. The tree needs to be protected against strong winds as it has a shallow root system and its branches are rather brittle and its foliage soft. Tamarillo does best on friable, well-drained, light soils and is intolerant of heavy clays, compacted soils, and waterlogged soils.

Edible Plant Parts and Uses

Ripe fruit is eaten raw by sprinkling sugar over the flesh and scooping the flesh from a halved fruit or remove the stem end and squeeze the flesh directly into the mouth. Or the halves may be seasoned and grilled or baked for 15 min and served as a vegetable. Only mature, tree-ripened fruits grown under favourable conditions develop the full flavour and aroma. The peeled fruit can be sliced and the slices served with a sprinkling of sugar and perhaps with a scoop of vanilla ice cream as dessert fruit. The slices are also added to compote, stews, soups, and curries. Tamarillo slices are tasty and decorative in fresh salads. Seasoned with salt and pepper, the slices can serve as sandwich-filling, or the chopped slices are blended with cream cheese and used as sandwich spread. The peeled, stewed fruits are combined with gelatin, milk, sugar and lemon juice to make a dessert which is then garnished with

fresh tamarillo slices. Tamarillo slices, alone, or combined with sliced apples, are cooked in pies. Tamarillo fruit may be preserved after cooking in water or sugar syrup and frozen for later use in pies, puddings and cakes. Peeled, diced fruits, with diced onion, breadcrumbs, butter and appropriate seasonings are employed as stuffing for roast lamb. The unripe fruit can be used together with onions and apples to make chutney, or used in curries and sambal (hot, chilli-based condiment). Peeled, sliced tamarillo, with lemon rind, lemon juice and sugar, are cooked to a jam. Being high in pectin, the fruit is easily made into jelly but the fruit oxidizes and discolours without special treatment during processing. Whole, peeled fruits, with sugar, are cooked to a sauce for use on ice cream. The peeled fruits may be pickled whole, or may be substituted for tomatoes in a hot chilli sauce. In Peru, almost ripe fruit is used to prepare a sauce with *Capsicum pubescens* (large green pepper) to prepare a spicy sauce that is relish as an appetizer. Tamarillo pulp is frequently combined with water and sugar in a blender to create fresh juices, smoothies, sherbet and even alcoholic beverages; the pulp can be processed into puree, packed in plastic bags and frozen. Lemon juice may be added to the puree to enhance the flavour.

Botany

Solanum betaceam is a small, unarmed, pubescent tree, growing 2–5 m high rarely 7 m with a single, short, grey trunk that is monopodial and branched at a height of 1–1.5 m into two or three branches. Leaves alternate, simple, entire, usually grouped at the branch tips, with a robust petiole, 4–8 cm long. Lamina is ovate, 17–30 cm long, 12–19 cm wide, subcarnose, shortly acuminate with cordate base and lightly pubescent on the underside (Plate 1). Flowers fleshy pink, 1.3–1.5 cm across (Plate 2), hermaphroditic, pentamerous, fragrant, pedicellate, in groups of 3–10 in axillary cymes or racemes, near the ends of the branches. Calyx campanulate with broadly ovate, subacute lobes, which are thick and accrescent in fruit. Corolla



Plate 1 Leaves and unripe fruits



Plate 3 Tamarillo fruit with long peduncles

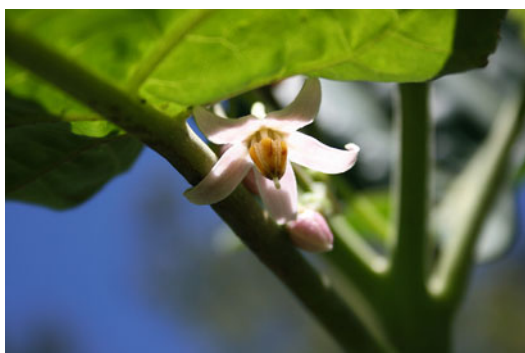


Plate 2 Close-up of flower

rotate-campanulate, 12 mm long, with 5 long, narrow, lanceolate segments; reflexed at the apex. Stamens 5, inserted at the throat of the corolla with yellow anthers that is dehiscent through two apical pores. Ovary glabrous and style cylindrical and glabrous, stigma punctiform. Fruit ellipsoidal or ovoid, obtuse or acute at apex, 4–10 cm long, 3–5 cm in diameter, glabrous, yellow to orange, red, or purple, often with darker longitudinal markings (Plates 1, 3–5). Mesocarp is orange, pulpy and contains numerous small, circular, flat, thin, hard pubescent seeds 3–4 mm long by 3.5–4 mm wide (Plate 5).

Nutritive/Medicinal Properties

Food value of tamarillo fruit per 100 g of edible portion (seeds excluded) based on analyses made in Ecuador, Guatemala and India (Morton 1987)

is: moisture 82.7–87.8 g, protein 1.5 g, carbohydrates 10.3 g, fat (ether extract) 0.06–1.28 g, fibre 1.4–4.2 g, nitrogen 0.223–0.445 g, ash 0.61–0.84 g, calcium 3.9–11.3 mg, phosphorus 13.1 mg, iron 0.66–0.94 mg, carotene 0.371–0.653 mg (or calculated as vitamin A 540 I.U.), thiamine 0.038–0.137 mg, riboflavin 0.035–0.048 mg, niacin 1.011 mg and ascorbic acid 23.3–33.9 mg.

Food value of tamarillo fruit per 100 g of edible portion (seeds excluded) based on analyses made in Australia (Wills 1987) is : moisture 86.2%, protein 2.0 g, fat 0.1 g, glucose 0.8 g, fructose 0.9 g, sucrose 1.7 g, dietary fibre 4.7 g, organic acids – malic acid 0.17 g, citric acid 1.82 g, energy 113 kJ; vitamins – β -carotene equivalent 0.93 mg, thiamine 0.03 mg, riboflavin 0.04 mg, niacin 0.3 mg, vitamin C 15 mg, K 280 mg, Na 1 mg, Ca 8 mg, Mg 16 mg, Fe 0.7 mg and Zn 0.2 mg.

Forty-six volatile constituents were identified in tamarillo fruit (Torrado et al. 1995). Among them, methyl hexanoate, (E)-hex-2-enal, (Z)-hex-3-en-1-ol, eugenol and 4-allyl-2,6-dimethoxyphenol were found to be the major constituents. Others identified included the presence of racemic mixtures both of butan-2-ol and methyl 3-hydroxybutanoate. For ethyl 3-hydroxybutanoate, methyl 3-hydroxyhexanoate and ethyl 3-hydroxyhexanoate enantiomeric distributions of 68:32%, 73:27%, and 63:37%, each of (S):(R), respectively, were determined. For α -terpineol



Plate 4 Tamarillo fruit on sale as loose fruit and in stringed bags in various markets



Plate 5 Whole and halved tamarillo fruit

and 4-terpineol enantiomeric excesses of 76% (S) and 48% (R), respectively, were found. In another analysis, 49 volatile components were identified in tamarillo fruit, non-terpenoid alcohols and esters were dominant accounting for 44.7% and 37.4% of the total volatiles, respectively (Wong and Wong 1997). The major components were (Z)-3-hexenol (26.6%), ethyl butyrate (14.8%), methyl butyrate (12.0%) and methyl hexanoate (8.6%).

A hydrocolloid with a yield of 8.30% dry weight basis, was extracted from *S. betaceum* puree (Gannasin et al. 2012). The hydrocolloid comprised 0.83% starch, 21.18% protein and 66.48% dietary fibre with 49.47% degree of esterification and the monosaccharides identified were mannose, ribose, rhamnose, galacturonic acid, glucose, galactose, xylose and arabinose.

Higher oil-holding capacity, emulsifying activity and emulsion stability compared to commercial hydrocolloids indicated its possible application as a food emulsifier and bile acid binder. Foaming capacity of 32.19% and good foam stabilisation (79.36% of initial foam volume after 2 h of foam formation) suggested its promising application in frothy beverages and other foam based food products. The findings suggested that water-extracted tamarillo hydrocolloid could be utilised as an alternative to low methoxyl pectin.

Antioxidant Activity

Tamarillo was found to have 3 anthocyanins and 17 carotenoids (Wrolstad and Heatherbell 1974). Levels of anthocyanins and carotenoids found in tamarillo fruits were 8.5 and 4.4 mg/100 g, respectively. Although dovyalis and tamarillo fruits belong to different families, delphinidin 3-rutinoside and β -cryptoxanthin were found to be, respectively, the major anthocyanin and carotenoid in both fruits (de Rosso and Mercadante 2007). Anthocyanins were proven to be good antioxidants against peroxy radicals but not against peroxynitrite and hydroxyl radicals. The measured activity against the both latter suggested that maybe other compounds take part in antioxidant reactions.

Ascorbic acid was identified as a potent antioxidant constituent in tamarillos. Its antioxidant efficiency was good against peroxy radicals

(Gordon et al. 2007). Ascorbic acid demonstrated a moderate antioxidant behaviour towards peroxynitrite. No activity in relevant concentrations was exhibited towards hydroxyl radicals. Amounts of ascorbic acid were 4.5 fold higher in the seed jelly rather than the fruit pulp. The seed jelly contains in total eight anthocyanins which were derived from the aglycons cyanidin, delphinidin, and pelargonidin with a pelargononidin-hexosyl-desoxyhexoside and a cyanidin-hexosyl-desoxyhexoside predominating (Gordon et al. 2007). Compared to oranges, tamarillo fruit contains a similar amount of ascorbic acid (between 25 and 30 mg/100 g fresh weight of the edible part) and showed a significantly higher TOSC (Total Oxygen Scavenging Capacity) value against peroxy radicals which may be explained by the presence of anthocyanins. The antioxidant activity of the tree tomato fruit was determined by free radical 1,1-diphenyl-2-picrylhydrazyl (DPPH) method to be $IC_{50} = 7.5$ mg/mL and phenolic compound content of 1,125 mg/100 g, which was better than that reported for orange (*Citrus sinensis*) $IC_{50} = 18.3$ mg/mL and phenolic compound content of 64.2 mg/mL (Franco 2006).

Vasco et al. (2009) found that the golden-yellow and purple-red Ecuadorian tamarillo fruits were larger (107 and 188 g) than the respective Spanish fruits (43 and 63 g), softer but generally similar in chemical composition except for fat (0.72 and 0.6%) and malic acid (0.32 and 0.53%) contents in the golden-yellow and purple-red Ecuadorian fruits respectively. Tamarillo fruits were found to be a good source of potassium (approximately 400 mg/100 g fresh weight). Total phenolics in the golden-yellow and purple-red varieties were 125 and 187 mg gallic acid equivalents/100 g fresh weight, respectively. The golden-yellow variety had weaker anti-DPPH radical activity than the purple-red variety. Flavonols were only found in the peel of both varieties, while hydroxycinnamic acid derivatives were found in peel and pulp.

Cyphomandra betacea ripe fruit preparations (juice, decoction and maceration) were found to have good free radical scavenging activity (DPPH and ABTS*+ radical scavenging, nitrite scaveng-

ing activities) with SC_{50} values between 1.88 and 44 μ g/mL and exerted protection against β -carotene oxidation (Ordóñez et al. 2010). Total phenolic compounds and flavonoids showed a better correlation than anthocyanins with the free radical scavenging effect of the assayed food preparations. The best antioxidant activity was found in *C. betacea* fruit maceration, probably as a consequence of the high flavonoid and anthocyanin content. Also the insoluble matters (pomace) obtained after juice preparation showed antioxidant activity by quenching free radicals. Further, 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium (MTT) reduction assay showed that *C. betacea* preparations prevented oxidative stress-induced cell death in HepG2 cells in a dose-dependent manner. *Salmonella* microsome assays showed no mutagenic effect. The data suggested that *C. betacea* ripe fruits, aqueous and ethanolic preparations, and pomace may be a good source of antioxidant compounds in nutraceutical or functional-food products. A protein, cyphomine, with molecular mass around 17 kDa, was purified from *Solanum betaceum* fruits (Ordóñez et al. 2011). It reduced oxidative damage by scavenging hydroxyl radicals and superoxide anion in a dose-dependent manner and inhibited uric acid formation. It showed no genotoxic nor mutagenic effects in the *Allium cepa* and *Salmonella*/microsome assays. The authors concluded that it may be important source for the production of bioactive peptides in the development of functional foods with a beneficial impact on human health.

The ethyl acetate fraction of tamarillo fruit exhibited the highest DPPH scavenging activity, Trolox equivalent antioxidant capacity (TEAC) and total phenol content (Kou et al. 2009). *C. betacea* phenolics in ethyl acetate fraction inhibited copper-induced low density lipid (LDL) oxidation equally to or more effectively than dl- α -tocopherol, as measured by decreased formation of thiobarbituric acid-reactive substances (TBARS), conjugated diene and relative electrophoretic mobility (REM). Furthermore, MTT reduction assay showed that *C. betacea* phenolics in ethyl acetate fraction prevented oxidative stress-induced cell death in neuronal PC12 cells

in a dose-dependent manner via attenuation of ROS production. The studies concluded tamarillo phenolics to be potent antioxidants which could inhibit LDL oxidation in-vitro and ROS (reactive oxygen species) production in PC12 cancer cells.

Agglutinating Activity

Ripe tamarillo fruit juice was reported to have an acetylglucosamine oligomer binding agglutinin (lectin) called CBL3 (Sampietro et al. 2001). CBL3 was not inhibited by N-acetylglucosamine, the same as all known lectins of the Solanaceae family but was substantially different to the reported lectins isolated from Solanaceae. The human blood group recognition was non-specific and the agglutinating activity was not affected by EDTA nor by cations. Mitogenic activity was also not detected.

Root Phytochemicals

Alkaloids had been isolated from tamarillo roots and included solacaproine [NN-bis-(4-dimethylaminobutyl) hexanamide], the N-hexanoyl derivative of solamine (Evans et al. 1972). Other bases identified included solamine (principal component), tropinone, and cuscohygrine. The presence of hyoscyamine (atropine), tropine, Φ -tropine, tigloidine (1 α H,5 α H-tropan-3 β -yl 2-methylcrotonate), and a homologue of solacaproin were also found.

Traditional Medicinal Uses

Folkloric uses of tamarillo in traditional medicine are few. Indigenous folks use the fruit for alleviating respiratory diseases and combating anaemia. In Ecuador, warmed leaves are wrapped around the neck as a remedy for sore throat. The fruit pulp, after having been cooked in embers, is used as a poultice for inflamed tonsils in Colombia. Tamarillo was known as 'vegetable mercury' in Jamaica because of its presumed therapeutic value to the liver.

Other Uses

Tamarillo has been used as an intercrop with citrus and coffee. Tamarillo leaves have been employed as a dye. The unripe fruits are used in the Colombian tanning industry to decolour hides.

Tamarillo fruit has an invertase inhibitory protein (IIP) that was found to have broad-spectrum antimicrobial activity against xylophagous and phytopathogenic fungi (*Ganoderma applanatum*, *Schizophyllum commune*, *Lenzites elegans*, *Pycnoporus sanguineous*, *Penicillium notatum*, *Aspergillus niger*, *Phomopsis sojae* and *Fusarium in mango*) and phytopathogenic bacteria (*Xanthomonas campestris* pv. *vesicatoria*, *Pseudomonas solanacearum*, *Pseudomonas corrugata*, *Pseudomonas syringae* pv. *syringae* and *Erwinia carotovora* var. *carotovora*) (Ordóñez et al. 2006). The IIP concentration required to completely inhibit the growth of all studied fungi ranged from 7.8 to 62.5 μ g/mL. Phytopathogenic bacteria were the most sensitive, with MIC values between 7.8 and 31.25 μ g/mL. IIP may have potential application as a biocontrol agent against phytopathogenic fungi and bacteria.

Comments

Tamarillo can be propagated by seeds or cuttings.

Selected References

- Bohs L (1989) Ethnobotany of the Genus *Cyphomandra* (Solanaceae). Econ Bot 43:143–163
- Bohs L (1994) *Cyphomandra* (Solanaceae). In: Flora neotropica, monograph 63. New York Botanical Garden, New York, 175 pp
- Bohs L (1995) Transfer of *Cyphomandra* (Solanaceae) and its species to *Solanum*. Taxon 44:583–587
- Bohs L (2005) Major clades in *Solanum* based on ndhF sequences. In: Keating RC, Hollowell VC, Croat TB (eds) A festschrift for William G. D'Arcy: the legacy of a taxonomist, vol 104, Monographs in systematic botany from the Missouri Botanical Garden. Missouri Botanical Garden Press, St. Louis, pp 27–49
- de Rosso VV, Mercadante AZ (2007) HPLC-PDA-MS/MS of anthocyanins and carotenoids from dovyalis

- and tamarillo fruits. *J Agric Food Chem* 55(22):9135–9141
- Evans WC, Ghani A, Woolley VA (1972) Alkaloids of *Cyphomandra betacea* Sendt. *J Chem Soc Perk Trans* 1(16):2017–2019
- Fletcher WA (1979) Growing tamarillos. New Zealand Min Agric Bull 307, Wellington. 27 pp
- Franco EM (2006) Actividad antioxidante in vitro de las bebidas de frutas. *Bebidas -Alfa Editores Técnicos*, Junio/Julio:20–2 (In Spanish)
- Gannasin SP, Ramakrishnan Y, Adzahan NM, Muhammad K (2012) Functional and preliminary characterisation of hydrocolloid from tamarillo (*Solanum betaceum* Cav.) puree. *Molecules* 17(6):6869–6885
- Gordon A, Rodrigues RB, Marx F, Papagiannopoulos M (2007) Antioxidant capacity of tamarillo fruit (*Cyphomandra betacea*). Paper presented at international research on food security, natural resource management and rural development “Utilisation of diversity in land use systems: sustainable and organic approaches to meet human needs” Tropentag, 9–11 Oct 2007, Witzenhausen
- Hernández Bermejo JE, León J (eds) (1994) Neglected crops 1492 from a different perspective. FAO plant production and protection series, no.26. Food and Agriculture Organization of the United Nations, Rome
- Kou MC, Yen JH, Hong JT, Wang CL, Lin CW, Wu MJ (2009) *Cyphomandra betacea* Sendt. phenolics protect LDL from oxidation and PC12 cells from oxidative stress. *LWT- Food Sci Technol* 42(2):458–463
- Morton JF (1987) Tree tomato. In: Morton JF (ed) *Fruits of warm climates*. Julia F. Morton, Miami, pp 437–440
- National Research Council (1990) *The lost crops of the Incas: little-known plants of the Andes with promise for worldwide cultivation*. National Academy Press, Washington, DC
- Ordóñez RM, Ordóñez AA, Sayago JE, Moreno MIE, Isla MI (2006) Antimicrobial activity of glycosidase inhibitory protein isolated from *Cyphomandra betacea* Sendt. fruit. *Peptides* 27(6):1187–1191
- Ordóñez RM, Cardozo ML, Zampini IC, Isla MI (2010) Evaluation of antioxidant activity and genotoxicity of alcoholic and aqueous beverages and pomace derived from ripe fruits of *Cyphomandra betacea* Sendt. *J Agric Food Chem* 58(1):331–337
- Ordóñez RM, Zampini IC, Rodríguez F, Cattaneo F, Sayago JE, Isla MI (2011) Radical scavenging capacity and antimutagenic properties of purified proteins from *Solanum betaceum* fruits and *Solanum tuberosum* tubers. *J Agric Food Chem* 59(16):8655–8660
- Popenoe W (1974) *Manual of tropical and subtropical fruits*. Hafner Press, New York. Facsimile of the 1920 edition
- Sampietro AR, Isla MI, Quiroga EN, Vattuone MA (2001) An N-acetylglucosamine oligomer binding agglutinin (lectin) from ripe *Cyphomandra betacea* Sendt. fruits. *Plant Sci* 160(4):659–667
- Torrado A, Suárez M, Duque C, Krajewski D, Neugebauer W, Schreier P (1995) Volatile constituents from tamarillo (*Cyphomandra betacea* Sendtn.) fruit. *Flav Frag J* 10(6):349–354
- Tropicos Org (2012) Nomenclatural and Specimen Database of the Missouri Botanical Garden. <http://www.tropicos.org/Home.aspx>
- Vasco C, Avila J, Ruales J, Svanberg U, Kamal-Eldin A (2009) Physical and chemical characteristics of golden-yellow and purple-red varieties of tamarillo fruit (*Solanum betaceum* Cav.). *Int J Food Sci Nutr* 60(Suppl 7):278–288
- Verhoeven G (1991) *Cyphomandra betacea* (Cav.) Sendtner. In: Verheij EWM, Coronel RE (eds) *Plant resources of south-east Asia no 2 edible fruits and nuts*. Prosea Foundation, Bogor, pp 144–146
- Wills RBH (1987) Composition of Australian fresh fruit and vegetables. *Food Technol Aust* 39(11):523–526
- Wong KC, Wong SN (1997) Volatile constituents of *Cyphomandra betacea* Sendtn. fruit. *J Essen Oil Res* 9(3):358–359
- Wrolstad RE, Heatherbell DA (1974) Identification of anthocyanins and distribution of flavonoids in tamarillo fruit (*Cyphomandra betaceae* (Cav.) Sendt.). *J Sci Food Agric* 25(10):1221–1228

Solanum lasiocarpum

Scientific Name

Solanum lasiocarpum Dunal.

Synonyms

Solanum ferox var. *lasiocarpum* (Dunal) Miq., *Solanum hirsutum* Roxb., *Solanum immane* Hance ex Walp., *Solanum lasiocarpum* var. *domesticum* Heiser, *Solanum lasiocarpum* var. *velutinum* Dunal, *Solanum quadriloculare* Spreng., *Solanum zeylanicum* Blanco.

Family

Solanaceae

Common/English Names

Hairy Egg Plant, Hairy-Fruited Eggplant, Hairy Nightshade, Indian Nightshade, Terong Asam, Thai Hairy-Fruited Eggplant.

Vernacular Names

Brunei: Tarong Pasai; Tokung;
Chinese: Mao Ch'ieh, Mao Qie;
French: Aubergine De Siam R Fruit Hirsute;
India: Ram Begun (Bengal);

Indonesia: Terong Perat (Madura), Cung Bulu, Latteoeng, Terong Asam, (Sumatra);

Laotian: Khüa Khôn, Khüa Puux;

Malaysia: Terong Berui (Bidayuh, Sarawak), Terong Bulu (Sarawak), Terong Asam, Terong Dayak, Terung Iban;

Myanmar: Nbabawk, Sin-Hkayan, Sin-Kadi, Tarabi (Burmese), Kaw-Ku-Tha (Karen);

Papua New Guinea: Su, Su-Lamas (Pala, New Ireland), Kova-Sakau (Lamekot, New Ireland);

Philippines: Talong Ayam (Bikol), Tagutong (Bisaya), Balbalusangi (Iloko), Basula (Ibanag), Kamadaka (Ivatan), Tagatum (Panay Bisaya), Tarong-Tarong (Samar Leyte Bisaya), Dabutung, Dagutung (Sulu), Talong-Gubat, Talong-Talong, Tarambola, Tarambulo (Tagalog);

Sri Lanka: Mala-Butu (Sinhala);

Thailand: Mauek (General), Yang-Khui-Dee (Karen), Ma-Khuea-Puu, Ma-Puu (Northern);

Vietnamese: Cà Bung, Cà Du.

Origin/Distribution

The species is found in south Asia – India, Sri Lanka; southeast Asia – Kampuchea Thailand, Vietnam Laos; Malesia – Malaysia, Indonesia, Philippines, New Guinea; southern China – Guangdong, Guangxi, South and southeast Yunnan; and Taiwan. It is found in the Bamaga area at the tip of Cape York Peninsula, north Queensland, Australia, possibly an introduced species.

Agroecology

In its native range, extending from tropical India east through Indochina, extreme southern China, Malaysia and Indonesia to the Philippines and New Guinea, it is found from low to middle elevations, 0–1,000 m. It occurs in thickets, open forest, disturbed sites in rain forest or monsoon forest, near roads, humid places and wet places in ravines and valleys second growth thickets.

Edible Plant Parts and Uses

The edible fruits are harvested from the wild or from cultivation. In India and southeast Asia, the fruit is widely used as a sour-relish in curries and sauces such as *nam prek* in Thailand.

Botany

A sub-erect or spreading, lignescent perennial shrub, 1–1.5 m tall, armed, densely pubescent throughout with pale yellow, many-celled stellate hairs. Stem and branches stout, with flat, erect or slightly recurved, short, cauline prickles 1–8 mm. Leaves are ovate, 10–20 cm by 8–18 cm, pubescent and prickly along veins on both surfaces, base truncate or obtuse, apex acute, margin sinuately-lobed, petioles pubescent, 3–14 cm. Inflorescence short, extra-axillary, scorpioid-racemose with 6–16 andromonoecious flowers. Calyx campanulate, with ovate-deltoid lobes, 8–10 mm. Corolla white, with subrotate, ovate-lanceolate, 6–9×3–6 mm lobes; stamens with very short filaments, anthers linear-lanceolate, yellow; ovary pubescent, style cylindrical and glabrous, stigma capitate. Fruit a berry, green turning to yellow or orangey yellow when mature, globose, 2.5–3.5 cm diameter, pubescent, densely covered with stellate hairs (Plates 1 and 2), many seeded. Seeds 2–2.5 mm long, flat, broadly reniform-ovate, pale yellow with pitted surface.



Plate 1 Densely hairy ripe and unripe fruits



Plate 2 Close-up of ripe fruit

Nutritive/Medicinal Properties

The nutrient composition of *S. ferox* fruit per 100 g edible portion was reported as: dry matter 11.5 g, protein 2 g, fibre 2.9 g, sugar 1.04 g, β -carotene 0.19 mg, vitamin C 11 mg, δ -tocopherol 0.01 mg, γ -tocopherol 0.10 mg, α -tocopherol 0.30 mg, total tocopherol 0.41 mg, Ca 28 mg and Fe 0.92 mg (AVRDC 2003). Another analysis reported the nutrient composition of the fruit per 100 g edible portion as: energy 62 kcal, moisture 78.8%, protein 1.8 g (FW), 8.6 g (DW), fat 1.3 g, carbohydrate 10.9 g, fibre 5.3 g, ash 58 g, P 58 mg, K 381 mg, Ca 55 mg, Mg 23 mg, Fe 45 μ g, Mn 2 μ g, Zn 5.7 μ g (Voon et al. 1988; Voon and Kueh 1999).

A yellow coloured oil with a yield of 2.7% was obtained from seeds of *Solanum ferox* (Garg and Gupta 1966). The fatty acid composition of the oil comprised 12.15% palmitic acid, 9.96% stearic acid, 39.83% oleic acid and 38.06% linoleic acid.

Solanum ferox extract exhibited cytotoxicity in the brine shrimp lethality bioassay with an LC_{50} of 10 $\mu\text{g/mL}$ (Rahman et al. 2008).

Traditional Medicinal Uses

In the Philippines, the leaves are used as poultices for swellings. In Malaysia, a decoction of the roots is prescribed for violent pains all over the body and discomfort after meals. Also, a root decoction is taken for syphilis. The roots are used externally in a bath for fever at night, and in a poultice for itches, cuts, wounds, and severe bruises. The seeds are used for treating toothache by burning them and inhaling the fumes. In Bangladesh traditional folk medicine, *S. ferox* is used as a remedy for coughs, asthma, fever, vomiting, sore throat and gonorrhoea.

Other Uses

It is used in traditional folk medicine in Asia. The fruit was reported to be used in black magic in Malaysia. A bunch of terong asam fruits and *Dracaena* in a net is placed on an expectant mother's head and under the floor to prevent the approach of evil spirits.

Comments

S. lasiocarpum is closely related *S. repandum* G. Forster which occurs in the Western Pacific.

According to Tropicos (2012), *Solanum ferox* L. is a rejected name and not an accepted name or as a synonym. The Plant List (2010) further states that *S. ferox* L. is an unresolved name.

Selected References

- AVRDC (2003) *Solanum ferox*. AVRDC The World Vegetable Center Nutrient Database. <http://avrdcnutrition.gtdtestsite.comoj.com/nutrition/about.php>
- Backer CA, Bakhuizen van den Brink RC Jr (1965) Flora of Java (Spermatophytes only), vol 2. Wolters-Noordhoff, Groningen, 641 pp
- Bohs L (2011) *Solanum lasiocarpum* Dunal. In: Solanaceae Source. <http://www.nhm.ac.uk/research-curation/research/projects/solanaceaesource/taxonomy/description-detail.jsp?spnumber=3386>
- Bureau of Plant Industry (2005) Medicinal plants of the Philippines. Department of Agriculture Republic of Philippines. <http://www.bpi.da.gov.ph/Publications/mp/mplants.html>
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula, Revised reprint. 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Garg SK, Gupta DR (1966) Chemical examination of the seed fat of *Solanum ferox* L. Fette Seifen Anstrichm 68:449–450
- Hasan SMZ, Jansen PCM (1994) *Solanum* L. In: Siemonsma JB, Piluek K (eds) Plant resources of South-East Asia no 8: vegetables. Prosea, Bogor, pp 249–252
- Heiser CB Jr (1986) A new domesticated variety and relationships of *Solanum lasiocarpum*. In: D'Arcy WG (ed) Solanaceae: biology and systematics. Columbia University Press, New York, pp 412–415
- Heiser CB Jr (1987) Origins of *Solanum lasiocarpum* and *S. repandum*. Am J Bot 74:1045–1048
- Heiser CB Jr (1996) Reappraisal of *Solanum ferox*, *S. lasiocarpum* and *S. repandum*. Solanaceae Newsl 4(2):44–50
- Porcher MH et al (1995–2020) Searchable world wide web multilingual multiscrypt plant name database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Rahman MS, Begum B, Chowdhury R, Rahman KM, Rashid MA (2008) Preliminary cytotoxicity screening of some medicinal plants of Bangladesh. Dhaka Univ J Pharm Sci 7(1):47–52
- The Plant List (2010) Version 1. Published on the internet; <http://www.theplantlist.org/>
- Tropicos.org. (2012) Missouri Botanical Garden. <http://www.tropicos.org/Name/29604513>
- Voon BH, Kueh HS (1999) The nutritional value of indigenous fruits and vegetables in Sarawak. Asia Pac J Clin Nutr 8(1):24–31
- Voon BH, Chin TH, Sim CY, Sabariah P (1988) Wild fruits and vegetables in Sarawak. Department of Agriculture, Sarawak, 114 pp
- Whalen MD, Costich DE, Heiser CB Jr (1981) Taxonomy of *Solanum* section *Lasiocarpa*. Gentes Herbarum 12:41–129

Solanum linearifolium

Scientific Name

Solanum linearifolium Geras. ex Symon.

Synonyms

None recorded.

Family

Solanaceae

Common/English Names

Kangaroo Apple, Mountain Kangaroo Apple.

Vernacular Names

None

Origin/Distribution

The species is endemic to Australia and is found on coastal ranges and tablelands in eastern New South Wales and Victoria. It is also common in the vicinity of Lake George near Canberra.

Agroecology

Its habitat consists of disturbed areas habitats along forest margins, tracks and road verges, rocky outcrops, creeks and river gorges and disturbed dry sclerophyll such as margins of young pine plantations. It is hardy on all soils and exhibit vigorous growth.

Edible Plant Parts and Uses

The ripe fruit is eaten raw or roasted by the aboriginals when the outer skin bursts. The flavour has been variously described as sickly sweet to tangy- acidic.

Botany

Erect, perennial shrub, 1–4 m, green, sparsely pubescent with minute, simple and glandular hairs on leaves, calyx and corolla apices. Juvenile leaves broadly elliptic to ovate, lamina 15–40 cm long, concolorous, deeply lobed on short petioles. Adult leaves entire, linear to narrow-lanceolate, mostly 5–10 cm long, 5–10 mm wide, concolorous with distinct mid-rib (Plates 1 and 2). Inflorescence leaf-opposed, pseudo-cymose 5–10 flowered common peduncle absent. Flowers bisexual, pentamerous on 15–35 mm long pedicels, calyx lobes deltate at anthesis, corolla purple,



Plate 1 Rotate purple flowers linear leaves



Plate 2 Older linear leaves, dark green with distinct mid-vein

13–22 mm, broadly rotate, inner surface glabrous, anthers 3 mm long and yellow, ovary glabrous, style 7–8 mm long, erect (Plate 2). Fruit globose to ovoid, 15–20 mm across, green (Plate 3) turning to ochre yellow flushed with purple at the apex. Seeds pale yellow, 2–2.5 mm.



Plate 3 Immature mountain kangaroo apple fruits

Nutritive/Medicinal Properties

Nutritive value of the fruit has not been published.

The plant has been reported to contain solasodine (Bradley et al. 1978), solasonine and solamargine (Lewis and Liljegren 1970). Concentration of these alkaloids is, in general, higher in the immature fruits than in the leaves. Solasodine is commercially used as a precursor for the production of complex steroidal compounds such as contraceptive pills (Everist 1981). Solasodine also has anti cancer property. Studies in humans showed that solasodine glycoside cream Zycure to be a safe therapy for basal cell carcinoma, with a cure rate of 66% at 8 weeks and 78% at 1 year follow-up (Punjabi et al. 2008).

Other Uses

It makes an excellent screen plant.

Comments

S. linearifolium belongs to the subgenus *Archaeosolanum*. It is propagated by seeds and cuttings.

Selected References

- Bradley V, Collins DJ, Crabbe PG, Eastwood FW, Irvine MC, Swan JM, Symon DE (1978) A survey of Australian *Solanum* plants for potentially useful sources of solasodine. *Aust J Bot* 26(6):723–754
- Burbidge NT, Gray M (1970) Flora of the Australian capital territory. Australian National University Press, Canberra, 447 pp
- Conn BJ (1992) Solanaceae. In: Harden GJ (ed) Flora of new south Wales, vol 3. New South Wales University Press, Sydney
- Everist SL (1981) Poisonous plants of Australia (Rev edn). Angus & Robertson, Sydney
- Lewis DC, Liljegren DR (1970) Glycoalkaloids from *Archaeosolanum* species. *Phytochemistry* 9(10): 2193–2195
- Low T (1991) Wild food plants of Australia. Angus & Robertson, North Ryde, 240 pp
- Punjabi S, Cook LJ, Kersey P, Marks R, Cerio R (2008) Solasodine glycoalkaloids: a novel topical therapy for basal cell carcinoma. A double-blind, randomized, placebo-controlled, parallel group, multicenter study. *Int J Dermatol* 47:78–82
- Symon DE (1981) A revision of the genus *Solanum* in Australia. *J Adelaide Bot Gard* 4:81–83
- Symon DE (1994) Kangaroo apples: *Solanum* sect. *Archaeosolanum*. State Herbarium of South Australia, Adelaide, 56 pp

Solanum lycopersicum

Scientific Name

Solanum lycopersicum Lam.

Common/English Names

Garden Tomato, Tomato.

Synonyms

Lycopersicon cerasiforme Dunal, *Lycopersicon esculentum* Mill., *Lycopersicon esculentum* ssp. *galenii* (Mill.) Luckwill, *Lycopersicon esculentum* var. *cerasiforme* (Dunal) A. Gray, *Lycopersicon esculentum* var. *cerasiforme* (Dunal) Alef., *Lycopersicon esculentum* var. *esculentum* Mill., *Lycopersicon esculentum* var. *leptophyllum* (Dunal) D'Arcy, *Lycopersicon esculentum* var. *pyriforme* (Dunal) Alef., *Lycopersicon esculentum* var. *pyriforme* (Dunal) L. H. Bailey, *Lycopersicon humboldtii* (Willd.) Dunal, *Lycopersicon lycopersicum* (L.) Karst., *Lycopersicon lycopersicum* var. *cerasiforme* (Dunal) Alef., *Lycopersicon pyriforme* Dunal, *Lycopersicon cerasiforme* Dunal, *Scubulon humboldtii* (Willd.) Raf., *Solanum lycopersicum* var. *cerasiforme* (Dunal) Spooner, G. J. Anderson & R. K. Jansen, *Solanum lycopersicum* var. *lycopersicum* L.

Family

Solanaceae

Vernacular Names

Afrikaans: Tamatie;
Arabic: Banadhurah;
Aztecs: Xitomatl;
Brazil: Tomato;
Bulgarian: Domat, Domaten;
Chinese: Fan Qie;
Croatian: Poslijepodne, Rajčica;
Czech: Lilek Rajče, Rajče Jedlé;
Danish: Tomat;
Dutch: Tomaat;
Egypt: Tamatim;
Esperanto: Tomato;
Finnish: Kärleksäpple, Tomaatti;
Fiji: Tomata;
French: Pomme D'amour, Tomato;
Gaelic: Tráta;
German: Liebesäpfel, Paradeiser, Paradiesäpfel, Rispentomaten, Strauchtomaten, Tomato;
Greek: Tomata, Tomatas;
Guyana: Tomato;
Hebrew: Agvaniyat Hagina;
Hungarian: Paradicsom;

India: Tamato (Bengali), Tamatar (Hindu), Thakkali (Malayalam), Khamen Asinba (Manipuri), Taamataa (Marathi), Tamaatar (Punjabi), Rakta Vrantaka (Sanskrit), Takkali (Tamil), Tamaatar (Urdu);

Indonesia: Tomato;

Italian: Pomodoro, Tomatica;

Japanese: Tomato;

Kenya: Nyanya (Swahili);

Khmer: Peeng Pâh;

Korean: Tomado;

Nahuas: Tomatl;

Icelandic: Tómatúr;

Laotian: Khüa Sômz;

Latvian: Tomāts;

Lithuanian: Pomidoras;

Macedonia: Domat;

Malaysia: Tomato;

Mexico: Jitomate, Tomato;

Nepalese: Golbhedaa, Raamabhendaa, Rambhenda, Tamaatar;

Norwegian: Tomat;

Philippines: Kamatis (Cebu-Bisaya), Kamatis (Bikol), Umlí (Ifugao), Kamatis (Igorot), Kamatis (Sulu), Kamatis, Kamatis-Bundok (Tagalog);

Polish: Pomidor;

Portuguese: Tomato, Tomateiro;

Romanian: Pătlăgea Roşie, Roşie, Tomată, Tomată Roşie;

Russian: Pomidor, Tomat, Tomat Obyknovennyi;

Serbian: Crveni Patlidžan, Paradajz;

Shona: Domasi;

Slovaščina: Paradižnik;

Slovenčina: Rajčiak Jedlý;

Spanish: Tomato, Tomatera;

Surinam: Tomaat, Tomato (Sranan);

Swahili: Nyanya;

Swedish: Tomat;

Thai: Ma Khuea, Ma Khuea Som, Ma Khuea Thet;

Turkish: Domates;

Ukrainian: Pomidor, Tomat;

Vietnamese: Cà Chua, Cà Tômach;

Zulu: Utamatisi.

world. The leading tomato producers in 2010 are China 41,879,684 tonnes, USA 12,902,000 tonnes, India:11,979,700 tonnes, Turkey 10,052,000 tonnes, Egypt 8,544,990 tonnes, Italy 6,024,800 tonnes, Iran 5,256,110 tonnes, Spain 4,312,700 tonnes, Brazil 3,691,320 tonnes, and Mexico 2,997,640 tonnes (FAO 2012).

Agroecology

Tomato needs plenty of sun, moisture and warmth for high yield and premium quality. Tomato is intolerant of low cold temperatures and frost. Frost damages the plant and flowers and, cool night temperatures interfere with pollen formation and fruit ripening. High temperature above 27°C is detrimental to fruit set and yield. Tomato requires a temperature range of 15–20°C for good fruit set (Opeña 1985), as such it is grown in the cool highlands in tropical areas. Its optimum temperature range for growth and development has been reported as 20–27°C (van der Vossen et al. 2004). Tomatoes tend to develop small parthenocarpic fruits at both high (26°C) and low (14°C) temperature regimes which, combined with low flower numbers and poor fruit set at 26°C, resulted in low fruit yields (Adams et al. 2001). Tomato fruits ripened 95, 65, 46 and 42 d after flower opening when plants were grown under controlled environmental conditions at 14, 18, 22 and 26°C, respectively. Hot dry winds also cause flower abortion.

Tomato grows well on most mineral soils but prefers deep, well-drained sandy loams to clayey loams, moderately rich in organic matter. Tomato prefers a pH of 5.5–6.8 but will tolerate moderately acid soils.

Edible Plant Parts and Uses

Ripe tomatoes are consumed raw, usually in salad, and is also eaten stewed, grilled, roasted or broiled. They are also used as flavouring in soups, curries, meat or fish dishes. Ripe tomatoes are also processed into purée, paste, ketchup, sauces, tomato soups, sorbets, and tomato juice which is sold as a drink and used in cocktails

Origin/Distribution

Tomato is native to western South America, from central Ecuador through Peru to northern Chile. It has been introduced and grown around the

such as the 'Bloody Mary'. Ripe tomatoes are also processed as whole or diced fruit in cans. The fruit is also made into sweetened candies, dried fruit such sun-dried tomato pesto or processed into wine. Unripe green tomatoes can also be breaded and deep-fried, pickled or used in salsa.

Tomatoes are extensively used in Indian cuisines especially in curries, Middle eastern and Mediterranean – Italian and Spanish cuisines. Some popular Mediterranean recipes include pizza, spaghetti, *Pa amb tomàquet* a simple bread with tomato recipe in Catalonia, Majorca and Valencia; and *gazpacho*, the famous tomato based, vegetable soup of the Spaniards. In Thailand, tomato is an important ingredient in the famous prawn of chicken *Tom Yum* soups and tomato is used in various beef and fish recipes in Malaysia.

Botany

An annual erect or prostrate, sparingly branched herb, 0.5–2 m high or long with viscid pubescent, green stems (Plates 1 and 2) covered with odorous, glandular trichomes, and a strong tap root with dense lateral and adventitious root system. Leaves spirally arranged, pubescent on both surfaces, imparipinnate compound, in outline 15–50 cm long by 10–30 cm wide, on 3–6 cm long petioles. Leaflets variable in size, 5, 7–9 per leaf, ovate to elliptic, 5–10 cm long, irregularly toothed and sometimes pinnatifid at



Plate 1 Fruiting tomato plants



Plate 2 Close-up leaves and fruits

base, terminal leaflets larger than the lateral ones, petiolules 0.2–2.0 cm long (Plates 1 and 2). Inflorescence a cyme, normally 3–12-flowered, but sometimes more. Flowers on 1–1.5 cm pedicel, bisexual, regular, 1.5–2 cm across, pendent, (5) 6 (7)-merous. Calyx with short pubescent, green calyx tube with lanceolate lobes, persistent and enlarging on fruit. Corolla 2.25 cm across, stellate, lobes narrowly oblong, bright yellow, often reflexed. Stamens attached to corolla, filaments short 0.5 mm, anthers bright yellow, 6–10 mm. Ovary conical, minutely glandular villous, style 0.6–1.2 cm long with green capitate stigma. Berry pale green (Plate 3) turning red, orange, orangey-yellow, yellow, (purple in new cultivar) on ripening, usually subglobose, but often of varying shape, glabrescent, 2–3.5 cm (–10 cm in some cultivars) diameter (Plates 1–8), two- to multi-locular, fleshy and juicy. Seed flattened ovoid, 3–5 mm × 2–4 mm, straw coloured, pubescent, embryo coiled in endosperm.



Plate 3 Cluster of unripe tomatoes



Plate 6 Roman tomatoes



Plate 4 Harvested tomatoes



Plate 7 Cherry tomato



Plate 5 Truss tomatoes



Plate 8 Yellow cherry tomato

Nutritive/Medicinal Properties

Proximate nutrient composition of red, ripe raw tomato per 100 g edible portion was reported as: water 94.52 g, energy 18 kcal (74 kJ), protein 0.88 g, total lipid 0.20 g, ash 0.50 g, carbohydrate 3.89 g, total dietary fibre 1.2 g, total sugars 2.63 g, glucose 1.25 g, fructose 1.37 g, Ca 10 mg, Fe 0.27 mg, P 24 mg, Mg 11 mg, K 24 mg, Na 5 mg, Zn 0.17 mg, Cu 0.059 mg, Mn 0.114 mg, F 2.3 µg, vitamin C 13.7 mg, thiamine 0.037 mg, riboflavin 0.019 mg, niacin 0.594 mg, pantothenic acid 0.089 mg, vitamin B-6 0.080 mg, total folate 15 µg, total choline 6.7 mg, betaine 0.1 mg, vitamin A 42 µg RAE, vitamin A 833 IU, β -carotene 449 µg, α -carotene 101 µg, lycopene 2,573 µg, lutein + zeaxanthin 123 µg, vitamin E (α -tocopherol) 0.54 mg, β -tocopherol 0.01 mg, γ -tocopherol 0.12 mg, vitamin K (phylloquinone) 7.9 µg, total saturated fatty acids 0.028 mg, 16:0 (palmitic acid) 0.020 g, 18:0 (stearic acid) 0.008 g, total monounsaturated fatty acids 0.031 g, 16:1 undifferentiated (palmitoleic acid) 0.001 g, 18:1 undifferentiated (oleic) 0.030 g, total polyunsaturated fatty acids 0.083 g, 18:2 undifferentiated (linoleic acid) 0.080 g, 18:3 undifferentiated (linolenic acid) 0.003 g, phytosterols 7 mg, tryptophan 0.006 g, threonine 0.027 g, isoleucine 0.018 g, leucine 0.025 g, lysine 0.027 g, methionine 0.006 g, cystine 0.009 g, phenylalanine 0.027 g, tyrosine 0.014 g, valine 0.018 g, arginine 0.021 g, histidine 0.014 g, alanine 0.027 g, aspartic acid 0.135 g, glutamic acid 0.431 g, glycine 0.019 g, proline 0.015 g, and serine 0.026 g (USDA 2012). The most abundant carotenoid in tomato was reported to be lycopene, followed by phytoene, phytofluene, ζ -carotene, γ -carotene, β -carotene, neurosporene, and lutein (Khachik et al. 2002). Two oxidative metabolites of lycopene, 2,6-cyclolycopene-1,5-diols A and B were found to be present in tomatoes in extremely low concentrations.

Ripe fresh tomato had been found to have 5–7.5% mean dry matter comprising 25% fructose, 22% glucose, 1% saccharose, 9% citric acid, 4% malic acid, 8% protein, 2% dicarboxylic acid, 7% pectic substances, 6% cellulose, 4% hemicelluloses, 8% minerals, 2% lipids, 0.5% ascorbic

acid, other amino acids, vitamins and polyphenols 1% and volatiles 1% (Petro-Turza 1987). The free sugars in fresh tomatoes comprised predominantly reducing sugars, with negligible amount of sucrose. Citric acid was reported to be the most abundant organic acid with some malic acid also present (Gould 1983). The pectins, arabinogalactans, xylans, arabinoxylans, and cellulose comprised the major polysaccharides in tomatoes. Glutamic acid comprised up to 45% of the total weight of free amino acids in fresh tomato juice with the next highest in concentration being aspartic acid (Yilmaz 2001).

The carotenoids detected in supercritical CO₂ (S-CO₂) extracted tomato oleoresin extracts and solvent extract of tomato powder were: all-*trans*-lutein, β -carotene, as di-*cis*- β -carotene, *cis*- β -carotene and all-*trans*- β -carotene, and the lycopene isomers: 9-13-di-*cis*-, 13-*cis*-, 9-*cis*-, *cis*- and all-*trans*-lycopene, the last predominating and accounting for over 95% of the total carotenoids (Longo et al. 2012). The lycopene concentration in both the S-CO₂-oleoresins was higher compared to the starting tomato powder. The lipids present in the oleoresins were essentially triglycerides, diglycerides and monoglycerides. Saturated fatty acids (FAs) as palmitic and stearic acids, monounsaturated FA as oleic acid, and polyunsaturated fatty acids (PUFA) as linoleic and linolenic acids, were detected in both oleoresins and tomato matrix. However, S-CO₂-extraction resulted in enrichment in oleic acid, which represented above 80% of the total lipids in the oleoresins.

The carotenoid contents including lycopene and β -carotene of near-isogenic carotenoid biosynthetic mutant tomatoes were extremely low in the *r* mutant, increased in lycopene in cv. old gold, and higher in tetra-*cis*-lycopene and ζ -carotene in cv. tangerine (Vogel et al. 2010). The volatiles derived from these carotenoids (β -ionone, geranylacetone and 6-methyl-5-hepten-2-one) were proportionally altered relative to their precursors. Consumer panels rated the *r* mutant lowest for all sensory attributes, while Ailsa Craig, their parent was generally rated highest. Old gold and tangerine mutant tomatoes were rated intermediate in two of the three harvests.

Other Fruit Phytochemicals

Studies found a broad range of bioactive compounds across tomato varieties and products (Choi et al. 2011). Small tomatoes had higher contents of bioactive compounds than the large ones. The content of phenolic compounds of processed products was lower than that of fresh tomatoes.

Tomato fruit usually do not contain anthocyanins and the red color in tomato is from the carotenoid, lycopene (Rick and Stevens 1986). Jones et al. (2003) found that the purple colour of the anthocyanin rich *Aft* tomato, LAI 996 was produced by the anthocyanins petunidin, malvidin, and delphinidin 3-(*p*-coumaryl-rutinoside)-5-glucoside. Li et al. (2011) reported three major anthocyanins, which were mainly acylglycosides of petunidin and malvidin in purple tomato.

Eight oligosaccharide subunits were isolated from the culture filtrate of suspension-cultured tomato (Jia et al. 2005). These oligosaccharides, with up to three endogenous O-acetyl substituents, consisted of a cellotetraose core with α -D-Xylp residues at O-6 of the two β -D-Glcp residues at the non-reducing end of the core. Some of the α -D-Xylp residues themselves had either an α -L-Arap or a β -D-Galp residue at O-2. O-Acetyl substituents were located at O-6 of the unbranched (internal) β -D-Glcp residue, O-6 of the terminal β -D-Galp residue, and/or at O-5 of the terminal α -L-Arap residue. A polysaccharide (PS-I) isolated from the aqueous extract of the unripe (green) tomatoes consisted of D-galactose, D-methyl galacturonate, D-arabinose, L-arabinose, and l-rhamnose (Chandra et al. 2009).

The sweet-sour tomato flavour is reported to be due to the complex interaction of aromatic volatiles and non-volatile sugars, organic acids, free amino acids and minerals (Petro-Turza 1987; Malundo et al. 1995; Yilmaz 2001). Around 400 aroma compounds had been identified in fresh tomatoes (Petro-Truza 1987). But only 30 had concentrations higher than $>1 \mu\text{L/L}$ (Buttery 1993) and these were *cis*-3-hexenal 12,000 μL , 2-phenylethanol 1,900 μL , 1-penten-3-one 520 μL , 3-methylbutanol 380 μL , *trans*-2-hexenal 270 μL , *cis*-3-hexenol 150 μL , *trans*-2-pentenal 140 μL ,

6-methyl-5-hepten-2-one 130 μL , pentanol 120 μL , 1-penten-3-ol 110 μL , *trans*-2-heptenal 60 μL , 1-nitro-3-methyl-butane 59 μL , geranylacetone 57 μL , methyl salicylate 48 μL , 2-isobutylthiazole 36 μL , 3-methylbutanal 27 μL , 1-nitro-2-phenylethane 17 μL , phenylacetaldehyde 15 μL , isobutyl cyanide 13 μL , geranial 12 μL , pseudoionone 10 μL , hexanol 7 μL , β -ionone 4 μL , β -cyclocitral 3 μL , hexanal 3 μL , linalool 2 μL , neral 2, β -damascenone 1 μL , and epoxy- β -ionone 1 μL . Among these combination of *cis*-3-hexenal, *cis*-3-hexenol, hexanal, 1-penten-3-one, 3-methylbutanal, *trans*-2-hexenal, 6-methyl-5-hepten-2-one, methyl salicylate, 2-isobutylthiazole, and β -ionone at appropriate concentrations were deemed to contribute significantly to the aroma of fresh ripe tomato (Buttery 1993). Similarly, the most important volatile compounds in tomato aroma were listed as hexanal, *cis*-3-hexenal, *trans*-2-hexenal, hexanol, *cis*-3-hexenol, 2-isobutylthiazole, 6-methyl-5-hepten-2-one, β -ionone, geranylacetone, 1-penten-3-one, 3-methylbutanal, 3-methylbutanol, phenylethanol, 2-pentenal, acetone, ethanol, and methanol (Buttery and Ling 1993). Calculations based on quantitative and odour threshold data indicated that the major contributors to fresh tomato aroma included (Z)-3-hexenal, β -ionone, hexanal, β -damascenone, 1-penten-3-one, 3-methylbutanal, (E)-2-hexenal, 2-isobutylthiazole, 1-nitrophenylethane and (E)-2-heptenal (Buttery et al. 1989). The presence of the unusual volatile components β -damascenone, 1-nitro-2-phenylethane, 1-nitro-3-methylbutane, β -cyclocitral and epoxy- β -ionone were also found in fresh tomatoes. Free furaneol, furaneol glucoside and nirfuraneol were also found in tomatoes (Krammer et al. 1994). Furaneol, occurring at a concentration well above odour threshold was also found to be a significant contributor to both fresh and tomato aroma and flavour but not norfuraneol (Buttery et al. 1995). Thirty-four aroma compounds were found with flavour dilution factors ≥ 4 ; (Z)-3-hexenal, hexanal, 1-octen-3-one, methional, 1-penten-3-one and 3-methylbutanal belonged to the most odour-active aroma volatiles in fresh tomatoes (Krumbein and Auerswald 1998). Tandon et al. (2001) found 71 volatile compounds and

characterised 23 compounds to be important aroma compounds in fresh tomatoes: 2+3 methylbutanol, 1-penten-2-one, hexanal, *cis*-3-hexenal, *trans*-2-hexenal, *cis*-3-hexenol, *trans*-2-heptenal, 1-octen-3-one, 6-methyl-5-hepten-2-one, 2-isobutylthiazole, phenylacetaldehyde, methylsalicylate, 2-phenylethanol, geranylacetone, β -ionone, furaneol, linalool, methional, citral, *trans*, *trans*-2,4-decadienal and three unidentified compounds. The major volatile norisoprenoids present in lycopene-containing near-isogenic tomatoes were noncyclic, such as geranial, neral, 6-methyl-5-hepten-2-one, 2,6-dimethylhept-5-1-al, 2,3-epoxygeranial, (E,E)-pseudoionone, geranyl acetone, and farnesyl acetone, apparently derived from lycopene and other noncyclic tetraterpenoids (Lewinsohn et al. 2005). Beta-ionone, dihydroactinodiolide, and β -cyclocitral were prominent in tomato fruits containing β -carotene. Alpha-ionone was detected only in an orange-fleshed tomato mutant that accumulates δ -carotene. A yellow flesh (r) mutant tomato bearing a non-functional *psy1* gene also lacked norisoprenoid derivatives and geranial. Of 19 volatiles selected for quantification in 3 tasty and 2 less tasty tomato cultivars, compounds such as 1-penten-3-one, (E, E)- and (E, Z)-2,4-decadienal, and 4-hydroxy-2,5-dimethyl-3(2H)-furanone (furaneol) had higher odor units in the more preferred tomato cultivars, whereas methional, phenylacetaldehyde, 2-phenylethanol, or 2-isobutylthiazole had higher odor units in the less preferred cultivars (Mayer et al. 2008). Biogenesis of *cis*- and *trans*-4,5-epoxy-(E)-2-decenals from linoleic acid and methional from methionine was confirmed. Of 31 volatiles, compounds, (E)-2-octenal, (E)-2-pentenal, 2-isobutylthiazole, 6-methyl-5-hepten-2-one, and phenylacetaldehyde were significantly higher in the tomato varieties (vine-ripened tomato, roma tomato, cherry tomato, and grape tomato) than in tomatillo (*Physalis ixocarpa*) in the headspace (Xu and Barringer 2010a). After blending, volatiles in the headspace increased, and then decreased after reaching a maximum concentration, due to further degradation or depletion. Compounds (E)-2-pentenal and 1-penten-3-one reached a maximum concentration later than (E)-2-hexenal, (Z)-3-hexenal, and hexanal for

tomatillo and tomatoes. In subsequent studies on volatile release during chewing of tomatillo and tomato, they found that (Z)-3-hexenal, (E)-2-hexenal, hexanal, and 1-penten-3-one increased, while isobutyl alcohol, nonanal, and methylbutanal showed no significant change in the first 30 s of chewing (Xu and Barringer 2010b). Cherry tomato released more (E)-2-hexenal, (Z)-3-hexenal, and 1-penten-3-one than tomatillo, Roma tomato, and vine-ripened tomato during chewing. Methylbutanal, hexanal, and nonanal were retained at a higher percentage in the mouth after swallowing than (Z)-3-hexenal, (E)-2-hexenal, 1-penten-3-one, and isobutyl alcohol. The compounds and their volatile release patterns were similar for tomatillo and tomatoes during chewing. The green aldehydes released during chewing were not significantly higher than most tomato varieties, except for Roma tomatoes. Cherry tomato released relatively more volatiles during chewing, whereas Roma tomatoes were generally poor in mouthspace volatiles.

Several tomato volatiles conferred repellency to *Bemisia tabaci* (whitefly) (Bleeker et al. 2009). The sesquiterpenes zingiberene and curcumen and the monoterpenes *p*-cymene, α -terpinene, and α -phellandrene had the strongest effects in free-choice bioassays. Conversely, the monoterpene β -myrcene showed no activity. Two more sesquiterpenes from tomato, 7-epizingiberene and its derivative R-curcumen were found to repel whiteflies (Bleeker et al. 2011).

Tomato fruit were found to contain various types of glycosides and glycoalkaloids.

Tomato plants contain steroidal glycoalkaloids, nitrogen-containing compounds bearing a sugar chain (3–4 units) linked to a steroidal moiety (aglycone) by the 3-hydroxyl group (Cataldi et al. 2005). They confirmed the presence of α -tomatine and dehydrotomatine in the tomato leaves and fruits and identified an α -tomatine isomer glycoalkaloid, named filotomatine (MW 1033), which shared a common tetrasaccharide structure (i.e., lycotetraose) with α -tomatine and dehydrotomatine, and soladulcidine as an aglycon. Filotomatine occurred in significant levels in the leaves. The dehydrotomatine and α -tomatine content of tomato fruit varied from 42 to 1,498 and

521 to 16 285 µg/g of fresh weight, respectively (Kozukue et al. 2004). The ratio of α -tomatine to dehydrotomatine ranged from 10.9 to 12.5 in tomatoes and from 2.3 to 7.8 in the other plant tissues (calyxes, flowers, leaves, roots, and stems). Major steroidal alkaloid glycosides, named esculeoside A, a spirosolane glycoside, and esculeoside B, were isolated from the pink colour-type and the red colour-type, respectively, of ripe tomato fruits (Fujiwara et al. 2003, 2004). Their structures were characterized as 3-*O*- β -lycotetraosyl (5S,22S,23S,25S)-23-acetoxy-3 β ,27-dihydroxyspirosolane 27-*O*- β -d-glucopyranoside and 3-*O*- β -lycotetraosyl (5S,22S,23R,25S)-22,26-epimino-16 β ,23-epoxy-3 β ,23,27-trihydroxycholestane 27-*O*- β -d-glucopyranoside, respectively. Various triterpenoid glycosides were isolated from whole unripe tomato fruits (Yamanaka et al. 2008). The furostanol glycoside tomatoside A (749 mg/kg of DW) and the glycoalkaloids α -tomatine (196 mg/kg of DW) and esculeoside A (427 mg/kg of DW) were the major triterpenoid glycosides detected. The critical micelle concentrations of α -tomatine, tomatoside A, and esculeoside A, were determined as 0.099, 0.144, and 0.412 g/l, respectively indicating that tomatoside A, and not the more well-known α -tomatine, to be the predominant triterpenoidal surfactant in unripe tomato fruits. In addition, minor amounts of a new dehydrofurostanol glycoside, dehydrotomatoside, were found. Tomato fruit contained guaiacol, a small volatile molecule with a smoky aroma that contributes to tomato flavor (Mageroy et al. 2012). The enzyme, O-methyltransferase was found responsible for producing guaiacol in tomato fruit.

Two sapogenols, isoesculeogenin A and esculeogenin B of steroidal alkaloid glycosides, lycoperoside F and esculeoside B, a solanocapsine-type glycoside, respectively, isolated from the ripe tomato were characterized as (5 α ,22R,23R,25S)-3 β ,23,27-trihydroxyspirosolane and (5 α ,22S,23R,25S)-22,26-epimino-16 β ,23-epoxy-3 β ,23,27-trihydroxycholestane, respectively (Yoshizaki et al. 2005). Six steroidal alkaloid glycosides, esculeosides C and D, along with three known steroidal alkaloid glycosides,

esculeoside A, esculeoside B, lycoperoside G and 3-*O*- β -lycotetraosyl 3 β ,26-dihydroxycholestan-16, 22-dione 26-*O*- α -L-arabinopyranosyl-(1 $\rightarrow$ 6)- β -D-glucopyranoside, and six aromatic compounds, zizibeoside I, benzoyl alcohol β -gentiobioside, rutin, methyl caffeate, phenylalanine and 4-hydroxyphenyl β -D-glucopyranosyl- (1 $\rightarrow$ 2) - β -D- glucopyranoside, were isolated from ripe cherry tomato fruit (*Lycopersicon esculentum* var. *cerasiforme*) (Ono et al. 2006, 2008). Two pregnane glycosides: 3-*O*- β -lycotetraosyl 5 α -pregna-3 β ,16 β -diol-20-one and tomato pregnane were isolated from overripe tomato (Nohara et al. 2008). Esculeoside A, a major spirosolane-type glycoside contained in ripe tomato fruits, was found to be converted into a solanocapsine-type sapogenol, esculeogenin B-2, (5 α ,22S,23R,25S)-22,26-epimino-16 β ,23-epoxy-3 β ,23,27-trihydroxycholestan-16, 22-dione, and esculeogenin B-1, (5 α ,22R,23S,25S)-22,26-epimino-16 β ,23-epoxy-3 β ,23,27-trihydroxycholestan-16, 22-dione (El-Aasr et al. 2008). Three new aromatic glycosides: methyl salicylate 2-*O*- β -D-glucopyranosyl-($\rightarrow$ 2)-[*O*- β -D-xylopyranosyl-(1 $\rightarrow$ 6)]-*O*- β -D-glucopyranoside; phenethyl alcohol 8-*O*- β -D-glucopyranosyl-(1 $\rightarrow$ 2)-[*O*- α -L-arabinopyranosyl-(1 $\rightarrow$ 6)]-*O*- β -D-glucopyranoside; and benzyl alcohol 7-*O*- β -D-glucopyranosyl-(1 $\rightarrow$ 2)-[*O*- α -L-arabinopyranosyl-(1 $\rightarrow$ 6)]- β -D-glucopyranoside were isolated from ripe cherry tomato fruit along with six known aromatic glycosides: kaempferol-3-*O*-rutinoside, rutin, quercetin 3-*O*- β -apiofuranosyl-(1 $\rightarrow$ 2)-*O*-[α -rhamnopyranosyl-(1 $\rightarrow$ 6)]- β -glucopyranoside, phenethyl alcohol β -gentiobioside, zizybeoside I, dihydroconiferyl 4-*O*- β -D-glucopyranoside and one known steroidal alkaloid glycoside, esculeoside B (Ono et al. 2010). In the green immature tomato fruit, tomatine was oxidized at C-23 and C-27 to produce esculeoside A in the ripe fruit (Nohara et al. 2010). Further, esculeoside A was partly converted to 3 β -hydroxy-5 α -pregn-16-en-20-one 3-*O*- β -lycotetraoside, a pregnane glycoside, in the overripe fruit. Esculeogenin A, the sapogenol of esculeoside A, was converted into 3 β ,16 β -dihydroxy-5 α -pregn-20-one. The structure of esculeogenin A was elucidated as

(5 α , 22S,23S,25S)-3 β ,23,27-trihydroxyspirosolane and esculeoside A determined as 3-*O*- β -lycotetraosyl (5 α ,22S,23S,25S)-23-acetoxy-3 β ,27-dihydroxyspirosolane 27-*O*- β -D-glucopyranoside, and esculeoside B as 3-*O*- β -lycotetraosyl (5 α ,22S,23S,25S)-22,26-epimino-16 β ,23-epoxy-3 β ,23,27-trihydroxycholestane 27-*O*- β -D-glucopyranoside (Nohara 2010). Esculeoside A was broken down by β -glucosidase to prosapogenin A elucidated as 3-*O*- β -lycotetraosyl. When treated with tomatinase, esculeoside A yielded prosapogenin B elucidated as 27-*O*- β -D-glucopyranosyl esculeogenin A. Further esculeoside B was converted to prosapogenin C when treated with β -glucosidase to obtain esculeogenin B. A new solanocapsine-type tomato glycoside, esculeoside B-5 with the chemical structure, (5S,22R,23S,24R,25S)-22,26-epimino-16 β ,23-epoxy-3 β ,23,24-trihydroxycholestane 3-*O*- β -lycotetraoside, was isolated from a mini tomato (Ohno et al. 2011). The content of esculeoside A, a spirosolane-type glycoside, in tomatoes was 4-fold higher than that of lycopene (Fujiwara et al. 2007). The quantity of esculeoside A in cherry tomatoes and Momotaro tomatoes were 21- and 9-fold, respectively, higher than that of lycopene (Katsumata et al. 2011). The esculeoside A content in pericarp wall was higher than in the whole tomato fruit and increased in a time-dependent manner during maturation. Although the melting point of purified esculeoside A was 225°C, the esculeoside A in crude tomato extract decreased in a temperature-dependent manner. Degradation due to the heating process was inhibited under a pH of 9.

Three steroidal alkaloid glycosides, lycoperosides A-C, were isolated from tomato fruits and structurally elucidated as the 3-*O*- β -lycotetraosides of (23R)-23-acetoxy-tomatidine, (23S)-23-acetoxysoladulcidine and (23S,25S)-23-acetoxy-5 α ,22 α -N-spirosolan-3 β -ol (Yahara et al. 1996). Additionally, the fruit was found to contain the known major alkaloid tomatine (tomatidine 3-*O*- β -lycotetraoside) and leaves a small amount of γ -tomatine (tomatidine 3-*O*-[β -D-glucopyranosyl-(1-4)- β -D-galactopyranoside] lycoperoside D). Three new steroidal alkaloid

glycosides, lycoperosides F-H (1–3), were isolated from tomato fruits along with lycoperosides A-D, esculeoside A, and rutin (Yahara et al. 2004). The structures of these glycosides were characterized as the 3-*O*- β -lycotetraosides of 23(R)-23-acetoxy-27-hydroxy-27-*O*- β -D-glucopyranosyl-tomatidine (1), (23S,24R)-23-acetoxy-24-*O*- β -D-glucopyranosylsoladulcidine-24-ol (2), and 22-isopimpifolidine (3). Also obtained was the new natural product lycoperodine-1.

Studies showed that (a) the total content (in mg/100 g of FW) of the free amino acids and other nitrogen-containing compounds in the Korean Doturak world tomato variety extracts ranged from about 41–85 in the green tomato extracts at ripening stages S1–S7 and then increased to 251 (S9) in the red extracts, followed by a decrease to 124 in S11 red extracts; (b) the total initial concentration and composition of up to 12 phenolic compounds of approximately 2,000 μ g/100 g of FW varied throughout the ripening process, with the quantity decreasing and the number of individual compounds increasing in the red tomato; (c) chlorophyll a and b content of tomatoes harvested during S1 was 5.73 mg/100 g of fresh pericarp and then decreased continuously to 1.14 mg/100 g for S11; (d) the concentration (in mg/100 g of FW) of lycopene in the S8 red extract of 0.32 increased to 1.27 in S11; and (e) tomatoes harvested during S1 contained 48.2 mg of dehydrotomatine/100 g of FW, and this value continually decreased to 1.5 in S7, with no detectable levels in S8–S11. The corresponding α -tomatine content decreased from S1 (361) to S8 (13.8) (Choi et al. 2010). The tomato saponin, esculeoside A, may be metabolized into various steroidal hormones such as pregnane derivatives that are expected to exhibit various bioactivities in the body, such as anti-osteoporosis, anti-menopausal disorder and anti-tumour actions. (Manabe et al. 2011). The yield of esculeoside A was about 4-fold that of lycopene in mini tomatoes; yields of esculeoside A in mini and middy tomatoes were 3 times that in Momotaro tomatoes. Tomato saponins, sapogenol and prosapogenins of esculeoside A were not detected.

Phytochemicals in Other Plant Parts

A bitter principle of tomato seeds designated TFI with a structure of a new tetraside of the frusotan series was isolated by Sato and Skamuara (1973). Shchelochkova et al. (1980) isolated the furostanol glycoside tomatoside A from tomato seeds. Its structure was established as 25(S)-5 α -furostan-3 β ,22 α ,26-triol 26-O- β -D-glucopyranoside 3-O-[O- β -D-glucopyranosyl-(1 $\rightarrow$ 2)-O- β -D-glucopyranosyl-(1 $\rightarrow$ 4)- β -D-galactopyranoside]. Concurrently, by enzymatic and chemical transformations three new spirostanol glycosides of neotigogenin were obtained: tomatoside B, which was 25(S)-5 α -spirostan-3 β -ol 3-O-[O- β -D-glucopyranosyl-(1 $\rightarrow$ 2)- β -D-galactopyranoside], 25(S)-5 α -spirostan-3 β -ol 3-O-[O- β -D-glucopyranosyl-(1 $\rightarrow$ 4)- β -D-galactopyranoside], and 25(S)-5 α -spirostan-3 β -ol 3-O- β -D-galactopyranoside.

Three steroidal alkaloid glycosides, lycopersides A-C, were isolated from tomato leaves and structurally elucidated as the 3-O- β -lycotetraosides of (23R)-23-acetoxy-tomatidine, (23S)-23-acetoxysoladulcidine and (23S,25S)-23-acetoxy-5 α ,22 α N-spirosolan-3 β -ol (Yahara et al. 1996). Additionally, leaves were found to contain the known major alkaloid tomatine (tomatidine 3-O- β -lycotetraoside) and leaves a small amount of γ -tomatine (tomatidine 3-O-[β -D-glucopyranosyl-(1-4)- β -D-galactopyranoside] lycoperside D). Caffeic acid esters of a mixture of glucaric acid and lactone forms were found in tomato leaves (Elliger et al. 1981). Hydrolysis of these materials yields only caffeic acid and glucaric acid. The esters described were inhibitory to the growth development of the tomato fruit worm (*Heliothis zea*). The presence of vitamin D3 (cholecalciferol) and its hydroxylated metabolite 25-hydroxyvitamin D3 (25-OH D3) was detected in leaf extracts of *Lycopersicon esculentum* (Aburjai et al. 1998). The glucose ester of phaseic acid was isolated together with glucose esters of 4-dihydrophaseic and 4-epi-dihydrophaseic acid from tomato shoots (Carrington et al. 1988). Fletcher et al. (2004) reported the existence in tomato plants of both acetylcholinesterase activity and a steroidal glycoalkaloid,

α -tomatine, with anticholinesterase activity and suggested spatial mutual exclusivity of these antagonistic activities and their potential functions, including roles in plant-pathogen interactions.

From tomato cell cultures, the following were isolated: aromatic glycosides β -D-glucoside, gentiobioside and 6-O- α -L-arabinosyl- β -D-glucoside of benzyl alcohol, androsin and a simple aliphatic glycoside, isopentylgentiobioside (De Rosa et al. 1996); a mixture of acylglucosyl isofucosterols (De Rosa et al. 1998); triterpenoids and sterol glucoside namely lupeol, cycloartenol, isofucosterol and the new β -D-glucosyl isofucosterol (De Rosa et al. 1997). Exogenously applied 24-epi-teasterone was converted to 24-epi-teasterone-3-O- β -D-glucopyranosyl-(1 $\rightarrow$ 6)- β -D-glucopyranoside and 24-epi-teasterone-3-O- β -D-glucopyranosyl-(1 $\rightarrow$ 4)- β -D-galactopyranoside by tomato cell suspension cultures (Kolbe et al. 1997).

Lycopersiconolide, a steroid lactone, was isolated from tomato roots and characterised as (20S)-3 β ,16 β ,20-trihydroxy-5 α -pregnane-20-carboxylic acid 22,16-lactone (Nagaoka et al. 1987); Lycopersiconol, a pregnane derivative was isolated from tomato roots (Yoshihara et al. 1988). Six steroidal alkaloids were isolated from roots of a hybrid of *Lycopersicon esculentum* $\times$ *L. hirsutum* and their structures elucidated as 5 α -tomatidan-3-one; (23R)-23-acetoxytomatidine; (23S)-23-acetoxysoladulcidine; (23S,25S)-23-acetoxy-5 α ,22 α N-spirosolan-3 β -ol; 22,26-epimino-16 β ,23-epoxy-23 α -ethoxy-5 α ,25 α H-cholest-22(N)-ene-3 β ,20 α -diol and 22,26-epimino-16 β , 23-epoxy-5 α ,22 β H,25 α H-cholestane-3 β ,23 α -diol, respectively (Nagaoka et al. 1993).

Tomatoes had been reported to accumulate a variety of secondary metabolites including phenolic compounds, phytoalexins, protease inhibitors, and glycoalkaloids (Friedman 2002). These metabolites had been reported to protect against adverse effects of hosts of predators including fungi, bacteria, viruses, and insects. Glycoalkaloids were reported to be involved in host-plant resistance, and to possess an array of pharmacological and nutritional properties in animals and humans. Dietary lycopene, a non-provitamin A carotenoid, was reported to be

absorbed and distributed in the human body, but its bioavailability depended on various factors such as food processing or coingestion of fat (Stahl and Sies 1996; Sies and Stahl 1998). Lycopene was found in human blood (approximately 0.5 $\mu\text{mol/l}$ plasma), and the tissue levels vary from 1 nmol/g wet wt in adipose tissue to up to 20 nmol/g wet wt in adrenals and testes. Its biological activities reported include antioxidant activity (singlet oxygen quenching and peroxy radical scavenging), induction of cell-cell communication, and growth control, but no provitamin A activity. Epidemiological studies suggested protective effects of lycopene on some types of cancer, e.g., prostate cancer and this was supported by results of in-vitro and in-vivo studies. Dietary intake of tomatoes and tomato products containing the carotenoid lycopene had been shown to be associated with a decreased risk of chronic diseases, such as cancer and cardiovascular disease (Agarwal and Rao 2000). Serum and tissue lycopene levels had been found to be inversely related to the incidence of several types of cancer, including breast cancer and prostate cancer.

Tomatoes and related tomato products are the major source of lycopene compounds, and are also considered an important source of carotenoids in the human diet. Lycopene in fresh tomato fruits occurs essentially in the all-*trans* configuration (95%) (Shi and Le Maguer 2000; Longo et al. 2012). However, *cis*-isomers of lycopene represent approximately 50% of total lycopene in human serum and up to 80% in prostate tissues (Singh and Goyal 2008). This implies that *cis*-lycopenes were more bioavailable than *trans*-lycopenes (Boileau et al. 2002; Unlu et al. 2007). Numerous studies have suggested that *cis*-isomers, such as 15-*cis*-, 13-*cis*-, 9-*cis*- and 5-*cis*-lycopene, are present in human serum and seem more bioavailable (Boileau et al. 1999; Van Breemen et al. 2002; Wu et al. 2003). During food processing, lycopene may isomerize to mono- or poly-*cis*-isomers with the presence of heat and/or oil, or during dehydration (Xianquan et al. 2005). Reisomerization takes place during storage. With prolonged heating or temperatures above 50°C, degradation proceeds faster than isomerization,

the stability of lycopene isomers decreases in the order: 5-*cis*>all-*trans*>9-*cis*>13-*cis*>15-*cis*>7-*cis*>11-*cis* (Xianquan et al. 2005; Lambelet et al. 2009). Starting from the all-*trans*-lycopene, isomerization is characterized first by the formation and then by the disappearance of the unstable 13-*cis*-isomer. The maximum total lycopene content of 3 1.25 $\mu\text{g/g}$ of raw tomato was extracted at the highest temperature of 100°C, 40 MPa and 1.5 ml/min of SC- CO_2 extraction (Yi et al. 2009). For each unit of lycopene extract, the antioxidant activity level as determined by the TEAC assay, was constant below 70°C, but then gradually decreased above 70°C due to isomerization occurring as a result of the higher temperature. The ratio of all-*trans*-lycopene to the *cis*-isomers changed from 1.70 to 1.32 when the operating temperature was adjusted from 40 to 100°C, indicating an increased bioavailability due to the generation of the *cis*-isomers. Also, food processing may enhance lycopene bioavailability by breaking down cell walls, which weakens the bonding forces between lycopene and tissue matrix, thus making lycopene more accessible and enhancing the *cis*-isomerization (Shi and Le Maguer 2000). Lycopene bioavailability in processed tomato products is higher than in unprocessed fresh tomatoes. Lycopene is in high demand by the food, feed, cosmetic and pharmaceutical industries. Lycopene-rich foods have vast potential for the development of new functional foods, as well as food-grade and pharmaceutical-grade lycopene as new nutraceutical products.

Antioxidant Activity

Lycopene, a carotenoid, was found to exhibit the highest physical quenching rate constant with singlet oxygen ($k_q = 31 \times 10^9/\text{M/s}$), and its plasma level was slightly higher than that of β -carotene ($k_q = 14 \times 10^9/\text{M/s}$) (DiMascio et al. 1989). Nutritional carotenoids, particularly β -carotene, and other antioxidants such as α -tocopherol ($k_q = 0.3 \times 10^9/\text{M/s}$) had been implicated in the defence against prooxidant states; epidemiological evidence revealed that such compounds

exerted a protective action against certain types of cancer. Also, Albumin-bound bilirubin was also a singlet oxygen quencher ($k_q = 3.2 \times 10^9 \text{ M/s}$). The singlet oxygen quenching capacities of lycopene ($0.7 \mu\text{M}$ in plasma), β -carotene ($0.5 \mu\text{M}$ in plasma), albumin-bound bilirubin ($15 \mu\text{M}$ in plasma), and α -tocopherol ($22 \mu\text{M}$ in plasma) were found to be of comparable magnitude. Compared to lycopene, tocopherols and thiols were less effective as singlet oxygen quencher (DiMascio et al. 1990). The singlet oxygen quenching ability decreased in the following order: lycopene, γ -carotene, astaxanthin, canthaxanthin, α -carotene, β -carotene, bixin, zeaxanthin, lutein, bilirubin, biliverdin, tocopherols and thiols. However, the compounds with low quenching rate constants were found to occur at higher levels in biological tissues. Thus, carotenoids and tocopherols may contribute almost equally to the protection of tissues against the deleterious effects of singlet molecular oxygen. Carotenoids and tocopherols had been reported to exert a protective action against some types of cancer. The antioxidant activities of the lipophilic extract of purple tomato fruit as measured by luminol-photochemiluminescence (PCL) and ORAC-L (Oxygen radical absorbance capacity –lipophilic) assays were $30.11 \mu\text{mol TE/g DW}$ and $11.97 \mu\text{mol TE/g DW}$, respectively, while the hydrophilic extracts as determined by the ORAC-H (ORAC-hydrophilic) and FRAP assays were $323.23 \mu\text{mol TE/g DW}$ and $54.95 \mu\text{mol AAE/g DW}$, respectively (Li et al. 2010). The total carotenoid content of the fruit was $234.78 \mu\text{g/g}$ dry weight (DW), and the total phenolic content was $659.11 \text{ mg GAE/100 g DW}$.

Altuğ et al. (2007) found that Wistar albino rats administered tomato juice and carbon tetrachloride had significantly higher antioxidative enzymes SOD, GSH and GPx than those receiving only carbon tetrachloride. Tomato juice also lowered the elevated MDA level induced by carbon tetrachloride. The results indicated tomato juice containing lycopene and ascorbic acid, to possess a strong antioxidative effect on oxidative damage of carbon tetrachloride in the rat's liver.

After 2 weeks feeding, the renal reducing (i.e., antioxidant) ability of lycopene-treated rats was significantly greater than that of the control as indicated by in-vivo radiofrequency electron paramagnetic resonance (EPR) measurements (Yoshida et al. 2011). This represented the first verification of in-vivo antioxidant enhancement via dietary lycopene administration. Both the super critical carbon dioxide (S-CO₂)-extracted tomato oleoresins exhibited higher antioxidant activity, per gram of sample, compared to the hexane extract of tomato powder (Longo et al. 2012). The oil-fraction of the tomato oleoresin (S-CO₂ExT), showed a significantly higher activity compared to the oil fraction of the oleoresin obtained from tomato/hazelnut matrix (40.7 mmol TE/g and 18.6 mmol TE/g , respectively).

Hypocholesterolemic/ Antihyperlipidemic/Antiatherosclerotic Activities

β -carotene and lycopene were found to suppress of cholesterol synthesis and augmented LDL receptor activity in J-774 A. 1 macrophage cell line (Fuhramn et al. 1997). Dietary supplementation of tomato's lycopene (60 mg/day) to 6 males for a 3 months period resulted in a significant 14% reduction in their plasma LDL cholesterol concentrations. They concluded that dietary supplementation of carotenoids may act as moderate hypocholesterolemic agents, secondary to their inhibitory effect on macrophage 3-hydroxy-3-methyl glutaryl coenzyme A (HMGCoA) reductase, the rate limiting enzyme in cholesterol synthesis. Agarwal and Rao (1998) found that dietary supplementation of lycopene in healthy humans for a week significantly increased serum lycopene levels by at least twofold. Although there was no change in serum cholesterol levels (total, LDL, or high-density lipoprotein), serum lipid peroxidation and LDL oxidation were significantly decreased. In a multicenter case-control of individuals from 10 European countries, lycopene but not α - and β -carotene was found to contribute to the protective effect of

vegetable consumption on myocardial infarction risk (Kohlmeier et al. 1997). An examination of collinearity including all covariates and the three carotenoids, α -carotene, β -carotene, and lycopene, showed that the variables were sufficiently independent to model simultaneously. A randomized crossover dietary intervention study of 21 healthy subjects for 10 days found that serum lycopene level changed with dietary lycopene intake irrespective of the amount of fat intake (Ahuja et al. 2006). However, a diet high in olive oil and rich in lycopene may decrease the risk of coronary heart disease by improving the serum lipid profile compared with a high-carbohydrate, low-fat, lycopene-rich diet.

Friedman et al. (2000) found that tomatine diets induced lowering of serum low-density lipoprotein (LDL) without changing high-density lipoprotein (HDL) cholesterol in hamsters. Compared to the control diets, four- to fivefold more labeled dietary cholesterol and coprostanol were excreted in the faeces of the tomatine-fed hamsters. The amount of cholesterol excreted in the faeces corresponded to the amount of tomatine in the diet. Due to the formation of an insoluble tomatine-cholesterol complex and its excretion in the faeces, very little dietary tomatine was absorbed from the digestive tract into the blood stream confirming the reported low oral toxicity of tomatine compared to other glycoalkaloids. Esculeogenin A, aglycon of esculeoside A in tomato, significantly and dose-dependently inhibited the accumulation of cholesterol ester (CE) induced by acetylated low density lipoprotein (acetyl-LDL) in human monocyte-derived macrophages without inhibiting triglyceride accumulation, however, it did not inhibit the association of acetyl-LDL to the cells (Fujiwara et al. 2007). Esculeogenin A also inhibited CE formation in Chinese hamster ovary cells overexpressing acyl-coenzyme A (CoA): cholesterol acyl-transferase (ACAT)-1 or ACAT-2, suggesting that esculeogenin A suppresses the activity of both ACAT-1 and ACAT-2, and prevented the expression of ACAT-1 protein. Oral administration of esculeoside A to apoE-deficient mice significantly reduced the levels of serum chole-

sterol, triglycerides, LDL-cholesterol, and the areas of atherosclerotic lesions without any detectable side effects. The study provided evidence that purified esculeogenin A significantly suppressed the activity of ACAT protein leading to reduction of atherogenesis.

Nohara (2010) reported that administration of esculeoside A (50 mg/kg/day) to apoE-deficient mice, significantly reduced total cholesterol, serum LDL cholesterol and triglycerides compared to control group. Esculeoside A significantly reduced acyl-CoA:cholesterol acyl transferase (ACAT) activity in the liver and peritoneal macrophages, whereas intestinal ACAT activity did not change compared with the control mice. Oral administration of esculeoside A to apoE-deficient mice significantly reduced serum levels of cholesterol, triglycerides, and LDL-cholesterol and ameliorated the severity of atherosclerotic lesions. Similarly, esculeogenin A the sapogenol of esculeoside A from tomato fruit inhibited the accumulation of cholesterol esters in macrophages through its effects on ACAT (Nohara et al. 2010). human monocyte-derived macrophages.

In a quasi-experimental study of 32 type 2 diabetes patients, administered raw tomato 200 g daily for 8 weeks, resulted in significant decreases in systolic and diastolic blood pressure and also a significant increase in apoA-I at the end of study compared with initial values (Shidfar et al. 2011). The results indicating that consumption of tomato may be beneficial for reducing cardiovascular risk associated with type 2 diabetes.

The meta-analysis of 12 eligible intervention studies between 1955 and September 2010 by Reid and Fakler (2011) suggested lycopene taken in doses 25 mg daily to be effective in reducing LDL cholesterol by about 10% which was comparable to the effect of low doses of statins in patient with slightly elevated cholesterol levels. Meta-analysis of the effect of lycopene on systolic blood pressure of all trials suggested a significant blood pressure reducing effect albeit more research was advocated to confirm suggested beneficial effects on total serum cholesterol and systolic blood pressure.

Recent epidemiological studies had shown an inverse relationship between tissue and serum levels of lycopene, an oxygenated carotenoid with great antioxidant properties, and mortality from coronary heart disease, cerebrovascular disease, and myocardial infarction (Rao 2002). He cited that the most impressive population-based evidence came from a multicenter case-control study where subjects from 10 European countries were evaluated for relationship between antioxidant status and acute myocardial infarctions. After adjusting for a range of dietary variables, only lycopene levels but not β -carotene were found to be protective. Riccioni et al. (2008) also reported that lycopene had shown both in epidemiological studies and supplementation human trials to reduce cardiovascular risk. Epidemiological data, in-vitro data and results from animal experiments partly showed promising preventive mechanisms of lycopene (Böhm 2012). However, controlled human clinical trials and dietary intervention studies using well-defined subjects population had not provided a clear evidence of lycopene in the prevention of cardiovascular diseases (Riccioni et al. 2008; Böhm 2012). Thus, at present, the role of lycopene in the prevention of coronary heart disease is still strongly suggestive.

Anticancer Activity

Tomato glycoalkaloids, the tetrasaccharide tomato glycoalkaloid α -tomatine, the trisaccharide $\beta(1)$ -tomatine, the disaccharide γ -tomatine, the monosaccharide δ -tomatine, and their common aglycon tomatidine exhibited antiproliferative activities against human colon (HT29) and liver (HepG2) cancer cells antiproliferative activities against human colon (HT29) and liver (HepG2) cancer cells (Lee et al. 2004). The hydrolysis products were less active. The effectiveness against the liver cells was greater than against the colon cells. Potencies of α -tomatine at a concentration of 1 μ g/mL against the liver carcinoma cells were higher than those observed with the anticancer drugs doxorubicin and camptothecin. Because also inhibited normal human liver HeLa (Chang) cells, safety considerations should guide the use

of the compound as preventative or therapeutic treatments against carcinomas. A major spiro-solane glycoside, named esculeoside A and tomatine isolated from tomato fruit exhibited cytotoxicity against MCF-7 cells activity with IC_{50} values of 24.5 μ M and 15 μ M respectively (Fujiwara et al. 2003). The 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) cell assay IC_{50} values showed that HeL299 lung cells, A549 lung cancer cells, and HeLa cervical carcinoma cells were highly susceptible to inactivation by glycoalkaloid-rich green tomato extracts (Choi et al. 2010). Chang normal liver cells and U937 lymphoma cells were less susceptible. Tomato extracts promoted growth in normal liver (Chang) cells, had little effect in normal lung (HeL299) cells, mildly inhibited growth of lung cancer (A549) cells, and first promoted and then, at higher concentrations, inhibited growth in lymphoma (U937) cells (Choi et al. 2011). Compared to untreated controls, the high-tomatine green tomato extracts strongly inhibited the following human cancer cell lines: breast (MCF-7), colon (HT-29), gastric (AGS), and hepatoma (liver) (HepG2), as well as normal human liver cells (Chang) (Friedman et al. 2009). There was little inhibition of the cells by the three low-tomatine red tomato extracts. α -Tomatine was highly effective in inhibiting all of the cell lines. Dehydrotomatine, tomatidenol, and tomatidine had little, if any, effect on cell inhibition. Studies showed that α -tomatine from tomato significantly suppressed the abilities of the adhesion, invasion, and migration of human non-small cell lung cancer NCI-H460 cells under non-cytotoxic concentrations by inactivating FAK/PI3K/Akt signaling pathway and suppressing binding activity of nuclear factor kappa B (NF- κ B) (Shieh et al. 2011). Further, α -tomatine significantly decreased the levels of phospho-Akt and MMP-7 in Akt1-cDNA-transfected cells concomitantly with a marked reduction on cell invasion and migration. The results indicated α -tomatine might have application for treating cancer metastasis.

Two tomato cystine-knot miniproteins (TCMPs) purified either as recombinant or as native proteins from tomato fruits, inhibited in-vitro angiogenesis of HUVEC cells at concentrations

of 15–100 nM (Cavallini et al. 2011). The anti-angiogenic effect of TCMPs was associated with the inhibition of ERK phosphorylation. The two miniproteins did not alter the viability and proliferation of the endothelial cells.

Levy et al. (1995) found that lycopene, delivered in cell culture medium strongly inhibited proliferation of endometrial (Ishikawa), mammary (MCF-7), and lung (NCI-H226) human cancer cells with half-maximal inhibitory concentration of 1–2 μ M; α - and β -carotene were far less effective inhibitors. For example, in Ishikawa cells, a 4-fold higher concentration of α -carotene or a 10-fold higher concentration of β -carotene was needed for the same order of growth suppression. The inhibitory effect of lycopene was detected after 24 h of incubation, and it was maintained for at least 3 days. In contrast to cancer cells, human fibroblasts were less sensitive to lycopene, and the cells gradually escaped growth inhibition over time. In addition to its inhibitory effect on basal endometrial cancer cell proliferation, lycopene also suppressed insulin-like growth factor-I-stimulated growth. Insulin-like growth factors are major autocrine/paracrine regulators of mammary and endometrial cancer cell growth. Effects of the chronic ingestion of lycopene was found to significantly suppressed the mammary tumour development in SHN virgin mice (Nagasawa et al. 1995). The suppression was associated with a decrease in the mammary gland activity of thymidylate synthetase, serum levels of free fatty acid and prolactin. Kobayahsi et al. (1996) found that in the lycopene-treated mice, the abnormal intrathymic T cell differentiation was recovered and restored to non-tumorous levels. The peripheral CD4/CD8 ratio was partially augmented by lycopene treatment which resulted from an increased CD4+ subpopulation. Their observations suggested that one of the immunomodulating roles of lycopene was to normalize the change of intrathymic T cell differentiation caused by tumorigenesis. Karas et al. (2000) found that growth stimulation of MCF7 mammary cancer cells by insulin-like growth factor I (IGF-I) was markedly reduced by physiological concentrations of lycopene. The inhibitory effects of lycopene on MCF7 cell

growth were not accompanied by apoptotic or necrotic cell death. Lycopene treatment markedly reduced the IGF-I stimulation of tyrosine phosphorylation of insulin receptor substrate 1 and binding capacity of the AP-1 transcription complex. Their data suggested that the inhibitory effects of lycopene on MCF7 cell growth are not due to the toxicity of the carotenoid but, rather, to interference in IGF-I receptor signaling and cell cycle progression.

Astorg et al. (1997) found that feeding rats with lycopene significantly decreased the size of γ -glutamyl transpeptidase- and glutathione S-transferase-positive preneoplastic foci induced by the carcinogen diethylnitrosamine (by 64 and 65%, respectively), as well as the fraction of liver volume occupied by foci (by 84 and 79%, respectively), but did not significantly reduce their number. The other carotenoids, including β -carotene, exerted no significant effects on DEN-induced preneoplasias. Lycopene did not appear to act through its antioxidant properties, but rather through its modulating effect on the liver enzyme activating DEN, cytochrome P-450 2E.

Androgen-independent prostate cancer cells (PC-3 cells) treated with lycopene showed a significant decrease in cell proliferation and lycopene, at a dose of 40 μ M, significantly increased the level of IGF-binding protein 3 (IGFBP-3) (Kanagaraj et al. 2007). There was a significant decrease in the IGF-IR expression after the cells were treated with lycopene and insulin-like growth factor-I (IGF-I). The data obtained suggest that the components of the IGF system may act as a positive regulator of lycopene-induced apoptosis in PC-3 cells. Lee et al. (2011) found that α -tomatine induced apoptosis and inhibited NF- κ B activation on androgen-independent human prostatic adenocarcinoma PC-3 cells, suggesting that α -tomatine may be beneficial for protection against prostate cancer development and progression.

Increasing epidemiological evidence over the past decade suggested the consumption of fresh and processed tomato products to be associated with reduced risk of prostate cancer (van Breemen et al. 2002; Campbell et al. 2004). Results of their in-vitro and in-vivo studies supported the

hypothesis that whole tomato and its phytochemical components such as lycopene and other polyphenols may reduce the risk of prostate cancer (Campbell et al. 2004). Consumption of tomato powder but not lycopene inhibited prostate carcinogenesis, suggesting that tomato products contained compounds in addition to lycopene that modified prostate carcinogenesis (Boileau et al. 2003). Risk of death with prostate cancer was lower for rats fed the tomato powder diet than for rats fed control feed. In contrast, prostate cancer-specific mortality of the control and lycopene-fed rats was similar. The proportions of rats dying with prostate cancer in the control, lycopene, and tomato powder groups were 80% (95% CI=68% to 89%), 72% (95% CI=60% to 83%), and 62% (95% CI=48% to 75%), respectively. Rats in the diet-restricted group experienced longer prostate cancer-free survival than rats in the ad libitum-fed group indicating that diet restriction also reduced the risk of prostate cancer. The results suggested that tomato phytochemicals and diet restriction may act by independent mechanisms.

Using data from a series of case-control studies conducted in Italy between 1983 and 1992, including 317 histologically confirmed, incident cases of cancer of the oral cavity and pharynx, 85 of the esophagus, 723 of the stomach, 955 of the colon, and 629 of the rectum, and a total of 2879 controls, La Vecchia (1997) found that tomato intake was protective on the risk of digestive tract cancers. The multivariate odds ratios (ORs) for the highest consumption quartile were 0.65 (95% CI 0.4–1.0) for oral cavity, pharynx, and esophagus, 0.43 (95% CI 0.3–0.6) for stomach, 0.39 (95% CI 0.3–0.5) for colon, and 0.42 (95% CI 0.3–0.6) for rectum. Another study of colorectal cancer, based on 1,953 cases and 4,154 controls, conducted between 1992 and 1996 confirmed that tomato intake was significantly protective on colorectal cancer risk. The ORs for the highest consumption quintile were 0.79 (95% CI 0.6–0.9) for colon, and 0.71 (95% CI 0.5–0.9) for rectal cancer. In a case-control study of 12 prostate cancer patients and 12 age-matched subjects significantly lower serum and tissue lycopene

levels (44%; 78%, respectively) were observed in the cancer patients than in the controls. (Rao et al. 1999) Serum and tissue β -carotene and other major carotenoids did not differ between the two groups. Although there was no difference in serum lipid peroxidation between cancer patients and their controls, serum protein thiol levels were significantly lower among the cancer patients. Gann et al. (1999) conducted a nested case-control study using plasma samples obtained in 1982 from healthy men enrolled in the Physicians' Health Study, a randomized, placebo-controlled trial of aspirin and β -carotene. Subjects included 578 men who developed prostate cancer within 13 years of follow-up and 1294 age- and smoking status-matched controls. Their results concurred with a recent prospective dietary analysis, which identified lycopene as the carotenoid with the clearest inverse relation to the development of prostate cancer. The inverse association was particularly apparent for aggressive cancer and for men not consuming β -carotene supplements. For men with low lycopene, beta-carotene supplements were associated with risk reductions comparable to those observed with high lycopene. Their data provided further evidence that increased consumption of tomato products and other lycopene-containing foods might reduce the occurrence or progression of prostate cancer. In another case-control study of 65 patients with prostate cancer and 132 cancer-free controls confirmed the inverse associations between lycopene, other carotenoids such as zeaxanthin, lutein, and β -cryptoxanthin, and prostate cancer (Lu et al. 2001). After adjusting for age, race, years of education, daily caloric intake, pack-years of smoking, alcohol consumption, and family history of prostate cancer, significantly inverse associations with prostate cancer were observed with plasma concentrations of the following carotenoids: lycopene and zeaxanthin. Borderline associations were found for lutein and β -cryptoxanthin. No obvious associations were found for alpha- and beta-carotenes, retinol, and α - and γ -tocopherols. Studies of men with clinical stage T1 or T2 prostate adenocarcinoma found that after 3 weeks of consuming tomato sauce based

pasta dishes, total lycopene in serum increased 2.0-fold from 35.6 to 69.9 $\mu\text{g/dL}$ (from 0.664 to 1.30 μM) whereas total lycopene in prostate tissue increased 3.0-fold from 0.196 to 0.582 ng/mg of tissue (from 0.365 to 1.09 pmol/mg) (van Breemen et al. 2002). The results indicated that short-term supplementation with tomato sauce containing primarily all-*trans*-lycopene (83% of total lycopene) resulted in substantial increases in total lycopene in serum and prostate and a substantial increase in all-*trans*-lycopene in prostate but relatively less in serum. However, one large prospective study yielded conflicting results. In a large prospective multicenter, Prostate, Lung, Colorectal, and Ovarian Cancer Screening Study that included 692 incident prostate cancer cases, diagnosed 1–8 years after study entry, including 270 aggressive cases, with regional or distant stage and 844 randomly selected, matched controls, high serum β -carotene concentrations were found to be associated with increased risk for aggressive, clinically relevant prostate cancer (Peters et al. 2007). Lycopene and other carotenoids were unrelated to prostate cancer suggesting that lycopene or tomato-based regimens would not be effective for prostate cancer prevention.

In their review of human clinical trials, Basu and Imrhan (2007) found most of the clinical trials with tomato products suggested a synergistic action of lycopene with other nutrients, in lowering biomarkers of oxidative stress and carcinogenesis. The mechanisms of action listed involved protection of plasma lipoproteins, lymphocyte DNA and serum proteins against oxidative damage, and anticarcinogenic effects, including reduction of prostate-specific antigen, upregulation of connexin expression and overall decrease in prostate tumor aggressiveness. Also they stated that processed tomato products like tomato juice, tomato paste, tomato puree, tomato ketchup and tomato oleoresin had been shown to provide bioavailable sources of lycopene, with consequent increases in plasma lycopene levels and that dietary fats enhanced this process and should be consumed together with food sources of lycopene.

Antimutagenic Activity

Bhuvaneswari et al. (2004) reported that Swiss albino mice that received 7,12-dimethylbenz- [a] anthracene (DMBA) had increased frequency of micronuclei and enhanced lipid peroxidation accompanied by compromised antioxidant defences. Pretreatment with tomato or garlic significantly reduced the frequency of DMBA-induced bone marrow micronuclei, but the combination of tomato and garlic exhibited more profound effect in inhibiting DMBA-induced genotoxicity, mutagenicity, clastogenicity and oxidative stress. Studies indicated that lycopene had antimutagenic effects, although the effects were lower than that of tomato purée containing a complex mixture of bioactive phytochemicals (Polívková et al. 2010). The significant, dose-dependent, antimutagenic effects of two concentrations of lycopene (30 μg and 300 μg per plate) were demonstrated at various concentrations of both carcinogens aflatoxin B_1 (AFB_1) and -amino-3-methylimidazo[4,5-f]quinoline (IQ) in two strains of *Salmonella typhimurium* (TA98 and TA100). The protective effects of lycopene relative to the direct mutagen, N-nitroso-N-methylurea, were lower compared to its protective effects relative to AFB_1 and IQ. Mice treated for 3 days with different doses of lycopene (either 25 or 50 mg/kg of body weight) prior to administration of individual mutagens resulted in a significant reduction of micronuclei numbers in the micronucleus test. Tomato purée (tested using the Ames test and AFB_1) revealed a much stronger, dose-dependent, antimutagenic effect compared with corresponding doses of pure lycopene.

Antiplatelet Activity

Among several fruits tested in-vitro for their antiplatelet property, tomato had the highest activity followed by grapefruit, melon, and strawberry, whereas pear and apple had little or no activity (Dutta-roy et al. 2001). Tomato extract (20–50 μL of 100% juice) inhibited both adenosine diphosphate-induced and collagen-induced aggregation

by up to 70% but could not inhibit arachidonic acid-induced platelet aggregation and concomitant thromboxane synthesis. The antiplatelet components (MW <1,000 Da) in tomatoes were water soluble, heat stable and were concentrated in the yellow fluid around the seeds. The active fractions were found to contain antiplatelet compounds in addition to adenosine. Unlike aspirin, the tomato-derived compounds inhibited thrombin-induced platelet aggregation, indicating that consuming tomatoes might be beneficial both as a preventive and therapeutic regime for cardiovascular disease. Similarly, Lazarus and Garg (2004) found collagen-induced and adenosine diphosphate-induced platelet aggregation were significantly and dose-dependently inhibited by tomato extract whereas no effect was observed on arachidonic acid-induced platelet aggregation. Their data showed that the antiplatelet activity appeared to be modulated through inhibition of biochemical events in the phospholipase C pathway upstream of cyclooxygenase, rather than through increased cAMP levels. In a 7-hour time-course study conducted in 23 cannulated human subjects consumption of a supplement drink containing tomato extract caused a significant inhibition of ADP-, collagen-, thrombin-, and arachidonate-mediated platelet aggregation (O'Kennedy et al. 2006a). The observed effects persisted for >12 h. In another randomized, double-blinded, placebo-controlled crossover study conducted in 90 healthy human subjects, significant reductions in ex-vivo platelet aggregation induced by ADP and collagen were observed 3 h after supplementation with doses of tomato extract equivalent to 6 (6TE) and 2 (2TE) tomatoes (O'Kennedy et al. 2006b). Inhibition of platelet function was greatest in a subgroup with the highest plasma homocysteine and C-reactive protein concentrations. Aqueous and methanolic extracts of tomato treated at 22, 60 and 100°C and pH 2 and 10 still inhibited platelet aggregation in vitro (Fuentes et al. 2012). One of the fractions (fraction C), from both aqueous and methanolic extracts, presented the highest activity (~70% inhibition of platelet aggregation) and concentration dependently inhibited platelet aggregation significantly compared with control. Presence of nucleosides were detected in the fractions but not lycopene.

Ocular Disease Prevention

Tomato carotenoids phytoene, phytofluene, ζ -carotene, γ -carotene, β -carotene, neurosporene, and lutein, and two oxidative metabolites of lycopene, 2,6-cyclolycopene-1,5-diols A and B, had been isolated and identified in human serum, milk, organs (liver, lung, breast, liver, prostate, colon), ocular tissues and skin (Khachik et al. 2002). Studies suggested that carotenoids may also play an important role in the prevention of age-related macular degeneration, cataracts, and other blinding disorders. Among 25 dietary carotenoids and nine metabolites routinely found in human serum, mainly (3R,3 R,6 R)-lutein, (3R,3 R)-zeaxanthin, lycopene, and their metabolites were detected in ocular tissues. Although (3R,3 R,6 R)-lutein, (3R,3 R)-zeaxanthin, and their metabolites constituted the major carotenoids in human ocular tissues, lycopene and a wide range of dietary carotenoids had been detected in high concentrations in ciliary body and retinal pigment epithelium.

Lycopene was found to prevent galactose-induced morphological changes in human lens epithelial cells by modulating the antioxidant status (malondialdehyde, glutathione and antioxidant enzymes) (Mohanty et al. 2002). Lycopene protected against experimental cataract development by virtue of its antioxidant properties (Gupta et al. 2003). Lycopene supplementation significantly restored the activities of antioxidant enzymes superoxide dismutase, catalase and glutathione S-transferase, and reduced the incidence of selenite cataract. Only 9% of the eyes in the test group developed dense nuclear opacity as opposed to 83% in the control group. A significant delay in the onset and progression of galactose cataract was observed with oral feeding of lycopene. Only 35% of the eyes developed mature cataract as opposed to 100% in the control group. The results suggested that lycopene may be useful for prophylaxis or therapy against cataracts.

Brazionis et al. (2009) in a community-based, cross-sectional study of 111 individuals with type 2 diabetes found that the combined lycopene and lutein/zeaxanthin (non-pro-vitamin A (non-PVA) carotenoid) concentration when compared with the pro-vitamin A (PVA) carotenoids (alpha-carotene,

beta-carotene and beta-cryptoxanthin) was significantly lower in the retinopathy than non-retinopathy group. A higher concentration of PVA carotenoids was associated with greater odds of diabetic retinopathy, after adjustment for risk factors. Their observations indicated dietary modulation of retinopathy risk may be possible by increasing intakes of lutein- and lycopene-rich foods.

A separate study of diabetic patients, found that subjects with proliferative diabetic retinopathy had significantly lower serum lycopene levels than subjects without diabetic retinopathy or with nonproliferative diabetic retinopathy (Li et al. 2010). This suggested that lycopene may be helpful for the diagnosis, severity, and therapeutic evaluation of diabetic retinopathy.

In a study of 34 AMD patients and 21 control subjects, Cardinault et al. (2005) found no difference in serum total carotenoids but individual carotenoid levels showed that only lycopene was decreased significantly in serum, LDL and HDL fractions in AMD patients. It was hypothesised that lower lycopene status could result also from specific antioxidant protection of lutein and zeaxanthin by lycopene. Zhou et al. (2011) found in a case-control study of 263 elderly Chinese subjects aged between 50 and 88 years that higher levels of serum carotenoids, in particular zeaxanthin and lycopene, were associated with a lower likelihood of having exudative age-related macular degeneration (AMD). Early AMD was inversely associated only with lycopene but was positively associated with α -carotene. No significant associations were observed between serum lutein and cases with early or exudative AMD.

AntiParkinson's Disease Activity

There is extensive evidence that oxidative damage of dopamine (DA)-containing neurons in the substantia nigra pars compacta may contribute to the pathogenesis of Parkinson's disease (Suganuma et al. 2002; di Matteo et al. 2009). Studies showed that a 4-week ingestion of the experimental diet containing 20% (w/w) lyophilized tomato powders before 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP) treatment prevented a

decrease in the striatal dopamine level in mice (Suganuma et al. 2002). This suggested that the tomato ingestion might serve as a preventive against neurodegenerative diseases such as Parkinson's disease caused by MPTP and other environmental toxins. Studies by di Matteo et al. (2009) found rats fed a tomato-enriched diet (wild-type Red Setter tomato) protected from 6-hydroxydopamine-induced degeneration of rat nigral dopaminergic neurons and this was attributed to the ability of lycopene to prevent the degeneration of dopamine-containing neurons in the substantia nigra pars compacta. The plasma level of lycopene was 4.7 ng/mL in 5% tomato-enriched -fed rats, while it was undetectable (<2.5 ng/mL) in control and high carotene (β -carotene) tomato-fed rats.

Pulmonary Protective Activity

Studies in Wistar rats showed that supplementing the mother's diet with tomato juice protected the lungs of the offspring of female rats exposed to nicotine during gestation and lactation (Maritz et al. 2011). All the nicotine-induced changes that appeared at postnatal day 42 such as emphysema and structural changes, increase in male and female lung volume from postnatal day 63 and thickening of the alveolar walls at postnatal day 84 could be prevented by supplementing the mother's diet with tomato juice.

Heavy Metal Protective Activity

Oral administration of tomato paste was found to reduce the adverse effects of lead on blood constituents in Wistar rats (Salawu 2010). Administration of lead acetate to rats caused significant reductions in the following parameters: weight; packed cell volume; red blood cell and white blood cell counts; the percentages of lymphocytes and monocytes; total serum protein, albumin, and globulin levels; and plasma superoxide dismutase and catalase activities. In contrast, lead caused a significant increase in the percentage of neutrophils and the plasma malondialdehyde

concentration. Tomato paste however, significantly prevented the adverse effects of lead acetate.

Studies in rats showed that tomato consumption reduced uptake while enhancing the elimination of heavy metals in a time dependent manner (Nwokocha et al. 2012). The highest hepatoprotective effect was to cadmium followed by mercury and least to lead indicating that tomato administration to be beneficial in reducing heavy metal accumulation in the liver.

Radioprotective Activity

Dhirhe et al. (2011) showed that pre-treatment of Swiss albino rats with aqueous tomato extract before gamma radiation resulted in a significant reduction in the percentage of chromosomal aberrant metaphases as well as in the different types of aberration scored. The extract was not toxic at 1,500 mg/kg body weight and may have potential of use as radioprotective for human beings.

Traditional Medicinal Uses

Some traditional medicinal uses of tomato have been reported by Chiej (1984), Duke and Ayensu (1985), DeFilipps et al. (2004), and Stuart (2012). The fruit pulp and juice is deemed to be mildly aperient. Folkloric uses reported include the use for asthma and bronchitis, biliousness and dyspepsia and to stimulate a torpid liver. Sliced fruits are ingested for treating toothache and the fruit is also used for treating severe headache and rheumatism. In Surinam, tomato leaf extract is used to treat incipient leprosy spots. Tomato leaf in mixture with castor oil in a paste is applied to filarial worm swellings on a painful groin. The fruit is eaten for regular bowel movement.

Other Uses

Lycopene is highly requested not only by food companies but also for the feed, cosmetic and pharmaceutical industries. Some cosmetic uses of tomato pulp include as tomato facial wash,

cleansing mask, as shampoo against dandruff, and for treating acne and sunburn.

The plant has been report to emit volatiles that repel *Bemisia tabaci* (whitefly) (Bleeker et al. 2009, 2011) and a spray made its leaf extract is said to be effective against ants (Chiej 1984). A semidrying oils obtained from the seeds can be used in soap making.

Studies showed that pectin methylesterase, extracted from tomato, enhanced the pectin degradation process in apple juice clarification in combination with polygalacturonase (Kant and Gupta 2012).

Comments

Based on recent molecular phylogenetic analyses the formerly segregate genera *Lycopersicon*, *Cyphomandra*, *Normania*, and *Triguera* are now nested within *Solanum*, and all species of these four genera have been transferred to *Solanum* (PBI Solanum Project 2012). The genus *Solanum* has been divided into seven subgenera in the widely used classification of D'Arcy (1979, 1991). Bohs (2005) identified 13 major clades within *Solanum* based on molecular data from chloroplast *ndhF* sequences.

Selected References

- Aburjai T, Al-Khalil S, Abuirjeie M (1998) Vitamin D3 and its metabolites in tomato, potato, egg plant and zucchini leaves. *Phytochemistry* 49(8):2497–2499
- Adams SR, Cockshull KE, Cave CRJ (2001) Effect of temperature on the growth and development of tomato fruits. *Ann Bot* 88(5):869–877
- Agarwal S, Rao AV (1998) Tomato lycopene and low density lipoprotein oxidation: a human dietary intervention study. *Lipids* 33(10):981–984
- Agarwal S, Rao AV (2000) Tomato lycopene and its role in human health and chronic diseases. *CMAJ* 163(6):739–744
- Ahuja KD, Pittaway JK, Ball MJ (2006) Effects of olive oil and tomato lycopene combination on serum lycopene, lipid profile, and lipid oxidation. *Nutrition* 22(3):259–265
- Altuğ T, Aydın S, Taşkın EI, Dar KA, Caner M, Belce A (2007) Protective effects of tomato consumption against the oxidative damage caused by CCl4 in rat's liver. *Adv Mol Med* 3(4):183–188

- Astorg P, Gradelet S, Berges R, Suschetet M (1997) Dietary lycopene decreases the initiation of liver pre-neoplastic foci by diethylnitrosamine in the rat. *Nutr Cancer* 29(1):60–68
- Basu A, Imrhan V (2007) Tomatoes versus lycopene in oxidative stress and carcinogenesis: conclusions from clinical trials. *Eur J Clin Nutr* 61(3):295–303
- Bhuvaneswari V, Velmurugan B, Abraham SK, Nagini S (2004) Tomato and garlic by gavage modulate 7,12-dimethylbenz[a]anthracene-induced genotoxicity and oxidative stress in mice. *Braz J Med Biol Res* 37(7):1029–1034
- Bleeker PM, Diergaarde PJ, Ament K, Guerra J, Weidner M, Schütz S, de Both MTJ, Haring MA, Schuurink RC (2009) The role of specific tomato volatiles in tomato-whitefly interaction. *Plant Physiol* 151(2):925–935
- Bleeker PM, Diergaarde PJ, Ament K, Schütz S, John B, Dijkink J, Hiemstra H, de Gelder R, de Both MT, Sabelis MW, Haring MA, Schuurink RC (2011) Tomato-produced 7-epizingiberene and R-curcumen act as repellents to whiteflies. *Phytochemistry* 72(1):68–73
- Böhm V (2012) Lycopene and heart health. *Mol Nutr Food Res* 56(2):296–303
- Bohs L (2005) Major clades in *Solanum* based in *ndhF* sequences. In: Keating RC, Hollowell VC, Croat TB (eds) *A festschrift for William G. D'Arcy: the legacy of a taxonomist. Monographs in systematic botany from the Missouri Botanical Garden*, vol 104. Missouri Botanical Garden Press, St. Louis, pp 27–49
- Boileau AC, Merchen NR, Wasson K, Atkinson CA, Erdman JW Jr (1999) *Cis*-lycopene is more bioavailable than *trans*-lycopene *in vitro* and *in vivo* in lymph cannulated ferrets. *J Nutr* 129:1176–1181
- Boileau TWM, Boileau AC, Erdman JW (2002) Bioavailability of all-*trans* and *cis*-isomers of lycopene. *Exp Biol Med* 227:914–919
- Boileau TW, Liao Z, Kim S, Lemeshow S, Erdman JW Jr, Clinton SK (2003) Prostate carcinogenesis in N-methyl-N-nitrosourea (NMU)-testosterone-treated rats fed tomato powder, lycopene, or energy-restricted diets. *J Natl Cancer Inst* 95(21):1578–1586
- Brazionis L, Rowley K, Itsiopoulos C, O'Dea K (2009) Plasma carotenoids and diabetic retinopathy. *Br J Nutr* 101(2):270–277
- Buttery RG (1993) Quantitative and sensory aspects of flavor of tomato and other vegetables and fruits. In: Acree T, Teranishi R (eds) *Flavor science: sensible principles and techniques*. ACS, Washington, DC, pp 259–286
- Buttery RG, Ling LC (1993) Volatile components of tomato fruit and plant parts: relationship and biogenesis. In: Teranishi R, Buttery RG, Sugisawa H (eds) *Bioactive volatile compounds from plants*. ACS, Washington, DC, pp 22–33
- Buttery RG, Seifert RM, Guadagni DG, Ling LC (1971) Characterization of additional volatile components of tomato. *J Agric Food Chem* 19(3):524–529
- Buttery RG, Teranishi R, Ling LC (1987) Fresh tomato aroma volatiles: a quantitative study. *J Agric Food Chem* 35:540–544
- Buttery RG, Teranishi R, Flath RA, Ling LC (1989) Fresh tomato volatiles composition and sensory studies. *Flavour Chemistry. ACS Symposium Series*, Chapter 17, 388:213–222
- Buttery RG, Takeoka H, Ling LC (1995) Furanol: odor threshold and importance to tomato aroma. *J Agric Food Chem* 43:1638–1640
- Campbell JK, Canene-Adams K, Lindshield BL, Boileau TW, Clinton SK, Erdman JW Jr (2004) Tomato phytochemicals and prostate cancer risk. *J Nutr* 134(12 Suppl):3486S–3492S
- Cardinaut N, Abalain JH, Sairafi B, Coudray C, Grolier P, Rambeau M, Carré JL, Mazur A, Rock E (2005) Lycopene but not lutein nor zeaxanthin decreases in serum and lipoproteins in age-related macular degeneration patients. *Clin Chim Acta* 357(1):34–42
- Carrington NJ, Vaughan G, Milborrow BV (1988) β -D-glucopyranosyl phaseic acid from shoots of *Lycopersicon esculentum*. *Phytochemistry* 27:673–676
- Cataldi TR, Lelario F, Bufo SA (2005) Analysis of tomato glycoalkaloids by liquid chromatography coupled with electrospray ionization tandem mass spectrometry. *Rapid Commun Mass Spectrom* 19(21):3103–3110
- Cavallini C, Trettene M, Degan M, Delva P, Molesini B, Minuz P, Pandolfini T (2011) Anti-angiogenic effects of two cystine-knot miniproteins from tomato fruit. *Br J Pharmacol* 162(6):1261–1273
- Chandra K, Ghosh K, Ojha AK, Islam SS (2009) Chemical analysis of a polysaccharide of unripe (green) tomato (*Lycopersicon esculentum*). *Carbohydr Res* 344(16):2188–2194
- Chiej R (1984) *The Macdonald encyclopaedia of medicinal plants*. Macdonald & Co, London, 447 pp
- Choi SH, Lee SH, Kim HJ, Lee IS, Kozukue N, Levin CE, Friedman M (2010) Changes in free amino acid, phenolic, chlorophyll, carotenoid, and glycoalkaloid contents in tomatoes during 11 stages of growth and inhibition of cervical and lung human cancer cells by green tomato extracts. *J Agric Food Chem* 58(13):7547–7556
- Choi SH, Kim HR, Kim HJ, Lee IS, Kozukue N, Levin CE, Friedman M (2011) Free amino acid and phenolic contents and antioxidative and cancer cell-inhibiting activities of extracts of 11 greenhouse-grown tomato varieties and 13 tomato-based foods. *J Agric Food Chem* 59(24):12801–12814
- D'Arcy WG (1979) The classification of the Solanaceae. In: Hawkes JG, Lester RN, Skelding AD (eds) *The biology and taxonomy of the Solanaceae*. Academic, London, pp 3–47
- D'Arcy WG (1991) The Solanaceae since 1976, with a review of its biogeography. In: Hawkes JG, Lester RN, Nee M, Estrada N (eds) *Solanaceae III: taxonomy, chemistry, evolution*. Royal Botanic Gardens, Kew, pp 75–137
- De Rosa S, De Giulio A, Tommonaro G (1996) Aliphatic and aromatic glycosides from the cell cultures of *Lycopersicon esculentum*. *Phytochemistry* 42(4):1031–1034

- De Rosa S, De Giulio A, Tommonaro G (1997) Triterpenoids and sterol glucoside from cell cultures of *Lycopersicon esculentum*. *Phytochemistry* 44(5):861–864
- De Rosa S, De Giulio A, Tommonaro G, Belisario MA (1998) Acylglucosyl isofucosterol from cell cultures of *Lycopersicon esculentum*. *Phytochemistry* 48(1):103–105
- DeFilipps RA, Maina SL, Crepin J (2004) Medicinal plants of Guianas (Guyana, Surinam, French Guiana). Department of Botany, National Museum of Natural History, Smithsonian Institution, Washington, DC
- Dhirhe T, Maheshwari BK, Raut P, Dhirhe S (2011) Radio-protective effect of *Lycopersicon esculentum* extract against radiation induced chromosomal aberration in Swiss albino mice. *Int J Pharm Sci Rev Res* 7(1):Article-020 97–99
- di Matteo V, Pierucci M, Di Giovanni G, Dragani LK, Murzilli S, Poggi A, Esposito E (2009) Intake of tomato-enriched diet protects from 6-hydroxydopamine-induced degeneration of rat nigral dopaminergic neurons. *J Neural Transm Suppl* 73:333–341
- DiMascio P, Kaiser S, Sies H (1989) Lycopene as the most effective biological carotenoid singlet oxygen quencher. *Arch Biochem Biophys* 274(2):532–538
- DiMascio P, Devasagayam TP, Kaiser S, Sies H (1990) Carotenoids, tocopherols and thiols as biological singlet molecular oxygen quenchers. *Biochem Soc Trans* 18(6):1054–1056
- Duke JA, Ayensu ES (1985) Medicinal plants of China, vols 1 & 2. Reference Publications, Inc., Algonac, 705 pp
- Dutta-Roy AK, Crosbie L, Gordon MJ (2001) Effects of tomato extract on human platelet aggregation in vitro. *Platelets* 12(4):218–227
- El-Aasr ME, Oshiro Y, Fujiwara Y, Miyashita H, Ikeda T, Ono M, Yoshimitsu H, Nohara T (2008) Conversion of esculeoside A into esculeogenin B. *Chem Pharm Bull (Tokyo)* 56(7):926–929
- Elliger CA, Lundin RE, Haddon WF (1981) Caffey l esters of glucaric acid in *Lycopersicon esculentum* leaves. *Phytochemistry* 20(5):1133–1134
- FAO (2012) FAO STAT. Food and Agricultural Organization of United Nations: Economic and Social Department: The Statistical Division. <http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#anchor>
- Fletcher SP, Geyer BC, Smith A, Evron T, Joshi L, Soreq H, Mor TS (2004) Tissue distribution of cholinesterases and anticholinesterases in native and transgenic tomato plants. *Plant Mol Biol* 55(1):33–43
- Friedman M (2002) Tomato glycoalkaloids: role in the plant and in the diet. *J Agric Food Chem* 50(21):5751–5780
- Friedman M, Fitch TE, Yokoyama WE (2000) Lowering of plasma LDL cholesterol in hamsters by the tomato glycoalkaloid tomatine. *Food Chem Toxicol* 38(7):549–553
- Friedman M, Levin CE, Lee SU, Kim HJ, Lee IS, Byun JO, Kozukue N (2009) Tomatine-containing green tomato extracts inhibit growth of human breast, colon, liver, and stomach cancer cells. *J Agric Food Chem* 57(13):5727–5733
- Fuentes EJ, Astudillo LA, Gutiérrez MI, Contreras SO, Bustamante LO, Rubio PI, Moore-Carrasco R, Alarcón MA, Fuentes JA, González DE, Palomo IF (2012) Fractions of aqueous and methanolic extracts from tomato (*Solanum lycopersicum* L.) present platelet antiaggregant activity. *Blood Coagul Fibrinolysis* 23(2):109–117
- Fuhrman B, Elis A, Aviram M (1997) Hypocholesterolemic effect of lycopene and β -carotene is related to suppression of cholesterol synthesis and augmentation of LDL receptor activity in macrophage. *Biochem Biophys Res Commun* 233(3):658–662
- Fujiwara Y, Yahara S, Ikeda T, Ono M, Nohara T (2003) Cytotoxic major saponin from tomato fruits. *Chem Pharm Bull (Tokyo)* 51(2):234–235
- Fujiwara Y, Takaki A, Uehara Y, Ikeda T, Okawa M, Yamauchi K, Ono M, Yoshimitsu H, Nohara T (2004) Tomato steroidal alkaloid glycosides, esculeosides A and B, from ripe fruits. *Tetrahedron* 60(22):4915–4920
- Fujiwara Y, Kiyota N, Hori M, Matsushita S, Iijima Y, Aoki K, Shibata D, Takeya M, Ikeda T, Nohara T, Nagai R (2007) Esculeogenin A, a new tomato sapogenol, ameliorates hyperlipidemia and atherosclerosis in ApoE-deficient mice by inhibiting ACAT. *Arterioscler Thromb Vasc Biol* 27(11):2400–2406
- Fujiwara Y, Kiyota N, Tsurushima K, Yoshitomi M, Horlad H, Ikeda T, Nohara T, Takeya M, Nagai R (2012) Tomatidine, a tomato sapogenol, ameliorates hyperlipidemia and atherosclerosis in apoE-deficient mice by inhibiting acyl-CoA:cholesterol acyl-transferase (ACAT). *J Agric Food Chem* 60(10):2472–2479
- Gann PH, Ma J, Giovannucci E, Willett W, Sacks FM, Hennekens CH, Stampfer MJ (1999) Lower prostate cancer risk in men with elevated plasma lycopene levels: results of a prospective analysis. *Cancer Res* 59(6):1225–1230
- Gould WA (1983) Tomato production, processing and quality evaluation. Avi. Pub. Co., Westport, CO. pp 445
- Gupta SK, Trivedi D, Srivastava S, Joshi S, Halder N, Verma SD (2003) Lycopene attenuates oxidative stress induced experimental cataract development: an in vitro and in vivo study. *Nutrition* 19(9):794–799
- Jia Z, Cash M, Darvill AG, York WS (2005) NMR characterization of endogenously *O*-acetylated oligosaccharides isolated from tomato (*Lycopersicon esculentum*) xyloglucan. *Carbohydr Res* 340(11):1818–1825
- Jones CM, Mes P, Myers JR (2003) Characterization and identification of the anthocyanin fruit (Aft) tomato. *J Hered* 94:449–456
- Kanagaraj P, Vijayababu MR, Ravisankar B, Anbalagan J, Aruldas MM, Arunakaran J (2007) Effect of lycopene on insulin-like growth factor-I, IGF binding protein-3 and IGF type-I receptor in prostate cancer cells. *J Cancer Res Clin Oncol* 133(6):351–359
- Kant S, Gupta R (2012) Purification of pectin methyl-esterase from *Lycopersicon esculentum* and its application. *Protein Pept Lett* 19(11):1205–1211

- Karas M, Amir H, Fishman D, Danilenko M, Segal S, Nahum A, Koifmann A, Giat Y, Levy J, Sharoni Y (2000) Lycopene interferes with cell cycle progression and insulin-like growth factor I signaling in mammary cancer cells. *Nutr Cancer* 36(1):101–111
- Katsumata A, Kimura M, Saigo H, Aburaya K, Nakano M, Ikeda T, Fujiwara Y, Nagai R (2011) Changes in esculeoside A content in different regions of the tomato fruit during maturation and heat processing. *J Agric Food Chem* 59(8):4104–4110
- Khachik F, Carvalho L, Bernstein PS, Muir GJ, Zhao DY, Katz NB (2002) Chemistry, distribution, and metabolism of tomato carotenoids and their impact on human health. *Exp Biol Med* (Maywood) 227(10):845–851
- Kobayashi T, Iijima K, Mitamura T, Toriizuka K, Cyong JC, Nagasawa H (1996) Effects of lycopene, a carotenoid, on intrathymic T cell differentiation and peripheral CD4/CD8 ratio in a high mammary tumor strain of SHN retired mice. *Anticancer Drugs* 7(2):195–198
- Kohlmeier L, Kark JD, Gomez-Gracia E, Martin BC, Steck SE, Kardinaal AF, Ringstad J, Thamm M, Masaev V, Riemersma R, Martin-Moreno JM, Huttunen JK, Kok FJ (1997) Lycopene and myocardial infarction risk in the EURAMIC Study. *Am J Epidemiol* 146(8):618–626
- Kolbe A, Porzel A, Schneider B, Adam G (1997) Diglycosidic metabolites of 24-epi-teasterone in cell suspension cultures of *Lycopersicon esculentum* L. *Phytochemistry* 46(6):1019–1022
- Kozukue N, Han JS, Lee KR, Friedman M (2004) Dehydrotomatine and alpha-tomatine content in tomato fruits and vegetative plant tissues. *J Agric Food Chem* 52(7):2079–2083
- Krammer GE, Takeoka GR, Buttery RG (1994) Isolation and identification of 2, 5-dimethyl- 4-hydroxy-3(2 H)-furanone glucoside from tomatoes. *J Agric Food Chem* 42:1595–1597
- Krumbein A, Auerswald H (1998) Characterization of aroma volatiles in tomatoes by sensory analyses. *Nahrung* 42(6):395–399
- La Vecchia C (1997) Mediterranean epidemiological evidence on tomatoes and the prevention of digestive tract cancers. *Proc Soc Exp Biol Med* 218:125–128
- Lambelet P, Richelle M, Bortlik K, Franceschi F, Giori AM (2009) Improving the stability of lycopene Z-isomers in isomerised tomato extracts. *Food Chem* 112:156–161
- Lazarus SA, Garg ML (2004) Tomato extract inhibits human platelet aggregation in vitro without increasing basal cAMP levels. *Int J Food Sci Nutr* 55(3):249–256
- Lee KR, Kozukue N, Han JS, Park JH, Chang EY, Baek EJ, Chang JS, Friedman M (2004) Glycoalkaloids and metabolites inhibit the growth of human colon (HT29) and liver (HepG2) cancer cells. *J Agric Food Chem* 52(10):2832–2839
- Lee ST, Wong PF, Cheah SC, Mustafa MR (2011) Alpha-tomatine induces apoptosis and inhibits nuclear factor-kappa B activation on human prostatic adenocarcinoma PC-3 cells. *PLoS One* 6(4):e18915
- Levy J, Bosin E, Feldman B, Giat Y, Miinster A, Danilenko M, Sharoni Y (1995) Lycopene is a more potent inhibitor of human cancer cell proliferation than either α -carotene or β -carotene. *Nutr Cancer* 24(3):257–266
- Lewinsohn E, Sitrit Y, Bar E, Azulay Y, Meir A, Zamir D, Tadmor Y (2005) Carotenoid pigmentation affects the volatile composition of tomato and watermelon fruits, as revealed by comparative genetic analyses. *J Agric Food Chem* 53(8):3142–3148
- Li ZZ, Lu XZ, Ma CC, Chen L (2010) Serum lycopene levels in patients with diabetic retinopathy. *Eur J Ophthalmol* 20(4):719–723
- Li H, Deng Z, Liu R, Young JC, Zhu H, Loewen S, Tsao R (2011) Characterization of phytochemicals and antioxidant activities of a purple tomato (*Solanum lycopersicum* L.). *J Agric Food Chem* 59(21):11803–11811
- Longo C, Leo L, Leone A (2012) Carotenoids, fatty acid composition and heat stability of supercritical carbon dioxide-extracted-oleoresins. *Int J Mol Sci* 13:4233–4254
- Lu QY, Hung JC, Heber D, Go VL, Reuter VE, Cordon-Cardo C, Scher HI, Marshall JR, Zhang ZF (2001) Inverse associations between plasma lycopene and other carotenoids and prostate cancer. *Cancer Epidemiol Biomarkers Prev* 10(7):749–756
- Mageroy MH, Tieman DM, Floystad A, Taylor MG, Klee HJ (2012) A *Solanum lycopersicum* catechol-O-methyltransferase involved in synthesis of the flavor molecule guaiacol. *Plant J* 69(6):1043–1051
- Malundo TMM, Shewfelt RL, Scott JW (1995) Flavour quality of fresh tomato as affected by sugar and acid levels. *Postharv Biol Technol* 6:103–110
- Manabe H, Murakami Y, El-Aasr M, Ikeda T, Fujiwara Y, Ono M, Nohara T (2011) Content variations of the tomato saponin esculeoside A in various processed tomatoes. *J Nat Med* 65(1):176–179
- Maritz GS, Mutemwa M, Kayigire AX (2011) Tomato juice protects the lungs of the offspring of female rats exposed to nicotine during gestation and lactation. *Pediatr Pulmonol* 46(10):976–986
- Mayer F, Takeoka GR, Buttery RG, Whitehand LC, Naim M, Rabinowitch HD (2008) Studies on the aroma of five fresh tomato cultivars and the precursors of *cis*- and *trans*-4,5-epoxy-(E)-2-decenals and methional. *J Agric Food Chem* 56(10):3749–3757
- Mohanty I, Joshi S, Trivedi D, Srivastava S, Gupta SK (2002) Lycopene prevents sugar-induced morphological changes and modulates antioxidant status of human lens epithelial cells. *Br J Nutr* 88(4):347–354
- Nagaoka T, Yoshihara T, Sakamura S (1987) Lycopersiconolide, a steroid lactone from tomato roots. *Phytochemistry* 26(7):2113–2114
- Nagaoka T, Yoshihara T, Ohra J, Sakamura S (1993) Steroidal alkaloids from roots of tomato stock. *Phytochemistry* 34(4):1153–57
- Nagasawa H, Mitamura T, Sakamoto S, Yamamoto K (1995) Effects of lycopene on spontaneous mammary tumour development in SHN virgin mice. *Anticancer Res* 15(4):1173–1178

- Nohara T (2010) Efficacy of tomato-saponin, esculeoside A. *J Trad Med* 27:217–224
- Nohara T, Iwakawa E, Matsushita S, Fujiwara Y, Ikeda T, Miyashita H, Ono M, Yoshimitsu H (2008) A pregnane glycoside from overripe tomato. *Chem Pharm Bull (Tokyo)* 56(7):1013–1014
- Nohara T, Ono M, Ikeda T, Fujiwara Y, El-Aasr M (2010) The tomato saponin, esculeoside A. *J Nat Prod* 73(10):1734–1741
- Nwokocha CR, Nwokocha MI, Aneto I, Obi J, Udekweleze DC, Olatunde B, Owu DU, Iwuala MO (2012) Comparative analysis on the effect of *Lycopersicon esculentum* (tomato) in reducing cadmium, mercury and lead accumulation in liver. *Food Chem Toxicol* 50(6):2070–2073
- O'Kennedy N, Crosbie L, van Lieshout M, Broom JI, Webb DJ, Duttaroy AK (2006a) Effects of antiplatelet components of tomato extract on platelet function in vitro and ex vivo: a time-course cannulation study in healthy humans. *Am J Clin Nutr* 84(3):570–579
- O'Kennedy N, Crosbie L, Whelan S, Luther V, Horgan G, Broom JI, Webb DJ, Duttaroy AK (2006b) Effects of tomato extract on platelet function: a double-blinded crossover study in healthy humans. *Am J Clin Nutr* 84(3):561–569
- Ohno M, Ono M, Nohara T (2011) New solanocapsine-type tomato glycoside from ripe fruit of *Solanum lycopersicum*. *Chem Pharm Bull (Tokyo)* 59(11):1403–1405
- Ono M, Takara Y, Egami M, Uranaka K, Yoshimitsu H, Matsushita S, Fujiwara Y, Ikeda T, Nohara T (2006) Steroidal alkaloid glycosides, esculeosides C and D, from the ripe fruit of cherry tomato. *Chem Pharm Bull (Tokyo)* 54(2):237–239
- Ono M, Shiono Y, Yanai Y, Fujiwara Y, Ikeda T, Nohara T (2008) A new steroidal glycoside and a new phenyl glycoside from a ripe cherry tomato. *Chem Pharm Bull (Tokyo)* 56(10):1499–1501
- Ono M, Shiono Y, Tanaka T, Masuoka C, Yasuda S, Ikeda T, Okawa M, Kinjo J, Yoshimitsu H, Nohara T (2010) Three new aromatic glycosides from the ripe fruit of cherry tomato. *J Nat Med* 64(4):500–505
- Opeña RT (1985) Development of tomato and Chinese cabbage cultivars adapted to the hot, humid tropics. *Acta Hort* 153:421–436
- Opeña RT, van der Vossen HAM (1994) *Lycopersicon esculentum* Miller. In: Siemonsma JS, Piluek K (eds) Plant resources of South-East Asia no 8. Vegetables. Prosea Foundation, Bogor, pp 199–205
- PBI Solanum Project (2012) Solanaceae Source. Date accessed 20 February 2012. <http://www.nhm.ac.uk/solanaceaesource/>
- Peters U, Leitzmann MF, Chatterjee N, Wang Y, Albanes D, Gelmann EP, Friesen MD, Riboli E, Hayes RB (2007) Serum lycopene, other carotenoids, and prostate cancer risk: a nested case-control study in the prostate, lung, colorectal, and ovarian cancer screening trial. *Cancer Epidemiol Biomarkers Prev* 16(5):962–968
- Petro-Turza M (1987) Flavour of tomato and tomato products. *Food Rev Int* 2:309–351
- Polívková Z, Šmerák P, Demová H, Houška M (2010) Antimutagenic effects of lycopene and tomato purée. *J Med Food* 13(6):1443–1450
- Porcher MH et al (1995–2020) Searchable world wide web multilingual multiscrypt Plant Name Database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Rao AV (2002) Lycopene, tomatoes, and the prevention of coronary heart disease. *Exp Biol Med (Maywood)* 227(10):908–913
- Rao AV, Fleshner N, Agarwal S (1999) Serum and tissue lycopene and biomarkers of oxidation in prostate cancer patients: a case control study. *Nutr Cancer* 33(2):159–164
- Riccioni G, Mancini B, Di Ilio E, Bucciarelli T, D'Orazio N (2008) Protective effect of lycopene in cardiovascular disease. *Eur Rev Med Pharmacol Sci* 12(3):183–190
- Rick C, Stevens AM (1986) Genetics and breeding. In: Atherton JG, Rudick J (eds) The tomato crop: a scientific basis for improvement. Chapman and Hall, New York, pp 35–105
- Ried K, Fakler P (2011) Protective effect of lycopene on serum cholesterol and blood pressure: meta-analyses of intervention trials. *Maturitas* 68(4):299–310
- Salawu EO (2010) *Lycopersicon esculentum* (tomato) prevents adverse effects of lead on blood constituents. *Malaysian J Med Sci* 17(3):13–18
- Sato H, Sakamura S (1973) A bitter principle of tomato seeds: isolation and structure of a new furostanol saponin. *Agric Biol Chem* 37(2):225–231
- Shchelochkova AP, Vollner YS, Koshov KK (1980) Tomatoside A from seeds of *Lycopersicon esculentum*. *Chem Nat Comp* 169(4):386–392
- Shi J, Le Maguer M (2000) Lycopene in tomatoes: chemical and physical properties affected by food processing. *Crit Rev Biotechnol* 20(4):293–334
- Shidfar F, Froghifar N, Vafa M, Rajab A, Hosseini S, Shidfar S, Gohari M (2011) The effects of tomato consumption on serum glucose, apolipoprotein B, apolipoprotein A-I, homocysteine and blood pressure in type 2 diabetic patients. *Int J Food Sci Nutr* 62(3):289–294
- Shieh JM, Cheng TH, Shi MD, Wu PF, Chen Y, Ko SC, Shih YW (2011) α -Tomatine suppresses invasion and migration of human non-small cell lung cancer NCI-H460 cells through inactivating FAK/PI3K/Akt signaling pathway and reducing binding activity of NF- κ B. *Cell Biochem Biophys* 60(3):297–310
- Sies H, Stahl W (1998) Lycopene: antioxidant and biological effects and its bioavailability in the human. *Proc Exp Biol Med* 218:121–124
- Singh P, Goyal GK (2008) Dietary lycopene: its properties and anticarcinogenic effects. *Compr Rev Food Sci Food Saf* 7:255–270
- Stahl W, Sies H (1996) Lycopene: a biologically important carotenoid for humans? *Arch Biochem Biophys* 336(1):1–9
- Stuart GU (2012) Philippine alternative medicine. Manual of some Philippine medicinal plants. <http://www.stuartxchange.org/OtherHerbals.html>

- Suganuma H, Hirano T, Arimoto Y, Inakuma T (2002) Effect of tomato intake on striatal monoamine level in a mouse model of experimental Parkinson's disease. *J Nutr Sci Vitaminol (Tokyo)* 48(3):251–254
- Tandon KS, Jordan M, Goodner KL, Baldwin EA (2001) Characterization of fresh tomato aroma volatiles using GC-olfactometry. *Proc Florida State Hort Soc* 114:142–144
- Unlu NZ, Bohn T, Francis DM, Nagaraja HN, Clinton SK, Schwartz SJ (2007) Lycopene from heat-induced *cis*-isomer-rich tomato sauce is more bioavailable than from all-*trans*-rich tomato sauce in human subjects. *Br J Nutr* 98:140–146
- Uphof JCT (1968) Dictionary of economic plants, 2nd edn (1st edn 1959). Cramer, Lehre, 591 pp
- van Breemen RB, Xu X, Viana MA, Chen L, Stacewicz-Sapuntzakis M, Duncan C, Bowen PE, Sharifi R (2002) Liquid chromatography-mass spectrometry of *cis*- and all-*trans*-lycopene in human serum and prostate tissue after dietary supplementation with tomato sauce. *J Agric Food Chem* 50(8):2214–2219
- van der Vossen HAM, Nono-Womdim R, Messiaen C-M (2004) *Lycopersicon esculentum* Mill. In: Grubben GJH, Denton OA (eds) PROTA 2: vegetables/Légumes [CD-Rom]. PROTA, Wageningen
- Vogel JT, Tieman DM, Sims CA, Odabasi AZ, Clark DG, Klee HJ (2010) Carotenoid content impacts flavor acceptability in tomato (*Solanum lycopersicum*). *J Sci Food Agric* 90(13):2233–2240
- Wu K, Schwartz SJ, Platz EA, Clinton SK, Erdman JW Jr, Ferruzzi MG, Willett WC, Giovannucci EL (2003) Variations in plasma lycopene and specific isomers over time in a cohort of US men. *J Nutr* 133:1930–1936
- Xianquan S, Shi J, Kakuda Y, Yueming J (2005) Stability of lycopene during food processing and storage. *J Med Food* 8:413–422
- Xu Y, Barringer S (2010a) Comparison of tomatillo and tomato volatile compounds in the headspace by selected ion flow tube mass spectrometry (SIFT-MS). *J Food Sci* 75:C268–C273
- Xu Y, Barringer S (2010b) Comparison of volatile release in tomatillo and different varieties of tomato during chewing. *J Food Sci* 75(4):C352–C358
- Yahara S, Uda N, Nohara T (1996) Lycopersides A-C, three stereoisomeric 23-acetoxyspirosolan-3 β -ol β -lycotetraosides from *Lycopersicon esculentum*. *Phytochemistry* 42(1):169–172
- Yahara S, Uda N, Yoshio E, Yae E (2004) Steroidal alkaloid glycosides from tomato (*Lycopersicon esculentum*). *J Nat Prod* 67(3):500–502
- Yamanaka T, Vincken JP, de Waard P, Sanders M, Takada N, Gruppen H (2008) Isolation, characterization, and surfactant properties of the major triterpenoid glycosides from unripe tomato fruits. *J Agric Food Chem* 56(23):11432–11440
- Yi C, Shi J, Xue SJ, Jiang Y, Li D (2009) Effects of supercritical fluid extraction parameters on lycopene yield and antioxidant activity. *Food Chem* 113:1088–1094
- Yilmaz E (2001) The chemistry of fresh tomato flavor. *Turk J Agric For* 25:149–155
- Yoshida K, Yokoyama H, Oteki T, Matsumoto G, Aizawa K, Inakuma T (2011) Evaluation of the effect of dietary lycopene, the main carotenoid in tomato (*Lycopersicon esculentum*), on the in vivo renal reducing ability by a radiofrequency electron paramagnetic resonance method. *J Agric Food Chem* 59(7):2966–2971
- Yoshihara T, Nagaoka T, Ohra J, Sakamura S (1988) Lycopersiconol, a pregnane derivative from tomato stock roots. *Phytochemistry* 27(12):3982–3984
- Yoshizaki M, Matsushita S, Fujiwara Y, Ikeda T, Ono M, Nohara T (2005) Tomato new sapogenols, isoesculeogenin A and esculeogenin B. *Chem Pharm Bull (Tokyo)* 53(7):839–840
- Zhou H, Zhao X, Johnson EJ, Lim A, Sun E, Yu J, Zhang Y, Liu X, Snellings T, Shang F, Liu N (2011) Serum carotenoids and risk of age-related macular degeneration in a Chinese population sample. *Invest Ophthalmol Vis Sci* 52(7):4338–4344

Solanum mammosum

Scientific Name

Solanum mammosum L.

Synonyms

Solanum globiferum Dunal, *Solanum mammosissium* Ram. Goyena, *Solanum mammosum* var. *corniculum* Ridl., *Solanum platanifolium* Sims, *Solanum villosissimum* Zuccagni.

Family

Solanaceae

Common/English Names

Apple Of Sodom, Breastberry, Cow's Udder, Fox Face, Love Apple, Macaw Bush, Macawbush, Mickey Mouse Plant, Nipple Fruit, Nipple Nightshade, Pigs Ears, Tit Fruit, Tit Plant, Titty Fruit, Turkey Berry, Zombie Fruit.

Vernacular Names

Bolivia: Ku'bu're, Pimento, Popatoa, Tetilla, Toro Torito, Vaca Vaquita;

Brazil: Jurubeba-Do-Pará, Peito-De-Moça (Portuguese);

Brunei: Teron Susu;

Chinese: Huang Jin Guo, Niu Tou Qie, Ru Qie, Wu Dai Tong Tang, Wu Jiao Qie, Wu Zhi Qie;

Columbia: Hoja De Lun, Ku-Ku-Na, Lulo De Perro, Lulo De Perro Tetudo, Lulu De Teta, Tetilla;

Costa Rica: Pichichio, Pichichío, Pichichincho;

Dominican Republic: Berenjena De Gallina, Berenjena Del Teta;

Ecuador: Mutondo Puga, Atallpajambina, Chucho Muyo, Chuchularan (Quichua), Cura Gallinas, Estacudo, Jajapa, Jarjapa De Montana, Piñon, Regargar, Rejalgar, Teta De Vaca;

El Salvador: Chichimosa, Chichita;

French: Poire De Bachelier, Pomme A Chauve-Souris, Pomme D'mour, Pomme Teton, Pomme Zombie, Tétons De Jeune Fille, Morelle À Fruit Ornamental, Morelle Molle;

German: Euter-Nachtschatten, Zitzen Nachtschatten;

Guadeloupe: Pomme Poison, Pomme Zombie;

Guatemala: Chicha, Chichigua, Kekchi Rantu, Tetereta;

Guyana: Jumby Bubby, Tuwawa (Wapishana);

Haiti: Pomme D'amour, Tetan, Tete Jeune Fille;

Honduras: Chichigua, Chichihua;

Indonesia: Terung Susu, Tioeng Londo (Sumatra);

Jamaica: Young Girls Breast;

Japanese: Kanaria Nasu;

Malaysia: Terung Asam, Terung Balanda, Terung Puyuh, Terung Susu, Terung Susu Kambing

(Peninsular), Terong Semangat (Bajau, Sabah), Terung Tujang (Iban, Sarawak);

Mexico: Berenjena, Kan'tzu;

New Guinea: Sigalu;

Nicaragua: Chichigua;

Panama: Moza, Tetilla, Uña De Gato, Veninillo Tetón;

Peru: Cocona Venenose, Teta De Vaca, Tintuma, Vaca Chucho;

Philippines: Tagotong (Samar-Leyte Bisaya), Berenjenita Peluda (Spanish), Tagotong, Talong Susu, Utong (Tagalog);

Puerto Rico: Berengena Cimarrona, Pecho De Donceilla;

Samoan: Lapiti, Lau Lau Faiva;

Spanish: Berenjena De Cucarachas, Berenjena De Gallina, Berenjena De Teta, Berenjenade Marimbo, Gurito, Tetilla,;

Surinam: Baladona, Nkjoeng Wintje Bobi, Njoenwenkebobi, Njoen-Wenke-Bobi, Nyun Wentje Bobi (Creole), Terong Soesoe (Javan);

Turkish: Sofur;

Venezuela: Tuna, Uña De Gato;

Vietnamese: Cà Vú Dê;

Zaire: Babua, Gbangalangala.

Origin/Distribution

A tropical species indigenous to northern South America and possibly also the Caribbean. It is common in Central America—Mexico, Belize, Guatemala, Honduras, Nicaragua, Costa Rica, Panama, and in an arc around the Amazon basin from north-western Bolivia, Peru, Ecuador, Columbia, Venezuela, Guyana and Surinam in the Guyanas, rare and sporadic in the Amazon valley and east coast of Brazil. It has been introduced elsewhere and is commonly grown in east and south east Asia but rare in Africa.

Agroecology

In its native range, it occurs in thickets, grasslands, waste places along roadsides and cultivated land, mostly at low altitude of 100–200 but may reach 1,800 m. It prefers full sun and well-drained, moist soil.

Edible Plant Parts and Uses

Amongst 28 samples of 25 indigenous vegetable species in AVRDC project, the top three vegetables based on eating values were *Colocasia esculenta* and fruit of *Lagenaria siceraria* and *Solanum mammosum*; while the worst three were fruit of *Solanum indicum* and *Solanum melongena*, and young shoots of *Hibiscus sabdariffa* (Kuo 2002). The fruit makes an excellent vegetable and young leaves are also eaten as vegetables (Stuart 2010).

Botany

An annual or short-lived perennial, woody shrub to 1.5 m high villous with simple and occasionally stellate eglandular hairs and spiny with 10–15 mm straight, flat or curved, straw-coloured spines on stems and branches. Stem is branched, brownish or purplish-green and pilose. Leaves mostly paired; petiole 3–8 cm. Lamina broadly ovate or suborbicular in outline, 5–12 by 5–10 cm, 5-7-lobed, villous, armed on major veins with needle-like spines 0.8–2 cm, base cordate, apex acute or obtuse. Inflorescences extra-axillary, sub-sessile cyme, 3- or 4-flowered. Pedicel 5–10 mm. Calyx campanulate, lobes pubescent, ovate-lanceolate, 5–6 mm. Corolla pale purple stellate, deeply incised, 2.5–3.2 cm in diameter, lobes oblong-lanceolate, pilose abaxially. Stamens subequal; filaments 1 mm long, anthers narrow, corniculate, lanceolate, 7–10 mm. Style short, 3 mm. Berry pale green turning to glossy yellow or glossy orange with age, pyriform, 4.5–7 long by 3–4 cm across, with 2–5 papillate protuberances at the base and extended nipple at the tip; mesocarp white and spongy. Seeds dark brown to purplish red, punctate, somewhat compressed, 3–4 mm in diameter (Plates 1–3).

Nutritive/Medicinal Properties

Solanum mammosum fruit was reported to have the following nutrient value per 100 g edible portion: 7 g dry matter, 0.78 g fibre, 3.23 g



Plate 1 Fruit, spiny leaves and spiny stems



Plate 2 Fruit with prominent papillate protuberances at the base



Plate 3 Extended nipple at the fruit tip

sugar, 0.96 g protein, 0.05 mg vitamin C, 4 mg β -carotene, 7 mg Ca, 0.30 mg (Kuo 2002). The fruit also contained trigonelline, choline, vitamins A, B, and C besides fat and protein (DeFilipps et al. 2004).

Steroidal alkaloids and saponins were found as the major constituents of *S. mammosum* fruit (Seelkopf 1968; Gallo and Valeri 1954; Alzérreca and Hart 1982; Tran and Puong 2001; Wong 2008). Wong (2008) isolated the following saponins from *S. mammosum* fruit: solamargine, solasonine, protodioscin, pseudoprotodioscin and inidioside D.

Solanum mammosum fruit was found to contain solasodine (0.2–1.2% dry weight); leaves were devoid of steroidal alkaloids (Telek et al. 1977). Solasodine content was found to increase from green fruit to mature yellow fruit. Other steroidal glycoalkaloids present were solasonine, solarmargine and β -solarmarginine (Tarigan 1980). The fruit was also reported to contain diosgenin and phytosterols (Sawariam 1986). *S. mammosum* cultures also produced sterols such as cholesterol, sitosterol, stigmasterol and campesterol (Indrayanto and Sutarjadi 1986; Guo 2009).

Some biotransformation products, *p*-aminobenzoic acid 7-O- β -D-glucopyranosyl ester, N-acetyl *p*-aminobenzoic acid 7-O- β -D-glucopyranosyl ester, *o*-aminobenzoic acid 7-O- β -D-(β -1,6-O-D-glucopyranosyl)glucopyranosyl ester and *o*-aminobenzoic acid 7-O- β -D-glucopyranosyl ester were isolated from cell suspension cultures of *Solanum mammosum* following administration of *p*-aminobenzoic acid, N-acetyl *p*-aminobenzoic acid or *o*-aminobenzoic acid respectively (Syahrani et al. 1999). N-acetyl *p*-aminobenzoic acid and N-formyl *p*-aminobenzoic acid were also identified as cell suspension metabolites of *p*-aminobenzoic acid. The maximum production of *o*-aminobenzoic acid-7-O- β -D-(β -1,6-O-D-glucopyranosyl)-glucopyranosyl ester was 31.8% on dry weight basis. Aminobenzoic acid, β -D-glucopyranosyl-L-O-aminobenzoate, and O- β -D-glucopyranosyl-(1 $\rightarrow$ 6)-O- β -D-glucopyranosyl-L-O-aminobenzoate was extracted from cell-suspension cultures of *Solanum mammosum* (Indrayanto et al. 1999). Cell suspension cultures of *Solanum mammosum* cultured in modified Murashige & Skoog media could synthesize *o*-aminobenzoic acid-7-O- β -D-(β -1,6-O-D-glucopyranosyl)-glucopyranosyl ester from *o*-aminobenzoic acid with a yield of about 20% dry weight in 7 days (Hartanti et al. 2002).

Some reported pharmacological properties of the plant and its phytochemicals include:

Antioxidant Activity

Wetwitayaklung and Phaechamud (2011) reported low antioxidant activity of *S. mammosum* fruit with IC_{50} of 1706.95 μ g TEAC (Trolox equivalent antioxidant capacity) and total phenolic content of 3.08 g/100 g crude extract gallic acid. There was weak correlation between total phenolic content and antioxidant capacity.

Anticancer Activity

Studies showed that the *Solanum* glycoalkaloid solamargine induce cell death of human hepatoma cells (Hep3B) by apoptosis and involved up-regulation of both tumour necrosis factor receptor (TNFR)-I and -II on Hep3B cells (Kuo et al. 2000). Indioside D, a furostanol glycoside isolated from *Solanum mammosum*, was found to possess antiproliferative activity toward a panel of human cancer cell lines (Wong et al. 2008). The results suggested that indioside D induced apoptosis in HeLa cells via both intrinsic and extrinsic cell death pathways. Of the saponins isolated from the fruit, solamargine exhibited highest cytotoxicity towards HeLa cell line followed by inidioside D, protodioscin, solasonine and pseudoprotodioscin (Wong 2008).

Antimalarial Activity

In a study of 46 different species screened for antimalarial activity, *Solanum mammosum* fruit extract was one of those found moderately active (Muñoz et al. 2000). *S. mammosum* fruit is used for scabies by Mosetene Indians in Bolivia.

Molluscicidal Activity

Both the steroidal glycoalkaloid mixture obtained from *Solanum mammosum* fruits (solasonine 1

and solamargine 2) and the stereoisomeric glycosidic alkaloid tomatine 3 were toxic at 10 and 25 ppm to *Lymnaea cubensis* and *Biomphalaria glabratus*, respectively (Alzérreca and Hart 1982). Their aglycones solasodine 4 and tomatidine 5 showed no toxicity to either mollusc. Preliminary structure-activity correlations indicated that the molluscicidal properties depended on the type of aglycones and on the glycoside bond. A common molecular structure in molluscicidal spirosolane and spirostane glycosides was recognized.

Traditional Medicinal Uses

Various parts of the plant have been used in traditional ethnomedicine in the tropics (Burkill 1966; Grieve 1971; Muñoz et al. 2000; Wiart 2000; Herbal Medicine Research Center 2002; DeFilipps et al. 2004; Chai 2006; Stuart 2010; Crommett 2011).

Fruit is used to treat restlessness and irritability. In the Philippines, the fruit is employed for phthisis, cough and loss of appetite. Fruit is cooling, and when added with vinegar, is used as a poultice for abscesses and cracked nipples; burnt fruit is used for liver problems. The peduncle of the fruit when burnt used for piles, toothache and intestinal haemorrhages. Fruit juice mixed with pounded leaves and roots is used for skin ailments. A root decoction is ingested for asthma and as general stimulant. Roots are boiled with sour milk and grain porridge and employed to treat syphilis. Roots, dried stalk, and leaves are employed in a decoction for washing sores. Leaves are considered anodyne and narcotic and used for haemorrhoids. A leaf infusion or decoction is used for stomach ailments. Seeds are used as stimulant but may cause dyspepsia and constipation.

Solanum torvum and *S. mammosum* leaf juices are rubbed onto afflicted areas for athlete's foot in Belize. In Surinam, the mashed fruit is mixed with tobacco or *Mansoa alliacea* and rubbed on the feet to ward off sandflies. The Kofan people of Columbia and Ecuador use the plant as an insect repellent especially against cockroaches.

In Dominican Republic, extracts of leaf and fruit are used for mouth infections, skin wounds and taken, to lose weight and to lower high blood pressure and high cholesterol. In Peninsular Malaysia, the plant is used to heal caterpillar rash and the Malays drink the leaf sap to treat fever. In Sarawak, fresh fruit juice is used to treat sore eyes in children. In Cambodia, Laos, and Vietnam, the plant is used to induce narcosis.

Other Uses

It is popularly grown as an ornamental plant in gardens. In Taiwan and Hong Kong, the decorative foliage and fruit are used in religious and festival floral arrangements. Chinese in Asia would use the fruits to build an artificial tree during the Chinese Lunar New Year festive season because of its auspicious golden coloured fruit which symbolizes wealth.

Comments

The plant is readily grown from seeds and stem cuttings.

Selected References

- Alzérreca A, Hart G (1982) Molluscicidal steroid glycoalkaloids possessing stereoisomeric spirosolane structures. *Toxicol Lett* 12(2–3):151–155
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula, Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, Malaysia, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Chai PPK (2006) Medicinal plants of Sarawak. Lee Ming Press, Kuching, 212 pp
- Crommett MK (2011) Dominican medicinal plant inventory. <http://www.prhdr.org/docs/Dominican%20Medicinal%20Plants.pdf>
- DeFilipps RA, Maina SL, Crepin J (2004) Medicinal plants of Guianas (Guyana, Surinam, French Guiana). Department of Botany, National Museum of Natural History, Smithsonian Institution, Washington, DC
- Gallo P, Valeri H (1954) The antibiotic activity of some extracts of *Solanum mammosum*, *Cassia occidentalis*, and *Cecropia* species. *Rev Med Vet Parasitol* 12: 119–124
- Grieve M (1971) A modern herbal. Penguin, 2 vols. Dover publications, New York, 919 pp
- Guo TK (2009) The accumulation of copper ions in biomass, its influence on the growth and production of sterols and steroid alkaloid (Solasodine) in shoot cultures of *Solanum mammosum*. In: Second international conference and workshops on basic and applied sciences (2nd ICOWOBAS) regional annual fundamental science seminar 2009 (RAFSS 2009), Johor Bahru, Malaysia
- Hartanti L, Widjaja I, Syahrani A, Indrayanto G (2002) High yield formation of *o*-aminobenzoic acid-7-*O*-beta-D-(beta-1,6-*O*-d-glucopyranosyl)-glucopyranosyl ester in cell suspension cultures of *Solanum mammosum*. *J Asian Nat Prod Res* 4(1):63–67
- Herbal Medicine Research Center (2002) Compendium of medicinal plants used in Malaysia. Vol 1 & 2. Institute for Medical Research, Kuala Lumpur
- Indrayanto G, Sutarjadi I (1986) Sterols in callus of *Solanum mammosum*. *Planta Med* (5):413
- Indrayanto G, Margalin H, Ratnasari E, Syahrani A (1999) Densitometric determination of *o*-aminobenzoic acid, beta-D-glucopyranosyl-1-*o*-aminobenzoate, and *O*-β-D-glucopyranosyl-(1 → 6)-*O*-β-D-glucopyranosyl-1-*o*-aminobenzoate in cell-suspension cultures of *Solanum mammosum*. *J Planar Chromatogr – Mod TLC* 12:456–460
- Kuo G (2002) Project 9. Collaborative research and networks for vegetable production. AVRDC Progress Report 2002, pp 116–122
- Kuo KW, Hsu SH, Li YP, Lin WL, Liu LF, Chang LC, Lin CC, Lin CN, Sheu HM (2000) Anticancer activity evaluation of the *Solanum* glycoalkaloid solamargine: triggering apoptosis in human hepatoma cells. *Biochem Pharmacol* 60(12):1865–1873
- Muñoz V, Sauvain M, Bourdy G, Callapa J, Rojas I, Vargas L, Tae A, Deharo E (2000) The search for natural bioactive compounds through a multidisciplinary approach in Bolivia. Part II. Antimalarial activity of some plants used by Mosetene Indians. *J Ethnopharmacol* 69(2):139–155
- Nee M (1991) Synopsis of *Solanum* section *Acanthophora*: a group of interest for glycoalkaloids. In: Hawkes JG, Lester RN, Nee M, Estrada N (eds) *Solanaceae III: taxonomy, chemistry, evolution*. Kew Publishing, London, 492 pp
- Nee M (2001) Synopsis of *Solanum* in the New World. In: *Solanaceae IV: advances in biology and utilization*. Kew Publishing, London, 494 pp
- Nee M (2006) *Solanum mammosum* L. Description based on taxon concept by Nee, M. pages 89–90 in Nee, M. 1993. *Solanaceae II. Flora de Veracruz* 72:1–158. Instituto de Ecología, Xalapa, Veracruz. <http://www.nhm.ac.uk/research-curation/research/projects/solanaceaesource/taxonomy/description-detail.jsp?taxa=3697>
- Porcher MH et al (1995–2020) Searchable world wide web multilingual multiscript plant name database. Published by The University of Melbourne. Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>

- Sawariam I (1986) Studi kandungan buah *Solanum mammosum* L, Skripsi (BSc Thesis), Fakultas Farmasi Universitas Airlangga, Surabaya
- Seelkopf C (1968) Alkaloid glycosides of the fruit of *Solanum mammosum* L. Arch Pharm Ber Dtsch Pharm Ges 301(2):111–114 (In German)
- Stuart GU (2010) Philippine alternative medicine. Manual of some Philippine medicinal plants. <http://www.stu-artxchange.org/OtherHerbals.html>
- Syahrani A, Ratnasari E, Indrayanto G, Wilkins AL (1999) Biotransformation of *o*- and *p*-aminobenzoic acids and N-acetyl *p*-aminobenzoic acid by cell suspension cultures of *Solanum mammosum*. Phytochemistry 51(5):615–620
- Tarigan P (1980) Sapogenin steroid. Perbit Alumni, Bandung, pp 96–103
- Telek L, Delpin H, Cabanillas E (1977) *Solanum mammosum* as a source of solasodine in the lowland tropics. Econ Bot 31(2):120–128
- Tran VT, Puong TT (2001) Study on components of *Solanum mammosum* L. Tap Chi Duoc Hoc 8:10–12
- Wetwitayaklung P, Phaechamud T (2011) Antioxidant activities and phenolic content of *Solanum* and *Capsicum* sp. Res J Pharm Biol Chem Sci 2(2):146–154
- Wiat C (2000) Medicinal plants of Southeast Asia. Pelanduk Publications, K. Lumpur, 199 pp
- Wong CC (2008) Isolation of saponins from *Solanum mammosum* and characterization of their anticancer activity by proteonomics. M. Phil thesis, University of Hong Kong
- Wong CC, Wang Y, Cheng KW, Chiu JF, He QY, Chen F (2008) Comparative proteomic analysis of indioside D-triggered cell death in HeLa cells. J Proteome Res 7(5):2050–2058
- Zhang ZY, Lu AM, D'Arcy WG (1994) Solanaceae A. L. Jussieu. In: Wu ZY, Raven PH, Hong DY (eds) Flora of China, vol 17 (Verbenaceae through Solanaceae). Science Press/Missouri Botanical Garden Press, Beijing/St. Louis

Solanum melongena

Scientific Name

Solanum melongena L.

Synonyms

Melongena esculenta (Dunal) Grecescu, *Melongena ovata* Mill., *Solanum aethiopicum* var. *violaceum* Dunal, *Solanum edule* Schumacher & Thonn., *Solanum edule* var. *multifidum* Dunal, *Solanum esculentum* Dunal, *Solanum esculentum* var. *aculeatum* Dunal, *Solanum esculentum* var. *inermis* Dunal, *Solanum esculentum* var. *subinermis* Dunal, *Solanum insanum* L., *Solanum longum* Roxb., *Solanum melanocarpum* Dunal, *Solanum melongena* subsp. *agreste* Dikii, *Solanum melongena* var. *giganteum* (Alef.) Dikii, *Solanum melongena* var. *globosi* Dikii, *Solanum melongena* var. *inermis* (Dunal) Hiern, *Solanum melongena* var. *esculentum* (Dunal) Walp., *Solanum melongena* var. *leucoum* (Alef.) Dikii, *Solanum melongena* var. *ovigera* Pers., *Solanum melongena* var. *racemiflorum* Dikii, *Solanum melongena* var. *racemosum* Dikii, *Solanum melongena* var. *stenoleucum* (Alef.) Dikii, *Solanum melongena* var. *variegatum* (Alef.) Dikii, *Solanum melongena* var. *violaceum* (Alef.) Dikii, *Solanum melongena* var. *viride* Dikii, *Solanum melongenum* St.-Lag., *Solanum ovigerum* Salisb., *Solanum ovigerum* Dunal, *Solanum ovigerum* f. *oblongocylindricum* Dunal, *Solanum ovigerum sinuatorepandum* Dunal, *Solanum ovigerum subrepandum* Dunal, *Solanum ovigerum* var. *album* Sweet,

Solanum ovigerum var. *insanum* Blume, *Solanum ovigerum* var. *luteum* Sweet, *Solanum ovigerum* var. *ruber* Sweet, *Solanum ovigerum* var. *violaceum* Sweet, *Solanum ovigerum violaceum*, *Solanum trongum* Poir., *Solanum trongum* var. *divaricatum* Dunal, *Solanum trongum* var. *rumphii* Dunal, *Solanum trongum* var. *tongdongense* Dunal, *Solanum zeylanicum* Scop.

Family

Solanaceae

Common/English Names

Aubergine, Brinjal, Eggplant, Jews's Apple, Mad Apple.

Vernacular Names

Afrikaans: Eiervung;

Arabic: Al-Baḍinjān, Badhingan, Badinjan;

Brazil: Berinjela;

Bulgarian: Patladzsan;

Burmese: Kayan, Khayan, Khayan-Sat, Litnga-Shaba, Mak-Hku, Shaba, Ta-Gau;

Catalan: Albergínia;

Chinese: Ai Gua, Ngai Gwa, Qie Zi;

Croatian: Patlidžan;

Czech: Lilek Baklažán, Lilek Vejcoplodý;

Danish: Aubergine, Ægplante;

Dutch: Aubergine, Eierplant;
Eastonian: Baklažaan;
Finnish: Aubergiini, Munahedelmä, Munakoiso;
French: Aubergine, Aubergine Douce, Beringène, Bringègle, Marignan, Mayenne, Mélongène;
French Guiana: Aubergine;
German: Aubergine, Eierfrucht, Eierpflanze;
Greek: Melitzana;
Guinea: Ta-Kobo (Baga), Kobokobo, Tsobotsobo (Landoma), Kobokobo (Susu), A-Kobokobo (Temne);
Hebrew: Hatzil;
Hungarian: Padlizsán, Padlizsános;
India: Begun (Bengali), Ringna (Gujerati), Baigan, Baijani, Baingan (Hindu), Vazhudhanaikkai, Vazhuthananga (Malayalam), Vangi (Marathi), Bhantaki, Natingan, Vatica-Gama, Vatinganah, Varttaka (Sanskrit), Kathiri, Kathirikai, Kattiri (Tamil), Vankaya (Telugu), Baigan (Urdu);
Indonesia: Encung, Terong (Javanese), Terrong (Madurese), Terong (Malay), Chung, Tiung (Sumatra), Chokrom, Terung (Sundanese);
Iran: Bâdenjân;
Italy: Maranziana, Melanzana, Mulignana, Petrociana;
Japanese: Daimaru Nasu, Daimaru Nasu, Nasu;
Khmer: Trab Put Lonhoong, Trab Veeng;
Korean: Kaji;
Laotian: Khua Hleez, Khua Ham Maaz, Khua Poom;
Malaysia: Terong, Terung,
Nepali: Bhanta;
Papiamento: Bereheim;
Persian: Bâdinjân;
Philippines: Talong (Bikol), Bringhinas, Talong, Tarong (Bisaya), Talong (Bontok), Tarong (Iloko), Tolung (Sulu), Talong (Tagalog);
Polish: Bakłażan, Oberżynowy;
Portugal: Beringela, Berinjela;
Romanian: Patlagea Vanata, Pătlaḡele Vinete, Vanata, Vinete;
Russian: Baklažan;
Senegal: Bâdinjân (Arabic), Batansé, Diakhatu (Wolof);
Slovačcina: Jajčevéc, Melancana, Patlidžan Jajcevec;
Slovenčina: Baklažán, Baklažány, Ľufok Baklažánový;

Spanish: Berenjena;
Surinam: Aubergine, Boelansje (Sranan);
Swahili: Mbilingani, Mbiringanya;
Swedish: Äggört, Äggplanta, Aubergin, Aubergine (Äggört);
Thai: Makhua-Chan, Makhua-Khao, Makhua-Yao;
Trinidad: Meloogen;
Turkish: Patlıcan;
Vietnamese: Cà Bat, Cà Tim, Cà Tin.

Origin/Distribution

The centre origin of *Solanum melongena* is still controversial and debatable. The most commonly hypothesized region for the domestication of eggplant (*Solanum melongena*) is India, however China has an equally old written record of eggplant use dating about 2,000 years ago (Meyer et al. 2012). Both regions have a high diversity of landraces and populations of putatively wild eggplant: *Solanum incanum* L. in India and *Solanum undatum* Lam. in SE Asia. An additional complication is that there is taxonomic confusion regarding the two candidate progenitors. Analyses revealed two candidate progenitors of *Solanum melongena* may be conspecific. Gene flow appeared to have occurred among domesticated eggplant populations in Asia. Based on historic, morphologic, and molecular data (nrITS sequence and AFLP) among candidate progenitors and Asian eggplant landraces, their phylogeographic synthesis supported a minimum of two domestication events: one in India and one in southern China/SE Asia. Their results also supported separate domestication of *S. melongena* subsp. *ovigerum*, a group of morphologically distinct eggplants found in SE Asia, and suggested Asian *S. incanum* and *S. undatum* may not be genetically distinct.

Weese and Bohs (2010) using DNA sequence data showed that eggplants arose in Africa and were dispersed throughout the Middle East to Asia. The *S. melongena* complex encompasses a series of morphological intermediates from small-fruited spiny plants to large-fruited non-spiny plants. They reported that *Solanum linnaeanum*, a wild species not previously associated with

eggplant evolution, is a member of the *S. melongena* complex. Much earlier, Karihaloo and Gottlieb (1995) through their study on allozyme variation in *S. melongena* and similar wild and weedy forms postulated that *S. melongena* originated from an African species, *S. incanum*. Migration of *S. incanum*, or its derivative wild ancestor of *S. melongena*, into South and Southeast Asia would have occurred either by humans via land routes or by sea dispersal of fruits (D'Arcy and Pickett 1991; Lester and Hasan 1991).

Agroecology

Depending on varieties brinjal is adaptable to a tropical and cool temperate climate. It grows best between 20°C to 35°C. Temperatures below 20°C and above 40°C retards growth. Growth is halted at temperatures below 10°C–12°C and frost kills the plants. It thrives in full sun and ample water. It requires fertile, rich, well drained soil, and abhors waterlogged and strongly acidic soils.

Edible Plant Parts and Uses

The fruit can be eaten fresh or after rehydration of dried slices. In southeast Asia depending on varieties, slices of the raw fruit are eaten as ulam or in a vegetable salad or as lalab. Most often the fruits are eaten grilled, fried or steamed, or stewed with other vegetables, meat or fish, or roasted, cooked in curries, braised in ashes and seasoned with garlic, onion, spices, chillies, belacan (shrimp-paste), sugar, oil, soya sauce etc. In India, eggplant is widely used in many cuisines – *achar*, *chutney*, *sambhar*, *dalma* and curries. The fruit can be stewed as in many south Asian and Middle Eastern cuisines – Iranian *khoresh-e-bademjan* Turkish *karniyarik* or *musakka*, in French *ratatouille* and Italian *parmigiana di melanzane*. The fruit with intact skin can be roasted until charred and the pulp removed and mixed with other ingredients such as lemon, tahini, and garlic as in the Greek dish *melitzanosalata* and the Middle Eastern Levant dish of *baba ghanoush*. Eggplant is grilled, mashed and

blended with onions, tomatoes and spices in the Indian dish *baingan ka Bhartha* or *gojju*. Roasted eggplant is mixed with roasted red peppers, chopped onions, tomatoes, mushrooms, carrots, celery and spices in the Romanian dish *zacusca*, *ajvar* in Serbia and the Balkans. Strips of roasted eggplant, sweet pepper, onion and tomato is used in the Catalan cuisine *escalivada*. *Begun-Pora* (eggplant-charred or burnt), is popular in the east Indian state of Bengal and Bangladesh where the charred pulp is mixed with raw chopped onions, green chillies, salt and mustard oil.

The fruit can be sliced and deep fried, and served with plain yogurt topped with tomato and garlic sauce as in the Turkish *patlıcan kızartması* or without yogurt in *patlıcan şakşuka*. In Turkey, the most famous eggplant cuisine is the vegetarian *İmam bayıldı* and *Karniyarik* with meat. The fruit is also sliced, battered and fried and served with tahini sauce, tamarind or tomato sauce.

The fruit can also be stuffed with minced meat, fish-paste, minced crab and prawn paste and baked, fried or stewed. In the Caucasus, eggplant is stuffed with walnut paste and fried in the dish *nigvziani badrijani*. In India, eggplant is also stuffed with ground coconut, peanuts and *masala* and cooked in oil. In Chinese cuisines in China and southeast Asia, eggplant is steamed, braised, stewed, stuffed and fried.

The fruits are also made into pickles in vinegar e. g. '*torshi betingen*' in West Asia (Iran, Egypt) or sweet jam (Turkey, Greece). The fruit can be preserved by canning, freeze drying or air-drying, e.g. Turkish '*dolma*'. The fruit is cooked with ghee and sugar to make an appetiser called *pacheri*.

Botany

Annual herb to short-lived perennial sub-shrub 60 to 150 cm tall (Plates 1,5, and 8) branched, with long taproot; stems and leaves with or without prickles, and pubescent with stellate hairs. Leaves alternate, simple, petiolate (2–4.5 cm long), leaf blade ovate to oblong-ovate, 6–18 × 5–11 cm, stellate-tomentose or sometimes with a few fine prickles on both surfaces, base obliquely cordate, apex obtuse, margin sinuate-lobed (Plates, 1,5,8, 9, 10,



Plate 1 Plant of long purple eggplant



Plate 4 Long variegated green eggplant



Plate 2 Harvested long purple eggplants

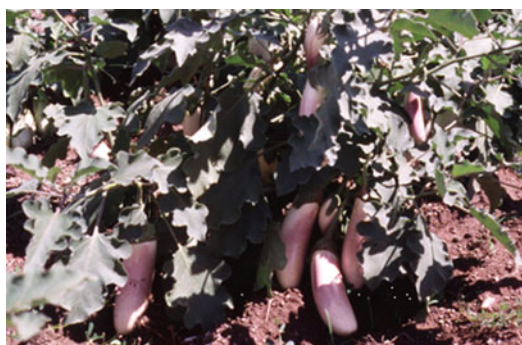


Plate 5 Plant of Asian Bride eggplant variety



Plate 3 Medium long purple eggplant



Plate 6 Thai Purple bulb eggplant (Makheua Lod Fai Muong)

and 12). Inflorescences mostly solitary flowers, rarely reduced racemes. Flowers andromonoecious; pedicel 1–1.8 cm, calyx campanulate with

lanceolate lobes, stellate tomentose, often with 3 mm prickles abaxially; corolla campanulate with deltoid lobes, 3–4 cm in diameter, purplish or



Plate 7 Thai Purple bulb eggplant (Makheua Lod Fai Muong)



Plate 10 Leaves and fruit of Thai yellow round eggplant (Makheu Luang)

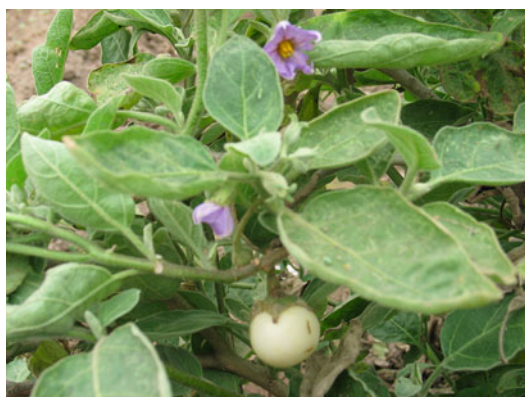


Plate 8 Flower, leaves and fruit of Thai mini white round eggplant (Malheua Khai Dtao Khao)



Plate 11 Harvested Thai yellow round eggplant



Plate 9 Leaves and fruit of Thai mini white round eggplant

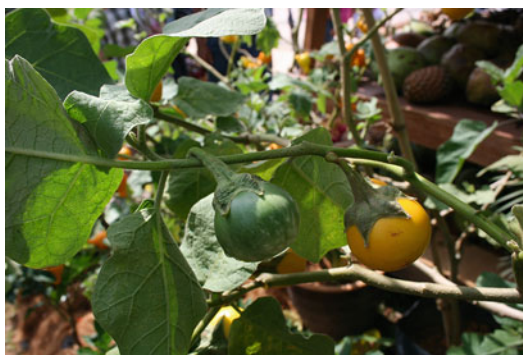


Plate 12 Thai round eggplant (Makheua Keaw Kaang Gap)



Plate 13 Thai mini white round eggplant (Makheua Khai Dtao Khao)



Plate 16 Thai mini purple round eggplant (Makheua Violet Prince)



Plate 14 Thai mini green round eggplant (Makheua Dor Lae)



Plate 17 Thai mini white egg-shaped eggplant



Plate 15 Thai mini purple round eggplant (Khai Dtao Moug Glom)



Plate 18 Thai green variegated egg-shaped eggplant (Makheua Keaw Sawoi)



Plate 19 Purple-red variegated egg-shaped eggplant

violet (Plate 8); filaments short, thick, 2.5 mm; anthers connivent, yellow; ovary superior, 2–many-celled, style 4–7 mm long with green capitate, lobed stigma. Fruit greatly variable in form, size and colour, from a depressed globose to ellipsoid, globose, ovoid, obovoid, elongate or even serpentine berry, 2–35 cm long (sometimes longer), 2–20 cm broad, smoothness and shininess variable, colour at commercial stage white, green, yellow, purple, pale violet-purple hues to black, sometimes netted (variegated) or streaked, when ripe (Plates 1–19), many-seeded. Seeds lenticular to reniform, flattened, pale brown, 2.8–3.9×2.5–3.5 mm.

Nutritive/Medicinal Properties

Aubergine was reported to contain per 100 g edible portion: water 92.9 g, energy 64 kJ (15 kcal), protein 0.9 g, fat 0.4 g, carbohydrate 2.2 g, fibre 2.3 g, Ca 10 mg, P 16 mg, Fe 0.3 mg, carotene 70 µg, thiamin 0.02 mg, riboflavin 0.01 mg, niacin 0.1 mg, folate 18 µg, and ascorbic acid 4 mg (Holland et al. 1991).

The nutritive composition of raw eggplant per 100 g edible portion was reported as:

Water 92.41 g, energy 24 kcal (102 kJ), protein 1.01 g, total lipid 0.19 g, ash 0.70 g, carbohydrate 5.70 g, total dietary fibre 3.4 g, total sugars, 2.35 g, Ca 9 mg, Fe 0.24 mg, Mg 14 mg, P 25 mg, K 230 mg, Na 2 mg, Zn 0.16 mg, Cu

0.082 mg, Mn 0.250 mg, Se 0.3 µg, vitamin C 2.2 mg, thiamin 0.039 mg, riboflavin 0.037 mg, niacin 0.649 mg, pantothenic acid 0.281 mg, vitamin B-6 0.084 mg, total folate 22 µg, total choline 6.9 mg, vitamin A 27 IU, vitamin A 1 µg RAE, vitamin E (α-tocopherol) 0.30 mg, vitamin K (phylloquinone) 3.5 µg, total saturated fatty acids 0.034 g, 16:0 (palmitic) 0.025 g, 18:0 (stearic) 0.009 g, total monounsaturated fatty acids 0.016 g, 16:1 undifferentiated (palmitoleic) 0.002 g, 18:1 undifferentiated (oleic) 0.014 g, total polyunsaturated fatty acids 0.076 g, 18:2 undifferentiated (linoleic) 0.063 g, 18:3 undifferentiated (linolenic) 0.013 g, phytosterols 7 mg, tryptophan 0.009 g, threonine 0.037 g, isoleucine 0.045 g, leucine 0.064 g, lysine 0.047 g, methionine 0.011 g, cystine 0.006 g, phenylalanine 0.043 g, tyrosine 0.027 g, valine 0.053 g, arginine 0.057 g, histidine 0.023 g, alanine 0.051 g, aspartic acid 0.164 g, glutamic acid 0.186 g, glycine 0.041 g, proline 0.043 g, serine 0.042 g and β-carotene 16 µg (USDA 2012). The presence of vitamin D3 (cholecalciferol) and its hydroxylated metabolite 25-hydroxyvitamin D3 (25-OH D3) was established in leaf extracts of *Solanum melongena* (Aburjai et al. 1998).

Other Phytochemicals

Potatoes, tomatoes, and aubergines, all species of the *Solanum* genus have been reported to contain a vast array of secondary metabolites including calystegine alkaloids, phenolic compounds, lectins, and glycoalkaloids (Milner et al. 2011).

Lutein, pheophorbide or chlorophyllide, pheophytin a and b, Mg-free derivatives of chlorophyll a and b were isolated from eggplant fruit juice (Yoshikwa et al. 1996).

Eggplant fruits and leaves were found to contain polyhydroxylated nortropane alkaloids called calystegines (Asano et al. 1997). Calystegines A3, B1, B2, and C1 were found. The glycoalkaloids solamargine and solasonine and their common aglycon solasodine were found in eggplant (Lee et al. 2004). Fruits of *Solanum aethiopicum* and *S. melongena* contained 0.58–4.56 mg/100 g of α-solamargine and 0.17–1 mg/100 g of

α -solasonine, on a wet basis (Sánchez-Mata et al. 2010). The glycoalkaloid levels of *S. aethiopicum* were similar to those of *S. melongena* (about 14% of values considered as toxic) and could be considered as safe for consumption. Chlorogenic acid (5-O-caffeoylquinic acid) was the predominant compound in eggplant fruit, and its 3-O-, 4-O-, and 5-O-*cis* isomers were also found (Whitaker and Stommel 2003). The 10 other phenolics fell into four groups, including 3,5- and 4,5-dicafeoylquinic acid isomers, four amide conjugates, two unknown caffeic acid conjugates, and 3-O-acetyl esters of 5-O- and 4-O-caffeoylquinic acid. Dicafeoylquinic and 3-O-acetyl chlorogenic acids were most variable among the cultivars. Dicafeoylquinic acids were most abundant in the blossom end, whereas 3-O-acetyl esters were highest in the fruit midsection. Chlorogenic acid (CA) was the most abundant phenolic acid constituting >75% of the total phenolic acids content extracted from the eggplant sample (Luthria and Mukhopadhyay 2006). The predominant phenolic acids in the free phenolic acid fraction of Black Beauty cultivar of eggplant were CA isomers. However, caffeic acid isomers were the major phenolic acids extracted from the base-hydrolyzed fraction.

Anthocyanin profiles in 123 accessions of eggplants were classified into four types (Azuma et al. 2008). The major anthocyanins were identified as delphinidin 3-(*p*-coumaroylrutinoside)-5-glucoside (nasunin) (type 1, Japanese eggplant), delphinidin 3-rutinoside (type 2, non-Japanese eggplant), delphinidin 3-glucoside (type 3), and petunidin 3-(*p*-coumaroylrutinoside)-5-glucoside (petunidin 3RGc5G) (type 4). Delphinidin 3-cafeoylrutinoside-5-glucoside (delphinidin 3RGcaf5G) was isolated from the hybrid (F1) plants of a type 1 cultivar and a type 3 germplasm. Two major anthocyanins were isolated from the acidified methanolic eggplant extract (Ichiyana et al. 2005). Their structures were identified and elucidated as delphinidin 3-[4-(*cis*-*p*-coumaroyl)-1-rhamnosyl(1 $\rightarrow$ 6)glucopyranoside]-5-glucopyranoside (compound 1) and delphinidin 3-[4-(*trans*-*p*-coumaroyl)-1-rhamnosyl(1 $\rightarrow$ 6)glucopyranoside]-5-glucopyranoside (compound 2), respectively. These anthocyanins were interconvertible under room light illumination condi-

tion. The results indicated that nasunin comprised *cis* and *trans* isomers of the *p*-coumaric acid moiety in its structure.

Eggplant also contained nicotine with a content of 100 ng/g (or 0.01 mg/100 g) (Domino et al. 1993). The amount of eggplant required to obtain one μ g of nicotine is 10 g. However, the amount of nicotine from eggplant or any other food is negligible compared to passive smoking. Eggplant was found to have a trypsin inhibitor with a molecular weight of about 6,200 and characteristic amino acid composition lacking in tryptophan, histidine, valine and methionine (Ibuki et al. 1977).

Solanum melongena seeds contain steroidal saponins without a nitrogenous called melongosides: melongoside A elucidated as (25R)-5 α -spirostan-3 β -ol 3O- β -D-glucopyranoside; melongoside B as trillin; melongoside E as (25R)-5 α -spirostan-3 β -ol 3-O-[O- β -D-glucopyranosyl-(1 $\rightarrow$ 2)- β -D-glucopyranoside]; glycoside F as (25R)-spirost-5-en-3 β -ol 3-O-[O- β -D-glucopyranosyl-(1 $\rightarrow$ 2)- β -D-glucopyranoside]; and melongoside H as (25R)-spirost-5-en-3 β -ol 3-O-[[O- β -D-glucopyranosyl-(1 $\rightarrow$ 2)] [O- α -L-rhamnopyranosyl-(1 $\rightarrow$ 3)]- β -D-glucopyranoside} (Kintya and Shvets 1984), melongoside L, M (Kintya and Shvets 1985), and melongoside N, O, P (Kintya and Shvets 2001); melongoside N was elucidated as 3-O-[β -D-glucopyranosyl-(1 $\rightarrow$ 2)- β -D-glucopyranosyl]-26-O-(β -D-glucopyranosyl)-(25R)-5 α -furostan-3 β ,22 α ,26-triol, whereas melongoside O as 3-O-[β -D-glucopyranosyl-(1 $\rightarrow$ 2)- β -D-glucopyranosyl]-26-O-(β -D-glucopyranosyl)-(25R)-furost-5-en-3 β ,22 α ,26-triol and melongoside P as 3-O-[β -D-glucopyranosyl-(1 $\rightarrow$ 2)]-[α -L-rhamnopyranosyl-(1 $\rightarrow$ 3)]- β -D-glucopyranosyl]-26-O-(β -D-glucopyranosyl)-(25R)-5 α -furostan-3 β ,22 α ,26-triol. The seeds also contained 4 α -methylsterols such as 24(R)-ethyllophenol (Itoh et al. 1978, 1980; Farines et al. 1988), 4-desmethylsterols (Itoh et al. 1977a; Farines et al. 1988), and triterpene alcohols (Itoh et al. 1977b), and a new phytosterol 14 α -methyl-5 α -cholest-9(11)-en-3 β -ol (Farines et al. 1988). Eggplant seed contained 47% 4-desmethylsterol made up of cholesterol (4.1%), 14 α -methyl-5 α -cholest-9(1)-en-3 β -ol (0.5%), campesterol and 24-methylene-cholesterol (5.2%), stigmasterol (3.8%), sitosterol and stigmasta-5,25-

diene-3 β -ol (30.3%, isofucosterol (3%) and unknown 0.1% (Farines et al. 1988). Eggplant seed contained 34% 4-methylsterol made up of lophenol (3.0%), 24-methylenlophenol (2.3%), 24-ethyllophenol (18.3%), citrostadienol (6.8%) and unknown (3.6%). The seed also contained 19.0% triterpene alcohol made up of dihydrolanosterol (2.4%), cycloartanol (9.95%), cycloartenol (5.8%), 24-methylenecycloartanol (0.3%) and unknown (0.6%).

A new biflavonol glycoside named as solano flavone was isolated from aerial part of *Solanum melongena* (Shen et al. 2005). Its chemical structure was elucidated as isorhamnetin-3-O- β -D-glucopyranoside-(4' $\rightarrow$ O $\rightarrow$ 4'')-galangin-3''-O- β -D-glucopyranoside.

Glycoalkaloids and their aglycones of the *Solanum* species have been reported to have anticancer, anticholesterol, antimicrobial, antiinflammatory, antinociceptive, and antipyretic effects (Milner et al. 2011) and other pharmacological activities.

Antioxidant Activity

Studies by Noda et al. (1998, 2000) found nasunin (delphinidine-3-(*p*-coumaroylrutinoside)-5-glucoside) anthocyanin from purple eggplant peel, to be a potent O₂^{*}- scavenger and iron chelator which could protect against lipid peroxidation. Nasunin exhibited potent O₂^{*}- scavenging with a potency of 143 superoxide dismutase (SOD) -equivalent units/mg, and OH scavenging (0.65 EPC-K2-equivalent μ mol/mg) activities. Nasunin formed an iron complex indicating its hydroxyl radical scavenging by nasunin was not due to direct radical scavenging but inhibition of .OH generation by chelating iron. Nasunin (1 μ M) significantly protected against hydrogen peroxide-induced lipid peroxidation of brain homogenates as measured by malonaldehyde and 4-hydroxyalkenals. Flavonoids isolated from brinjal exhibited potent antioxidant activity (Sudheesh et al. 1999). Concentrations of malondialdehyde, hydroperoxides and conjugated dienes were reduced significantly. The activity of catalase was significantly enhanced in the tissues of normal and

cholesterol fed rats administered 1 mg flavonoid from brinjal/100 g BW/day. The concentration of glutathione also showed elevated values in the experimental animals. They elucidated that the elevated levels of glutathione and significantly stimulated activity of catalase may be responsible for the antioxidant effect of these flavonoids.

Acetone extract of egg plant peel exhibited higher in-vitro antioxidant activity than the acetone extract of violet pepper (*Capsicum annum*) which was ascribed to 3,5-diglycosylated structures predominating in anthocyanins in the latter (Sadilova et al. 2006). The major anthocyanin in eggplant was delphinidin-3-rutinoside, while the predominant pigment in violet pepper was assigned to delphinidin-3-*trans*-coumaroylrutinoside-5-glucoside. Among five purified anthocyanins in eggplant fruit, delphinidin 3RGcaf5G showed the highest radical-scavenging activities toward both 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical and linoleic acid radical, followed in order by nasunin and petunidin 3RGc5G (Azuma et al. 2008). Extracts from purple colour small size eggplant fruit demonstrated better antioxidant activities (DPPH, total reducing power, superoxide radical scavenging activity, metal chelating activity) than the other samples (long green, purple coloured big size, purple coloured moderate size) which may be attributed to their higher phenolic and anthocyanin content (Nisha et al. 2009).

Thermally treated eggplant samples showed various changes in their chemical composition (dry matter, soluble solids, acidity, and the amount of alcohol insoluble substances) due to the cooking processes and were much richer in the main phenolic compounds such as chlorogenic and caffeic acids antioxidants (Lo Scalzo et al. 2010). Their free radical scavenging activity was significantly higher, especially that of superoxide anion. The biological assay of oxidative bursts from human neutrophils in the presence of N-formyl-methionyl-leucyl-phenylalanine confirmed the greater activity of extracts of the cooked eggplants with respect to raw eggplants. Successive extract dilutions showed a significant activity up to 1.25 μ g/mL after cooking, while raw fruits resulted in an activity up to 10.00 μ g/mL.

Hepatoprotective Activity

Pretreatment of human hepatoma HepG2 cells with 50 and 100 µg/mL of five varieties of eggplant (purple coloured moderate size, white-green coloured moderate size, long green, green striped moderate size and pale-green coloured small size, respectively, designated SM1-SM5) significantly increased the viability of t-BuOOH-exposed HepG2 cells by 14.49% to 44.95% (Akanitapichat et al. 2010). Total phenolic content found in methanol extracts of SM1-SM5 ranged from 739.36 to 1116.13 gallic acid equivalents mg/100 g extract and total flavonoid content from 1991.29 to 3954.20 catechin equivalents mg/100 g extract. SM1 and SM2 which contained high total phenolic and flavonoid had better antioxidant activities than the other varieties. The antioxidant activities of the eggplant were correlated with the total amounts of phenolic and flavonoid ($R^2=0.5310 - 0.7961$). Significant correlation was found between hepatoprotective activities and total phenolic/flavonoid content ($R^2=0.6371 - 0.8842$) and antioxidant activities ($R^2=0.5846 - 0.9588$), indicating the contribution of the phenolic antioxidant present in eggplant to its hepatoprotective effect on t-BuOOH-induced toxicity.

Oral administration of the combined methanol extract of *Solanum trilobatum* and *Solanum melongena* significantly reduced the elevated levels of the rat serum aspartate transaminase (AST), alanine transaminase (ALT), alkaline phosphatase (ALP), lactate dehydrogenase (LDH) and γ glutamyl transferase (γ -GT) induced by β -galactosamine (Shahjahan et al. 2012). The enzymic and non enzymic antioxidants in liver were restored to normal values after the oral administration of the plants extract and suppressed the formation of the superoxide anion radical and reduced β -galactosamine induced lipid peroxidation. The results showed the synergistic effects of the plants extract against β -galactosamine induced hepatic damage in rats.

Cardioprotective Activity

Das et al. (2011) reported that eggplant contained potent cardioprotective compounds as reflected

by its ability to increase left ventricular function, and reduce myocardial infarct size and cardiomyocyte apoptosis in isolated perfusion heart model taken from animals fed on either raw or grilled eggplants for 30 days. There was no difference in cardioprotective ability between the raw and grilled products. The antioxidant vitamins, including vitamin A, vitamin C and β -carotene, were lower and some of the polyphenolic components, especially nasunin content, were higher in grilled eggplants, but they were unable to demonstrate better cardioprotective properties compared to the raw fruit.

Antidiabetic and Hypotensive Activity

Phenolic-enriched extracts of eggplant with moderate free radical scavenging-linked antioxidant activity exhibited high α -glucosidase inhibitory activity and in specific cases moderate to high angiotensin I-converting enzyme (ACE) inhibitory activity (Kwon et al. 2008). Inhibition of these enzymes provided a strong biochemical basis for management of type 2 diabetes by controlling glucose absorption and reducing associated hypertension, respectively. This phenolic antioxidant-enriched dietary strategy suggested its potential to reduce hyperglycemia-induced pathogenesis linked to cellular oxidation stress.

Anticancer Activities

Delphinidin, the flavonoid pigment found in eggplant peel, exhibited inhibitory effect on human fibrosarcoma HT-1080 invasiveness in-vitro (Nagase et al. 1998). The small inhibitory effect on the activity of matrix metalloproteinase (MMP)-2 and MMP-9 secreted by HT-1080 may partly account for the inhibition of tumour cell invasiveness. The eggplant glycoalkaloids solamargine and solasonine and their common aglycon solasodine exhibited antiproliferative activities against human colon (HT29) and liver (HepG2) cancer cells (Lee et al. 2004) with the glycoalkaloids being the most active and the hydrolysis products less so.

BEC, a standard mixture of solasodine glycosides was effective in-vivo against murine sarcoma 180 (S180), whereas the aglycone solasodine at equimolar concentrations was ineffective (Cham and Daunter 1990). The efficacy of BEC against S180 in-vivo could be inhibited by rhamnose. Mice in their terminal stage with S180 could tolerate and become symptom-free of cancer by single dose administration of BEC at concentrations of BEC three times the LD_{100} for normal mice. These observations suggested that the binding of solasodine glycosides on tumour cells may be mediated through the monosaccharide rhamnose, which formed part of solasonine, solamargine and di-glycosides of solasodine in BEC. Kuo et al. (2000) showed that treating human hepatoma cells (Hep3B) with solamargine caused chromatin condensation, DNA fragmentation, and a sub-G(1) peak in a DNA histogram suggesting that solamargine induced cell death by apoptosis and may involved upregulation of tumour necrosis factor receptor (TNFR)-I and -II. Solamargine significantly inhibited the growth of human hepatoma SMMC-7721 and HepG2 cells and induced cell apoptosis (Ding et al. 2012). Solamargine caused cell cycle arrest at the G2/M phase and up-regulated caspase-3 expression.

Solamargine exhibited potent cytotoxicity in four human lung cancer cell lines H441, H520, H661 and H69 cells with IC_{50} values of 3, 6.7, 7.2 and 5.8 μ M, respectively (Liu et al. 2004). Solamargine dose-dependently induced apoptosis of these cells and increased sub-G1 fraction. Solamargine modulate the expressions of TNFRs and Bcl-2, and might be a potential anticancer agent for TNFs and Bcl-2 related resistance of human lung cancer cells. The scientists (Liang et al. 2004) further found solamargin induced morphological changes of chromatin condensation, DNA fragmentation, and sub-G(1) peak in a DNA histogram of human A549 lung adenocarcinoma cells. Solamargin elevated the expressions of TNF-R1 and -R2 and overcame the resistance of A549 cells to TNF- α and - β . In addition, release of cytochrome c from mitochondria, down-expression of Bcl-2 and Bcl-x(L), up-regulation of Bax, and caspase-9 activities were observed in solamargin-treated A549 cells.

Combinatorial treatment of solamargin and cisplatin synergistically enhanced caspase-8, -9, and -3 activities in A549 cells. Their results suggested that solamargin may have anticancer potential against TNFs- and cisplatin-resistance lung cancer cells. The combinatorial use of low concentrations of solamargine with low-toxic topoisomerase II inhibitor epirubicin accelerated apoptotic cell death of nonsmall-cell lung cancer (NSCLC) (Liang et al. 2007). The downregulation of the HER2 and TOP2A (topoisomerase II α) expression by solamargin with epirubicin may partially explain the solamargin and epirubicin cytotoxicity synergy effect in NSCLC. Results of their study suggested that solamargin induced Fas expression and TNFR-induced NSCLC cell apoptosis and reduced HER2 expression. Liang et al. (2008) further reported that solamargin enhanced HER2 and TOP2A expressions in NSCLC large cell carcinoma H661 and small cell lung cancer (SCLC) H69 cells and augmented trastuzumab and epirubicin-induced deaths of lung cancer H661 and H69 cells.

Solamargine exhibited potent cytotoxic effect comparable with that of cisplatin, methotrexate, 5-fluorouracil, epirubicin and cyclophosphamide against human breast cancer cells (Shiu et al. 2007). Solamargin induced apoptosis of the breast cancer cells by up-regulating the expressions of external death receptors, such as tumour necrosis factor receptor I (TNFR-I), Fas receptor (Fas), TNFR-I-associated death domain (TRADD), and Fas-associated death domain (FADD). Solamargin also enhanced the intrinsic ratio of Bax to Bcl-2 by up-regulating Bax and down-regulating Bcl-2 and Bcl-xL expressions. The combined treatment of solamargin and cisplatin significantly reduced Bcl-2 and Bcl-xL expressions, and enhanced Bax, cytochrome c, caspase-9 and -3 expressions in breast cancer cells and thus may be effective in cisplatin-resistant breast cancer. They also found that solamargin co-modulated HER2/neu and TopoII α expression markedly and enhanced TopoII inhibitor-EPI (epirubicin)-induced cytotoxicity to breast cancer MCF-7 and SK-BR-3 cells (Shiu et al. 2009).

Solamargine was found to induce oncosis in human K562 leukemia and squamous cell

carcinoma KB cells (Sun et al. 2011). It rapidly permeated into tumour cells, induce membrane perturbation and blebbing, leakage of cytoplasmic content and LDH release. Solamargine also disrupted the cytoskeletal systems: degradation of microtubules and actin proteins. Solamargine may offer a novel therapeutic strategy in treatment of cancer.

Nasunin, delphinidin-3-(*p*-coumaroylrutinoside)-5-glucoside, an antioxidant anthocyanin isolated from eggplant peels, was demonstrated to be an angiogenesis inhibitor (Matsubara et al. 2005). Nasunin at higher 10 μ M suppressed microvessel outgrowth in an ex-vivo angiogenesis assay using a rat aortic ring. Nasunin suppressed human umbilical vein endothelial cells (HUVEC) proliferation in a dose-dependent manner (50–200 μ M); however, it had no significant effect on HUVEC chemotaxis in a Boyden chamber assay and HUVEC tube formation on a reconstituted basement membrane. The results implied that nasunin with both antioxidant and antiangiogenic activities might be useful to prevent angiogenesis-related diseases.

Antiviral Activity

The infectivity of herpes simplex virus Type I in tissue culture was inhibited by prior incubation with aqueous suspensions of *Solanum* glycoalkaloids in order of activity α -chaconine > α -tomatine > α -solasanine but not by the corresponding aglycones, solanidine, tomatidine and solasodine (Thorne et al. 1985). The glycones, but not the aglycones, exhibited cytopathic effects on cellular membranes of Vero cells and erythrocytes; suggesting that inactivation of virus resulted from insertion of the glycones into the viral envelope. *Solanum* steroidal glycosides including solasodine showed anti-herpes simplex virus type 1 (HSV-1) activity (Ikeda et al. 2000a).

Hypolipidemic/Hypocholesterolemic Activity

Kritchevsky et al. (1975) reported that feeding rats with eggplant leaf or fruit powder did not

lower serum cholesterol pool whereas alfalfa and clofibrate did. Dried powdered eggplant fruit had been commercialized in Brazil to treat human hyperlipidemia, but a double-blind placebo-controlled study found the absence of a hypolipidemic effect of eggplant on hyperlipidemic patients (Silva et al. 2004). Serum total cholesterol, LDL-c (low density lipoprotein-cholesterol) and LDL-c/HDL-c decreased in volunteers given the eggplant capsules and those receiving placebo after 3 months. No significant difference were found in other parameters, including serum triglycerides, HDL-c (high density lipoprotein-cholesterol), VLDL-c (very low density lipoprotein-cholesterol), AST (aspartate transaminase), ALT (alanine transaminase), gGT (γ glutamyl transpeptidase), glucose and body mass index between both groups. Earlier the study of hypercholesterolemic human volunteers by Guimarães et al. (2000) found no difference after 5 weeks in total cholesterol and its fractions, triglycerides, and apolipoproteins A and B in the serum between subjects given the eggplant infusion and those given the placebo. They concluded that *S. melongena* infusion had a modest and transitory effect, which was not different from that obtained with standard orientation for dyslipidemia patients (diet and physical activities). In separate studies, Praça et al. (2004) found that eggplant extract did not alter serum lipid levels. No significant difference in total cholesterol and LDL-c between volunteers that received eggplant extract and orange juice and those receiving no treatment whilst there was a significant reduction in those given lovastatin. They concluded that eggplant extract with orange juice should not to be considered an alternative to statins in reducing serum levels of cholesterol. Separate studies in LDLR(–/–) mice by Botelho et al. (2004) also did not support the use of eggplant extract as hypocholesterolemic agent. Total cholesterol and atherogenic lipoproteins did not decrease after eggplant intake. No differences were seen in lesion area of aortic valve. Eggplant extract had high histamine and other amine levels that could enhance LDL oxidation and its endocytosis. Eggplant did not decrease plasma cholesterol nor prevent the development of atherosclerosis in LDLR(–/–) mice.

Contrariwise, some studies found eggplant to have a hypolipidemic effect. Sudheesh et al. (1997) found that flavonoids extracted from brinjal fruits orally administered at a dose of 1 mg/100 g body weight/day showed significant hypolipidemic action in normal and cholesterol fed rats. HMG CoA (3-hydroxy-3-methylglutaryl-coenzyme A) reductase, lipoprotein lipase and plasma LCAT (lecithin: cholesterol acyl-transferase) activities were found to be enhanced, while activities of glucose-6-phosphate dehydrogenase and malate dehydrogenase were significantly reduced. A significant increase in the concentrations of hepatic and faecal bile acids and faecal neutral sterols was also observed indicating a higher rate of degradation of cholesterol. In another study, diet supplementation of hypercholesterolemic rabbit's diet with *Solanum melongena* and *Solanum gilo* significantly reduced serum total cholesterol by 65.40 and 52.69% respectively, triglyceride by 47.7 and 27%, LDL cholesterol by 85 and 83% respectively (Odetola et al. 2004). They also increased significantly serum HDL by 24.7 and 25% respectively leading to increased HDL/LDL cholesterol ratio (3.37 and 3.25 respectively). This trend was also similar with liver lipid levels. The observations demonstrated that *Solanum melongena* and *Solanum gilo* had strong hypolipidemic effect.

Antiinflammatory Activity

Oral administration of *S. melongena* water extract (1, 5, 10, and 100 mg/kg) to mice one hour before induction of inflammation significantly inhibited both paw edema and vascular permeability (Han et al. 2003). The extract (10 mg/kg) significantly also inhibited PAR2 agonist-induced myeloperoxidase (MPO) activity and tumour necrosis factor (TNF)- α expression in paw tissue.

Spasmogenic Activity

Solanum melongena fresh leaf extract was found to exert a bronchospasmogenic rather than a bronchospasmolytic effect, probably through

muscarinic receptor stimulation (Mans et al. 2004). The extract was found to cause a dose-dependent increase in the force of muscle contraction of guinea pig tracheal chains and its EC_{50} value was 0.46 mg/mL. The concomitant use of acetylcholine did not significantly affect the force of contraction induced by the extract whilst histamine and salbutamol antagonise its constrictive effect by about 30% and atropine by about 60%.

Analgesic Activity

A crude alkaloidal eggplant leaf fraction exhibited significant non-narcotic analgesic effect and some CNS depression but no anticonvulsant action (Vohora et al. 1984). LD_{50} was estimated to be higher than 1 g/kg i.p. in mice.

Lipoxygenase Activity

Lipoxygenase was purified from eggplant fruit chloroplast; the enzyme was not localized in the stroma (Pérez-Gilabert et al. 2001). Eggplant lipoxygenase converted linoleic acid almost totally into the 9-hydroperoxy isomer, whereas the 13-hydroperoxy isomer was only a minor product (López-Nicolás et al. 2001). Linoleic acid aggregates were used more efficiently than monomeric linoleic acid as substrate, indicating a substrate-aggregation dependent activity.

Antigenotoxic/Antimutagenic Activity

The eggplant fruit juice exhibited an antimutagenic activity against 3-amino-1-methyl-5 H-pyrido [4,3-b]indole (Trp-P-2) induced mutagenicity in the Salmonella/microsome assay (Yoshihawa et al. 1996). In some of the fractions extracted with several organic solvents (acetone, petroleum ether, ethyl acetate, and methanol), the activity was observed. No mutagenicity or toxicity for *Salmonella typhimurium* TA98 in the presence of S9 mixture was observed with any of the extracts.

Further, lutein was isolated from the 84% methanol (methanol/water, v/v) layer, pheophorbide or chlorophyllide from the 70% methanol layer and tannins containing sugar-moieties from the water layer. Pheophytin a and b, Mg-free derivatives of chlorophyll a and b, were isolated from the petroleum ether layer as possible antimutagens. The pheophytin a with S9 mix inhibited by 30–40% the mutagenicity of Trp-P-2.

Pretreatment with higher doses of the purified eggplant anthocyanin (10 and 20 mg/kg b.w.) led to a statistically significant reduction in the frequency of micronuclei in polychromatic erythrocytes induced by cyclophosphamide (Azevedo et al. 2007). The pattern of reduction ranged from 48% to 57% independent of concentration. No apparent genotoxicity and mutagenicity was found for either the anthocyanin or delphinidin extracts.

Antiglaucoma Activity

Bolus consumption of 10 g of *S. melongena* by male Igbo volunteers was found to reduce pupil size by 23% and NPC (near point of convergence) by 9%, and increased AA (amplitude of accommodation) 22% and decreased intraocular pressure by 25% with no effect on visual acuity, and habitual phoria (Igwe et al. 2003). The miotic effect lowered the intraocular pressure appreciably and the reduced NPC which was still within normal range did not produce any vision discomfort. The increased AA and convergence excess positively correlated provided an efficient visual mechanism. The results suggested that *S. melongena* would be of benefit to patients suffering from raised intraocular pressure (glaucoma) and convergence insufficiency.

Antimalarial Activity

The *Solanum* glycoalkaloids with chacotriose (chaconine and solamargine) were more active against *Plasmodium yoelii* than those with solatriose (solanine and solasonine) (Chen et al. 2010). At a dose of 7.50 mg/kg, the parasitemia suppressions of chaconine, tomatine, solamar-

gine, solasonine and solanine were 71.38, 65.25, 64.89, 57.47 and 41.30%, respectively. Chaconine was the most active in antimalarial among the five glycoalkaloids.

Bioavailability of Eggplant Anthocyanin

Orally administered nasunins (acylated anthocyanins from eggplant peels) were quickly absorbed in their original acylated forms and maximally appeared in the rat's blood plasma after 15 min. There was no significant difference in the uptake efficiency between two nasunin isomers and both exhibited a plasma level almost identical to that of delphinidin 3-O- β -D-glucopyranoside. However, metabolites such as 4'-O-methyl analogues and extended glucuronides which were observed for delphinidin 3-O- β -D-glucopyranoside and cyanidin 3-O- β -D-glucopyranoside metabolisms were not detected in urine or blood plasma. Further, deacylated and glycolytic products of nasunins such as delphinidin 3-O- β -D-glucopyranoside or delphinidin (aglycone) were also not detected in blood plasma even after oral administration for 8 h. These results indicated that nasunins were absorbed in their original acylated forms and exhibit a bioavailability almost identical to that of nonacylated anthocyanins.

Glycosidase Inhibition Activity

Eggplant fruits and leaves were found to contain polyhydroxylated nortropane alkaloids called calystegines (Asano et al. 1997). Calystegines A3, B1, B2, and C1 were found. Calystegines B1 and C1 were found to be potent competitive inhibitors of the bovine, human, and rat β -glucosidase activities with K_i values of 150, 10, and 1.9 μ M, respectively for B1 and 15, 1.5, and 1 μ M, respectively, for C1. Calystegine B2 was a strong competitive inhibitor of the α -galactosidase activity in all the livers. Human β -xylosidase was inhibited by all four nortropanes, with calystegine C1 having a K_i of 0.13 μ M. Calystegines A3 and B2 selectively inhibited the rat liver β -glucosidase activity. The potent inhibi-

tion of mammalian β -glucosidase and α -galactosidase activities in-vitro suggests the possibility of toxicity in humans consuming large amounts of plants that contain these compounds.

Milk Clotting Activity

S. melongena fruit extract was found to have high milk clotting activity and may be a potential source for enzymes useful in dairy technology (Guiama et al. 2010).

Food Safety/Toxicological Studies

Friedman et al. (1996) found that in mice fed two *Solanum* aglycones for 7 days with the 2.4 mmol/kg diet dose, the liver weight/body weight $\times 100$, (%LW/BW) was greater than that of controls: solanidine, potato steroidal aglycone (27%) and solasodine, eggplant steroidal aglycone (8%). Under conditions of 2.4 mmol/kg diet for 28 days, the observed %LW/BW increases relative to the controls were as follows: solanidine (32%), solasodine (22%) and DHEA, non-alkaloid adrenal steroid dehydroepiandrosterone (16%)., solasodine and DHEA were equally potent and were more potent than tomatidine, aglycone from tomato. The greater %LW/BW in mice fed 2.4 mmol/kg diet solasodine or solanidine for 14 days declined to near control values if they were fed control diets for another 14 days. The increase in liver weight (hepatomegaly) induced by solanidine and solasodine was a reversible adaptive response. Further, Friedman et al. (2003) reported that after 14 days feeding, in non-pregnant mice, observed ratios of %LW/BWs were significantly greater than those of the control values as follows: solanidine, 25.5%; solasodine 16.8%; and tomatidine, 6.0%. The corresponding increases in pregnant mice were: solanidine, 5.3%; solasodine, 33.1%; tomatidine, 8.4%. For pregnant mice (a) body weight gains were less with the aglycones than with controls: solanidine, -36.1%; solasodine, -17.9%; tomatidine, -11.9%; (b) litter weights were less than controls: solanidine, -27.0%; solasodine, -15.5%; tomatidine, no difference; (c) the %LTW/BW ratio

was less than that of the controls and was significant only for solasodine, -8.7%; and (d) the average weight of the fetuses was less than the controls: solanidine, -11.2%; solasodine, -11.4%; tomatidine, no difference. Abortion of fetuses occurred in five of 24 pregnant mice on the solanidine and none on the other diets. These results could serve as a guide for the removal of the most toxic ++compounds from plant foods and have implications for food safety. Blankemeyer et al. (1998) reported that the relative potencies of glycoalkaloids, solamargine and solasonine were similar for *Xenopus laevis* frog embryo effects (survival and teratogenicities) and for membrane effects (membrane potential). Experiments with solasonine at pH 6 and 8 suggested that the unprotonated form of the glycoalkaloids appeared to be involved in the membrane effects.

Baker et al. (1989) found that hamsters administered *Solanum sarrachoides* or *S. melongena* plant material did not die and had only lesions compatible with gastric distension. Six of eight hamsters administered *S. eleagnifolium* and eight of 10 hamsters administered *S. dulcamara* died following administration of plant material and had gastric glandular mucosal necrosis and small intestinal mucosal necrosis with little inflammation. Lethality studies of α -solamargine in rats showed a dose-mortality relationship with a LD_{50} of 42 mg/kg body weight intraperitoneally (Al Chami et al. 2003). No appreciable toxic effects were observed at doses below 35 mg/kg body weight as indicated by blood parameters, enzyme levels and histological sections of kidney, liver and cardiac muscle. Alpha-solamargine did not affect the weight of the testes and epididymis or the number of spermatozoa but produced a slight irritation and congestion in the epididymis and testis at doses up to 50 mg/kg body weight.

Allergy Problems

Several cases of allergy to eggplant had been reported and in one case contact dermatitis (Kabashima and Miyachi 2004). Harish-Babu et al. (2008) reported that of 741 subjects randomly selected, 68 (9.2%) subjects reported adverse

reactions to ingestion of eggplant possibly due to the pharmacologic action of histamine and other non-protein components, rather than to specific protein allergen(s). The prevalence of IgE-mediated eggplant allergy was estimated at approximately 0.8%, with higher rates of sensitization in females. Sensitization to eggplant by skin prick test was more in atopic (16.7%) compared with non-atopic subjects (3.8%). Pramod and Venkatesh (2008), reported a case of allergy caused by ingestion of eggplant in an atopic subject. Symptoms included urticaria, itching of the throat, and hoarseness. Skin prick test was positive with 4 varieties of eggplant; however, allergen-specific immunoglobulin E was not detected. The causative allergen was a low molecular weight nonprotein secondary metabolite of less than 1 kd.

Traditional Medicinal Uses

Eggplant is also widely used for medicinal purposes in traditional medicine. Various plant parts are utilised in decoction, as powder or ash for treating ailments such as diabetes, cholera, bronchitis, dysuria, dysentery, asthma, otitis, toothache, skin infections, asthenia and haemorrhoids (Kumar and Chaudhary 2006). Eggplant is also regarded to possess narcotic, anti-asthmatic and anti-rheumatic properties. In Malaysia, ashes of the fruit had been prescribe for use in a dry hot poultice on haemorrhoids and pounded roots applied inside the nostrils for ulceration (Burkill 1966). In Ambon, the root juice was administered for difficult labour. In the Guianas, leaves mixed with stem bark is used as a remedy for dysentery. Powdered root is applied externally and taken internally to remedy bleeding and for asthma. Root sap is employed in French Guiana for tooth-ache and otitis. In Surinam, a warm frit paste is applied to painful joints.

Other Uses

In Peninsular Malaysia, the people of the Bera River used to place the prickly stems on the threshold during the first rice harvest as a form of protection against evil spirits.

Comments

Eggplant is readily established from seeds and transplanted seedlings. Studies have shown that eggplant can be asexually propagated from sodium alginate – encapsulated axillary buds on a Murashige and Skoog medium with gibberellic acid (Huda et al. 2009).

Selected References

- Aburjai T, Al-Khalil S, Abuirjeie M (1998) Vitamin D3 and its metabolites in tomato, potato, egg plant and zucchini leaves. *Phytochemistry* 49(8):2497–99
- Akanitapichat P, Phraibung K, Nuchklang K, Prompitakkul S (2010) Antioxidant and hepatoprotective activities of five eggplant varieties. *Food Chem Toxicol* 48(10):3017–21
- Al Chami L, Méndez R, Chataing B, O'Callaghan J, Usubillaga A, LaCruz L (2003) Toxicological effects of alpha-solamargine in experimental animals. *Phytother Res* 17(3):254–8
- Asano N, Kato A, Matsui K, Watson AA, Nash RJ, Molyneux RJ, Hackett L, Topping J, Winchester B (1997) The effects of calystegines isolated from edible fruits and vegetables on mammalian liver glycosidases. *Glycobiology* 7(8):1085–8
- Azevedo L, Alves de Lima PL, Gomes JC, Stringheta PC, Ribeiro DA, Salvadori DM (2007) Differential response related to genotoxicity between eggplant (*Solanum melanogena*) skin aqueous extract and its main purified anthocyanin (delphinidin) in vivo. *Food Chem Toxicol* 45(5):852–8
- Azuma K, Ohyama A, Ippoushi K, Ichiyaniagi T, Takeuchi A, Saito T, Fukuoka H (2008) Structures and antioxidant activity of anthocyanins in many accessions of eggplant and its related species. *J Agric Food Chem* 56(21):10154–9
- Backer CA, Bakhuizen van den Brink RC (1965) *Flora of Java (Spermatophytes only)*, vol 2. Noordhoff, Groningen, 641pp
- Baker DC, Keeler RF, Gaffield W (1989) Pathology in hamsters administered *Solanum* plant species that contain steroidal alkaloids. *Toxicol* 27(12):1331–7
- Blankemeyer JT, McWilliams ML, Rayburn JR, Weissenberg M, Friedman M (1998) Developmental toxicology of solamargine and solasonine glycoalkaloids in frog embryos. *Food Chem Toxicol* 36(5):383–9
- Botelho FV, Enéas LR, Cesar GC, Bizzotto CS, Tavares E, Oliveira FA, Gloria MB, Silvestre MP, Arantes RM, Alvarez-Leite JI (2004) Effects of eggplant (*Solanum melongena*) on the atherogenesis and oxidative stress in LDL receptor knock out mice (LDLR^{−/−}). *Food Chem Toxicol* 42(8):1259–67

- Burkill IH (1966) A Dictionary of the economic products of the Malay Peninsula, Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, Malaysia, vol 1 (A–H), pp 1–1240, vol 2 (I–Z), pp 1241–2444
- Chadha ML (1993) Improvement of brinjal. In: Chadha KL, Kalloo G (eds) Advances in horticulture, vol 5, Vegetable crops. Malhotra Publishing House, New Delhi, pp 105–135
- Cham BE, Daunter B (1990) Solasodine glycosides. selective cytotoxicity for cancer cells and inhibition of cytotoxicity by rhamnose in mice with sarcoma 180. *Cancer Lett* 55(3):221–5
- Chen Y, Li S, Sun F, Han H, Zhang X, Fan Y, Tai G, Zhou Y (2010) In vivo antimalarial activities of glycoalkaloids isolated from Solanaceae plants. *Pharm Biol* 48(9):1018–24
- Council of Scientific and Industrial Research (CSIR) (1972) The wealth of India. A dictionary of Indian raw materials and industrial products. (Raw materials 9). Publications and Information Directorate, New Delhi
- D'Arcy WG, Pickett K (1991) Salt water floatation of *Solanum* fruits and possible dispersal of eggplant. *Solanaceae News* 3:3
- Das S, Raychaudhuri U, Falchi M, Bertelli A, Braga PC, Das DK (2011) Cardioprotective properties of raw and cooked eggplant (*Solanum melongena* L.). *Food Funct* 2(7):395–9
- Daunay MC, Chadha ML (2004) *Solanum melongena* L. [Internet] Record from Protabase. Grubben GJH, Denton OA (eds) PROTA (Plant Resources of Tropical Africa/Ressources végétales de l'Afrique tropicale), Wageningen. <http://database.prota.org/search.htm>
- Deb DB (1989) *Solanum melongena*, *S. incanum* versus *S. insaanum* (Solanaceae). *Taxon* 38:138–9
- DeFilippis RA, Maina SL, Crepin J (2004) Medicinal plants of Guianas (Guyana, Surinam, French Guiana). Department of Botany, National Museum of Natural History, Smithsonian Institution, Washington, DC
- Ding X, Zhu FS, Li M, Gao SG (2012) Induction of apoptosis in human hepatoma SMMC-7721 cells by solamargine from *Solanum nigrum* L. *J Ethnopharmacol* 139(2):599–604
- Domino EF, Hornbach E, Demana T (1993) The nicotine content of common vegetables. *New Engl J Med* 329:437
- Farines M, Cocallemen S, Soulier J (1988) Triterpene alcohols, 4-methylsterols and 4-desmethylsterols of eggplant seed oil: a new phytosterol. *Lipids* 23(4):349–54
- Friedman M, Henika PR, Mackey BE (1996) Feeding of potato, tomato and eggplant alkaloids affects food consumption and body and liver weights in mice. *J Nutr* 126(4):989–99
- Friedman M, Henika PR, Mackey BE (2003) Effect of feeding solanidine, solasodine and tomatidine to non-pregnant and pregnant mice. *Food Chem Toxicol* 41(1):61–71
- Guiama VD, Libouga DG, Ngah E, Beka RG, Ndi KC, Maloga B, Bindzi JM, Donn P, Mbofung CM (2010) Milk-clotting potential of fruit extracts from *Solanum esculentum*, *Solanum macrocarpon* L. and *Solanum melongena*. *Afr J Biotechnol* 9(12):1797–1802
- Guimarães PR, Galvão AM, Batista CM, Azevedo GS, Oliveira RD, Lamounier RP, Freire N, Barros AM, Sakurai E, Oliveira JP, Vieira EC, Alvarez-Leite JJ (2000) Eggplant (*Solanum melongena*) infusion has a modest and transitory effect on hypercholesterolemic subjects. *Braz J Med Biol Res* 33(9):1027–36
- Han SW, Tae J, Kim JA, Kim DK, Seo GS, Yun KJ, Choi SC, Kim TH, Nah YH, Lee YM (2003) The aqueous extract of *Solanum melongena* inhibits PAR2 agonist-induced inflammation. *Clin Chim Acta* 328(1–2):39–44
- Harish Babu BN, Mahesh PA, Venkatesh YP (2008) A cross-sectional study on the prevalence of food allergy to eggplant (*Solanum melongena* L.) reveals female predominance. *Clin Exp Allergy* 38(11):1795–802
- Holland B, Unwin ID, Buss DH (1991) Vegetables, herbs and spices. Fifth supplement to McCance and Widdowson's the composition of foods. Royal Society of Chemistry, Cambridge
- Huda AKMN, Bari MA, Rahman M (2009) Asexual propagation of eggplant (*Solanum melongena* L.) through encapsulated axillary buds. *Plant Tissue Cult Biotech* 19(2):263–8
- Ibuki F, Yamada M, Tashiro M, Kanamori M (1977) An improved method for the purification of eggplant trypsin inhibitor. *J Nutr Sci Vitaminol (Tokyo)* 23(2):133–43
- Ichihyanagi T, Kashiwada Y, Shida Y, Ikeshiro Y, Kaneyuki T, Konishi T (2005) Nasunin from eggplant consists of *cis-trans* isomers of delphinidin 3-[4-(*p*-coumaroyl)-L-rhamnosyl (1→6)glucopyranoside]-5-glucopyranoside. *J Agric Food Chem* 53(24):9472–7
- Ichihyanagi T, Terahara N, Rahman MM, Konishi T (2006) Gastrointestinal uptake of nasunin, acylated anthocyanin in eggplant. *J Agric Food Chem* 54(15):5306–12
- Igwe SA, Akunyili DN, Ogbogu C (2003) Effects of *Solanum melongena* (garden egg) on some visual functions of visually active Igbos of Nigeria. *J Ethnopharmacol* 86(2–3):135–8
- Ikeda T, Ando J, Miyazono A et al (2000) Anti-herpes virus activity of *Solanum* steroidal glycosides. *Biol Pharm Bull* 23:363–4
- Itoh T, Tamura T, Matsumoto T (1977a) 4-desmethylsterols in the seeds of Solanaceae. *Steroids* 30(3):425–33
- Itoh T, Tamura T, Matsumoto T (1977b) Triterpene alcohols in the seeds of Solanaceae. *Phytochemistry* 16(11):1973–6
- Itoh T, Ishii T, Tamura T (1978) Matsumoto T (1978) Four new and other 4 α -methylsterols in the seeds of Solanaceae. *Phytochemistry* 17(5):971–7
- Itoh T, Tamura T, Sagawa M, Tamura T, Matsumoto T (1980) 24(R)-ethyllophenol from *Solanum melongena* seeds. *Phytochemistry* 19(11):2491–2
- Kabashima K, Miyachi Y (2004) Contact dermatitis due to eggplant. *Contact Dermatitis* 50(2):101–2

- Karihaloo JL, Gottlieb LD (1995) Allozyme variation in the eggplant, *Solanum melongena* L. (Solanaceae). Theor Appl Genet 90:578–83
- Kintya PK, Shvets SA (1984) Steroid glycosides of *Solanum melongena* seeds. structure of melongosides A,B, E, F, G and H. Khim Prii Soed 5:610–614, Chem Nat Comp 20(5):575–8
- Kintya PK, Shvets SA (1985) Melongoside L and melongoside M, steroidal saponins from *Solanum melongena* seeds. Phytochemistry 24(1):197–8
- Kintya PK, Shvets SA (2001) Melongosides n, o and p: steroidal saponins from seeds of *Solanum melongena*. Phytochemistry 24(7):1567–9
- Kritchevsky D, Tepper SA, Story JA (1975) Influence of an eggplant (*Solanum melongena*) preparation on cholesterol metabolism in rats. Exp Pathol (Jena) 10(3–4):180–3
- Kumar B, Chaudhary BR (2006) *Solanum melongena* and wild allies: potential birth control resource. Vegetos 19(1–2):81–83
- Kuo KW, Hsu SH, Li YP, Lin WL, Liu LF, Chang LC, Lin CC, Lin CN, Sheu HM (2000) Anticancer activity evaluation of the *solanum* glycoalkaloid solamargine. Triggering apoptosis in human hepatoma cells. Biochem Pharmacol 60(12):1865–73
- Kwon YI, Apostolidis E, Shetty K (2008) In vitro studies of eggplant (*Solanum melongena*) phenolics as inhibitors of key enzymes relevant for type 2 diabetes and hypertension. Bioresour Technol 99(8):2981–8
- Lee KR, Kozukue N, Han JS, Park JH, Chang EY, Baek EJ, Chang JS, Friedman M (2004) Glycoalkaloids and metabolites inhibit the growth of human colon (HT29) and liver (HepG2) cancer cells. J Agric Food Chem 52:2832–39
- Lester RN, Hasan SMZ (1991) Origin and domestication of the brinjal egg-plant, *Solanum melongena* from *S. incanum*, in Africa and Asia (pp 369–387). In: Hawkes JG, Leste, RN, Nee M, Estrada-R N (eds) Solanaceae III: Taxonomy, chemistry, evolution. Royal Bot. Gardens, Kew, 483 pp
- Liang CH, Liu LF, Shiu LY, Huang YS, Chang LC, Kuo KW (2004) Action of solamargine on TNFs and cisplatin-resistant human lung cancer cells. Biochem Biophys Res Commun 322(3):751–8
- Liang CH, Shiu LY, Chang LC, Sheu HM, Kuo KW (2007) Solamargine upregulation of Fas, downregulation of HER2, and enhancement of cytotoxicity using epirubicin in NSCLC cells. Mol Nutr Food Res 51:999–1005
- Liang CH, Shiu LY, Chang LC, Sheu HM, Tsai EM, Kuo KW (2008) Solamargine enhances HER2 expression and increases the susceptibility of human lung cancer H661 and H69 cells to trastuzumab and epirubicin. Chem Res Toxicol 21(2):393–9
- Liu LF, Liang CH, Shiu LY, Lin WL, Lin CC, Kuo KW (2004) Action of solamargine on human lung cancer cells—enhancement of the susceptibility of cancer cells to TNFs. FEBS Lett 577(1–2):67–74
- Lo Scalzo R, Fibiani M, Mennella G, Rotino GL, Dal Sasso M, Culici M, Spallino A, Braga PC (2010) Thermal treatment of eggplant (*Solanum melongena* L.) increases the antioxidant content and the inhibitory effect on human neutrophil burst. J Agric Food Chem 58(6):3371–9
- López-Nicolás JM, Pérez-Gilabert M, García-Carmona F (2001) Eggplant lipoxygenase (*Solanum melongena*): product characterization and effect of physicochemical properties of linoleic acid on the enzymatic activity. J Agric Food Chem 49(1):433–8
- Luthria DL, Mukhopadhyay S (2006) Influence of sample preparation on assay of phenolic acids from eggplant. J Agric Food Chem 54(1):41–7
- Mans DR, Toelsie J, Mohan S, Jurgens S, Muhringen M, Illes S, Macnack R, Bipat R (2004) Spasmogenic effect of a *Solanum melongena* leaf extract on guinea pig tracheal chains and its possible mechanism(s). J Ethnopharmacol 95(2–3):329–33
- Matsubara K, Kaneyuki T, Miyake T, Mori M (2005) Antiangiogenic activity of nasunin, an antioxidant anthocyanin, in eggplant peels. J Agric Food Chem 53(16):6272–5
- Meyer RS, Karol KG, Little DP, Nee MH, Litt A (2012) Phylogeographic relationships among Asian eggplants and new perspectives on eggplant domestication. Mol Phylogenet Evol 63(3):685–701
- Milner SE, Brunton NP, Jones PW, O' Brien NM, Collins SG, Maguire AR (2011) Bioactivities of glycoalkaloids and their aglycones from *Solanum* species. J Agric Food Chem 59(8):3454–84
- Nagase H, Sasaki K, Kito H, Haga A, Sato T (1998) Inhibitory effect of delphinidin from *Solanum melongena* on human fibrosarcoma HT-1080 invasiveness in vitro. Planta Med 64(3):216–9
- Nisha P, Abdul Nazar P, Jayamurthy P (2009) A comparative study on antioxidant activities of different varieties of *Solanum melongena*. Food Chem Toxicol 47(10):2640–4
- Noda Y, Kneyuki T, Igarashi K, Mori A, Packer L (1998) Antioxidant activity of nasunin, an anthocyanin in eggplant. Res Commun Mol Pathol Pharmacol 102(2):175–87
- Noda Y, Kneyuki T, Igarashi K, Mori A, Packer L (2000) Antioxidant activity of nasunin, an anthocyanin in eggplant peels. Toxicology 148(2–3):119–23
- Ochse JJ, Bakhuizen van den Brink RC (1980) Vegetables of the Dutch Indies, 3rd Edition. Ascher & Co., Amsterdam, 1016 pp
- Odetola AA, Iranloye YO, Akinloye O (2004) Hypolipidaemic potentials of *Solanum melongena* and *Solanum gilo* on hypercholesterolemic rabbits. Pak J Nutr 3(3):180–187
- PBI Solanum Project (2011) Solanaceae source. <http://www.nhm.ac.uk/solanaceaesource/>. Accessed 10 Nov 2011
- Pérez-Gilabert M, López-Nicolás JM, García Carmona F (2001) Purification of a novel lipoxygenase from eggplant (*Solanum melongena*) fruit chloroplasts. Physiol Plant 111(3):276–282

- Praça JM, Thomaz A, Caramelli B (2004) Eggplant (*Solanum melongena*) extract does not alter serum lipid levels. *Arq Bras Cardiol* 82(3):269–76
- Pramod SN, Venkatesh YP (2008) Allergy to eggplant (*Solanum melongena*) caused by a putative secondary metabolite. *J Investig Allergol Clin Immunol* 18(1):59–62
- Purseglove JW (1968) Tropical crops: dicotyledons, vol 1 & 2. Longman, London, 719pp
- Sadilova E, Stintzing FC, Carle R (2006) Anthocyanins, colour and antioxidant properties of eggplant (*Solanum melongena* L.) and violet pepper (*Capsicum annuum* L.) peel extracts. *Z Naturforsch [C]* 61(7–8):527–35
- Sánchez-Mata MC, Yokoyama WE, Hong YJ, Prohens J (2010) Alpha-solasonine and alpha-solamargine contents of gboma (*Solanum macrocarpon* L.) and scarlet (*Solanum aethiopicum* L.) eggplants. *J Agric Food Chem* 58(9):5502–8
- Shahjahan M, Purushothaman A, Kathiravan MN, Meenatchi P, Saravanan S, Thangaraj A (2012) Synergistic effects of *Solanum trilobatum* and *Solanum melongena* extract against β -galactosamine induced hepatic damage in rats. *Am J Biopharm Biochem Life Sci* 1(Supp 1):A36
- Shen G, Van Kiem P, Cai XF, Li G, Dat NT, Choi YA, Lee YM, Park YK, Kim YH (2005) Solanoflavone, a new biflavonol glycoside from *Solanum melongena*: seeking for anti-inflammatory components. *Arch Pharm Res* 28(6):657–9
- Shiu LY, Chang LC, Liang CH, Huang YS, Sheu HM, Kuo KW (2007) Solamargine induces apoptosis and sensitizes breast cancer cells to cisplatin. *Food Chem Toxicol* 45(11):2155–64
- Shiu LY, Liang CH, Chang LC, Sheu HM, Tsai EM, Kuo KW (2009) Solamargine induces apoptosis and enhances susceptibility to trastuzumab and epirubicin in breast cancer cells with low or high expression levels of HER2/neu. *Biosci Rep* 29(1):35–45
- Silva GE, Takahashi MH, Eik Filho W, Albino CC, Tasim GE, Serri Lde A, Assef AH, Cortez DA, Bazotte RB (2004) Absence of hypolipidemic effect of *Solanum melongena* L. (eggplant) on hyperlipidemic patients. *Arq Bras Endocrinol Metabol* 48(3):368–73, In Portuguese
- Sudheesh S, Presannakumar G, Vijayakumar S, Vijayalakshmi NR (1997) Hypolipidemic effect of flavonoids from *Solanum melongena*. *Plant Foods Hum Nutr* 51(4):321–30
- Sudheesh S, Sandhya C, Sarah Koshy A, Vijayalakshmi NR (1999) Antioxidant activity of flavonoids from *Solanum melongena*. *Phytother Res* 13(5):393–6
- Sun L, Zhao Y, Yuan H, Li X, Cheng A, Lou H (2011) Solamargine, a steroidal alkaloid glycoside, induces oncosis in human K562 leukemia and squamous cell carcinoma KB cells. *Cancer Chemother Pharmacol* 67(4):813–21
- Sutarno H, Danimihardja S, Grubben GJH (1994) *Solanum melongena* L. In: Siemonsma JS, Piluek K (eds) Plant resources of South-East Asia, vol 8, Vegetables. Pudoc, Wageningen, pp 255–258
- Thorne HV, Clarke GF, Skuce R (1985) The inactivation of herpes simplex virus by some Solanaceae glycoalkaloids. *Antiviral Res* 5(6):335–43
- U.S. Department of Agriculture, Agricultural Research Service (USDA) (2012) USDA National Nutrient Database for Standard Reference, Release 25. Nutrient Data Laboratory Home Page, <http://www.ars.usda.gov/ba/bhnrc/ndl>
- Vohora SB, Kumar I, Khan MS (1984) Effect of alkaloids of *Solanum melongena* on the central nervous system. *J Ethnopharmacol* 11(3):331–6
- Wees TL, Bohs L (2010) Eggplant origins: out of Africa, into the orient. *Taxon* 59(1):49–56
- Whitaker BD, Stommel JR (2003) Distribution of hydroxycinnamic acid conjugates in fruit of commercial eggplant (*Solanum melongena* L.) cultivars. *Agric Food Chem* 51(11):3448–54
- Wikipedia (2012) Eggplant. <http://en.wikipedia.org/wiki/Eggplant>
- Yoshikawa K, Inagaki K, Terashita T, Shishiyama J, Kuo S, Shankel DM (1996) Antimutagenic activity of extracts from Japanese eggplant. *Mut Res* 371(1–2): 65–71

Solanum muricatum

Scientific Name

Solanum muricatum Aiton.

Synonyms

Solanum guatemalense Hort. ex Bitter, *Solanum hebeophorum* Dunal, *Solanum longifolium* Sessé & Moc., *Solanum muricatum* forma *glaberrimum* Correll, *Solanum muricatum* var. *dissectum* Dunal, *Solanum muricatum* var. *papillosistylum* Bitter, *Solanum muricatum* var. *parvifolium* Kunth, *Solanum muricatum* var. *popayanum* Bitter, *Solanum muricatum* var. *praecedens* Bitter, *Solanum muricatum* var. *protogenum* Bitter, *Solanum muricatum* var. *teleutogenum* Bitter, *Solanum pedunculatum* Roem. & Schult, *Solanum scabrum* Lam., *Solanum variegatum* Ruiz & Pavon, *Solanum wallisii* Carrière.

Family

Solanaceae

Common/English Names

Honey Pear, Melon Pear, Melon Shrub, Mellow Fruit, Pepino, Pepino Dulce, Pepino Melon, Peruvian Pepino, Sweet Cucumber, Sweet Pepino, Tree Melon.

Vernacular Names

Aymara: Kachuma;

Bolivia: Pepino, Pepino Blanco, Pepino Dulce;

Brazil: Melão-Andino, Melão-De-Árvore, Tomateiro-Francês ([Portuguese](#));

Canary Islands: Pera Melón;

Chinese: Xiang Gua Quie;

Colombia: Pepino, Pepino Amarillo, Pepino Blanco, Pepino De Agua, Pepino De Fruta, Pepino Dulce, Pepino Morado, Pepino Redondo;

Costa Rica: Manguena;

Cuba: Huevo De Gato, Melón Pera;

Danish: Melonpaere, Pepino;

Dutch: Applemeloen, Meloen Peer, Peermelon, Pepino;

Ecuador: Pepino De Chupar;

Ethiopia: Ambarut;

French: Melon Poire, Pepino, Poire-Melon;

German: Melonbirne, Melonenbirne, Pepino;

Italian: Pera-Melone, Pepino;

Japanese: Pepiino;

Peru: Kachuma, Mataserrana, Pepino Blanco,

Pepino De Las Indias, Pepino De La Tierra;

Portuguese: Pepino Doce, Pêra-Melão, Tomateiro Frances;

Quechua: Cahum, Xachum;

Russian: Dynnaja Gruša;

Spanish: Pepino, Peramelon, Pepino Dulce;

Venezuela: Pepino Mango.

Origin/Distribution

Pepino originates from the Andean region and has been domesticated since pre-Hispanic times. The original cultivation extended along the Andes, from southern Colombia to Bolivia and the Peruvian coast and was subsequently introduced into Central America. It is now cultivated pantropically at high altitudes and also in subtropical countries or in glass houses.

Agroecology

It is a cool climate crop that grows in the inter Andean valleys and on the western slopes, from 900–2,800 m, up to 3,300 m in Colombia, and from sea level in Chile, New Zealand and California. The climatic characteristics described correspond to the high part of the subtropical dry forest and the low dry mountain forest or to the high Yungas and Quechua of Peru. Reported latitudinal range is 0–40° with the optimum between 0° and 35°. It is also grown in the highlands in Malaysia and Indonesia in the tropics. Its temperature range for growth is 10–30°C with the optimum between 15°C and 25°C. It is quite tolerant of frost. It is well adapted to high relative humidity, mists and drizzle. It requires an annual precipitation range for growth of 500–2,000 mm with the optimum between 800 and 1,400 mm. It thrives in well-drained, loamy soils but will

grow in most soils but is intolerant of saline soils. Its optimum pH range is 6–7.5.

Edible Plant Parts and Uses

Pulp of the ripe fruit is eaten raw, fresh as dessert fruit or in fruit salad. The early ripened fruit is also cooked as vegetable in stews, canned, preserved or made into conserves. The fruit has moderate appeal but has good potential for commercial production and exploitation. Also, pepino is harvested at an early stage of ripening for shipping purposes.

Botany

A herbaceous short-lived, much branched, ever-green, perennial shrub growing to 1.2 m high with a woody stem base (Plate 3). Leaves are alternate, green, simple or pinnate (one to three pairs of folioles) and elliptical-lanceolate, lanceolate or ovate with strigose or glabrous laminae and folioles (Plates 1–3). The inflorescence is subterminal with few flowers. The flowers are pentamerous, the calyx persists on the fruit and the actinomorphic corolla is 2 cm across and violet in colour with whitish margins (Plate 1). The stamens are shorter than the corolla, the anthers are yellow, connivent and dehiscent through apical pores. The style emerges slightly in between the anthers. Fruit ovoid to ellipsoid to



Plate 1 Pepino flowers and leaves

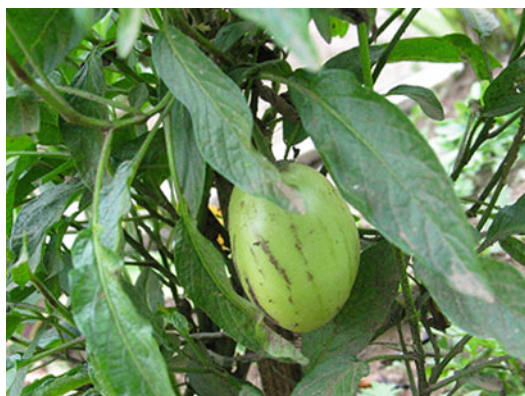


Plate 2 Immature pepino fruit



Plate 4 Harvested large ellipsoid pepino fruit



Plate 3 Ripening ovoid pepino fruits on the plant

subspherical, 5–20 cm long, of variable form, green, white or creamy white, with purple streaks (Plates 2–4) and yellowish within, and pleasant in aroma and taste, pulp very juicy and slightly sweet flavour. It may be with or without seeds.

Nutritive/Medicinal Properties

Pepino fruit is not nutrient rich and has been reported to contain 90% water, 7% carbohydrates and 29 mg/100 g of Vitamin C and iodine (Hernández Bermejo and León 1994). It is regarded for its diuretic properties and it is recommended for treating goitre as it is rich in iodine. Pepino fruit at the green stage was found to have the following nutrient composition (in g/kg): moisture 907 g, Brix 6.53%, total sugars 70.1 g, neutral detergent fibre 10.71 g, pectins 0.55 g; and ripe stage: moisture 915 g, Brix 7.97%, total sugars 66.3 g, neutral detergent fibre 3.61, and pectins 1.23 g (Sanchez et al. 2000). Pepino fruits were found to contain higher amounts of fructose than glucose and contents of both did not change dramatically during ripening. However, sucrose rose sharply as ripening progressed, being low in green fruits. Ripening process was characterised by a decline in insoluble fibres with a concomitant increase in total sugars and sucrose. Composition characteristics of pepino fruit cv “round Sweet” at the green stage were reported as: moisture 90.91%, soluble solid content SSC (°Brix) 6.40, titratable acidity 0.246 mg/100 g, pH 4.74, maturity index 26.02, ascorbic acid 12.98 mg/100 g, soluble proteins 0.112 mg/100 g, and total proteins 0.928 mg/100 g (Gonzales et al. 2000). At the ripe stage, the composition characteristics were: moisture 91.051%, soluble solid content SSC (°Brix) 7.33, titratable acidity 0.203 mg/100 g,

pH 5.4, maturity index 36.10, ascorbic acid 29.39 mg/100 g, soluble proteins 0.072 mg/100 g, and total proteins 0.920 mg/100 g.

In a more recent study, proximate nutrient composition of raw (early ripe) pepino fruit was reported as: moisture 93.80%, protein 0.93%, ash 0.46%, oil 0.05%, sugar 4.48%, glucose 34.6%, fructose 43.2%, sucrose 22.2%, NDF (neutral detergent fibre) 6.27 g/kg, and ADF (acid detergent fibre) 5.12 g/kg, (Yalçın 2010). Proximate nutrient composition of mature ripe pepino fruit was reported as: moisture 91.45%, protein 0.78%, ash 0.47%, oil 0.09%, sugar 7.03%, glucose 20.2%, fructose 27.9%, sucrose 55.7%, NDF 6.272.28 g/kg, and ADF 1.48 g/kg. Sugar was found to be the main component of dry matter especially in mature fruit (7.03%). NDF comprised cell walls with polymeric carbohydrate such as hemicelluloses, cellulose, etc. ADF also contained these carbohydrates except hemicelluloses. Hemicellulose were maintained during early ripening but began to decrease as pepino fruit entered the late ripening stage. These values indicated that the ripening period had a decreasing effect on the polymeric carbohydrates especially cellulose and hemicellulose. The breakdown of polymeric carbohydrates, especially hemicellulose, resulted in weakening of cell walls leading to fruit softening. High sucrose content was found responsible for its sweet taste and justifies its use as a dessert fruit, in contrast to the raw fruits which are more suitable for use in salads as a vegetable.

Shiota et al. (1988) identified up to 30 volatile compounds from three cultivars of pepino. The main constituents of the volatile fraction in pepino were 3-methylbut-2-en-1-ol, 3-methylbut-3-en-1-ol, (Z)-non-6-en-1-ol, 3-methylbut-2-en-1-yl acetate, 3-methylbut-3-en-1-yl acetate, butyl acetate, and hexyl acetate (all of them related to fruity aromas) and a series of linear C9 aldehydes (related to green-herbaceous odours). Ruiz-Bevia et al. (2002) confirmed that 3-methyl-2-buten-1-ol, 3-methyl-3-buten-1-ol and their acetates were also major components of pepino fruit from 2 cultivars. Rodríguez-Burruezo et al. (2004) found the volatile components of pepino fruit to comprise 24 esters (acetates, 3-methylbutanoates, and 3-methylbut-2-enoates), 7 aldehydes (especially hexenals and non-

enals), 6 ketones, 9 alcohols, 3 lactones, 2 terpenes, β -damascenone, and mesifurane (2,5-dimethyl-4-methoxy-3(2H)-furanone). Among these compounds, 17 were found to contribute significantly to pepino aroma. Odour-contributing volatiles (OCVs) were assigned to three groups according to their odour quality: fruity fresh (acetates and prenol) comprising butyl acetate, pentyl acetate, hexyl acetate, 3-methylbutyl acetate, 3-methylbut-2-en-1-yl acetate, 3-methylbut-3-en-1-yl acetate; green vegetable (C6 and C9 aldehydes) comprising hexanal, (E)-hex-2-enal, (E)-hex-2-enal, (E)-non-2-enal, (Z)-non-6-enal; and exotic comprising lactones – γ -nonalactone (4-nonanolide), γ -decalactone (4-decanolide), massoia lactone (5-dec-2-enolid); mesifuran, and β -damascenone.

Convective drying of pepino fruits at temperatures of (50, 60, 70, 80 and 90°C) resulted in important reductions of proteins and crude fibres (Di Scala et al. 2011). Discoloration of fruit was noticeable for all treatments due to effects of non-enzymatic browning and changes in chromatic coordinates leading to a modification of the original colour. An increase of drying temperature resulted in a considerable reduction of both vitamin C and total phenolic initial contents. Softening of the dried product was observed for all the treatments indicating structural modifications of the fruit due to thermal process. Antioxidant activity showed an important decrease especially at low temperatures (e.g. 50°C).

Antioxidant Activity

The ethyl acetate extract of ripe pepino fruit exhibited good scavenging activity with EC_{50} values of 0.16, 0.82, 39.51, 9.53, 1.06 and 0.26 mg/mL for DPPH, reducing power, iron chelation, ABTS radical, FRAP and hydroxyl radical respectively (Sudha et al. 2011). The antioxidant characteristics were postulate to be attributable to the presence of polyphenols in the fruit extracts. The total phenol and flavonoid content of pepino extract were found to be 20.43 mg GAE/g dry weight, 53.85 mg RE/g dry weight. The total antioxidant capacity observed in the ripe ethyl acetate extract of pepino fruit was 238.27 nM GAE/g.

Anticancer Activity

Studies showed pepino to have anticancer activity (Ren and Tang 1999). The pepino extract exhibited selective cytotoxic activity against all the human tumour cell lines being tested that included: prostate (PC3, DU145), stomach (MKN45), liver (QGY-7721, SK-HEP-1), breast (MDA-MB-435), ovarian (OVCAR), colon (HT29) and lung (NCI-H209) cancer cells; NHP (prostate), HUVEC (umbilical vein endothelial cell), and WI-38 (lung diploid fibroblasts) normal cells with LD₅₀ values from 561–825 µg/mL. The extract showed a much lower cytotoxicity to NHP, HUVEC and WI-38 normal cell lines with LD₅₀ value of 2.8–3.2 mg/mL which was 3–6 fold higher than on tumour cells. Injection of pepino extract (100 µg) directly into tumour mass was found to reduce the tumour volume dramatically in nude mice inoculated with MKN45 gastric cancer cells. The pepino extract mediated tumour growth inhibition through induction of apoptotic cell death, as manifested by typical apoptotic morphology, DNA ladder formation and PARP (poly ADP ribose polymerase) cleavage assay.

Antidiabetic Activity

Studies in diabetic mice suggested that pepino aqueous extract (PAE) could attenuate the progression of diabetes via its antioxidative, anti-inflammatory and antiglycative effects (Hsu et al. 2011). Aqueous and ethanol pepino extracts had similar levels of total phenolic acids, but PAE had a higher content of ascorbic acid and total flavonoids than the ethanol extract. PAE treatments with pepino extract at 2% and 4% administered for 5 weeks significantly lowered plasma glucose level but only the 4% PAE significantly elevated plasma insulin level. PAE treatments significantly decreased the levels of malonyldialdehyde and reactive oxygen species in kidney and significantly reduced oxidised glutathione formation, increased glutathione level, and retained renal glutathione peroxidase and catalase activities. PAE treatments at 2% and 4% significantly lowered renal interleukin (IL)-6 and

tumour necrosis factor- α levels. Also the 4% treatments significantly diminished renal IL-1 β and levels of monocyte chemoattractant protein-1 and significantly decreased aldose reductase activity and sorbitol production in the kidney.

Traditional Medicinal Uses

The Spanish have been reported to use the fruit juice mixed with pink ointment against kidney heat (Prohens et al. 1996). The fruit is also regarded as a good ascorbatic.

Other Uses

Pepino (*Solanum muricatum*) was found to be a very good source for α -galactosidase (Şen et al. 2011). Three-phase partitioning was found to be a very rapid, simple and highly efficient method of bioseparation of pepino α -galactosidase making the enzyme a good candidate for industrial applications.

Comments

Commercial pepino crops using advanced production technology are occurring in Chile, New Zealand and the United States (California) as a result of pepino's acceptance on the North American, European and Japanese markets.

Selected References

- Anderson GJ, Jansen RK, Kim Y (1996) The origin and relationships of the pepino, *Solanum muricatum* (Solanaceae): DNA restriction fragment evidence. *Econ Bot* 50:369–80
- Di Scala K, Vega-Gálvez A, Uribe E, Oyanadel R, Miranda M, Vergara J, Quispe I, Lemus-Mondaca R (2011) Changes of quality characteristics of pepino fruit (*Solanum muricatum* Ait) during convective drying. *Int J Food Sci Technol* 46:746–53
- Gonzales M, Camara M, Prohens J, Ruiz JJ, Torija E, Nuez F (2000) Colour and composition of improved pepino cultivars at three ripening stages. *Gartenbauwissenschaft* 65:83–87

- Hernández Bermejo JE, León J (eds) (1994) Neglected crops 1492 from a different perspective. FAO Plant Production and Protection Series, No.26. Food and Agriculture Organization of the United Nations, Rome
- Hsu CC, Guo YR, Wang ZH, Yin MC (2011) Protective effects of an aqueous extract from pepino (*Solanum muricatum* Ait.) in diabetic mice. J Sci Food Agric 91(8):1517–22
- McBride JF (1962) Solanaceae. In: Flora of Peru, vol XIII, Part V-B No I. Field Museum of Natural History, Chicago
- National Research Council (USA) (1990) The lost crops of the Incas: little-known plants of the Andes with promise for worldwide cultivation. National Academy Press, Washington, DC
- Prohens J, Ruiz JJ, Nuez F (1996) The pepino (*Solanum muricatum*, Solanaceae): a “new” crop with a history. Econ Bot 50:355–68
- Ren W, Tang DG (1999) Extract of *Solanum muricatum* (pepino/CSG) inhibits tumour growth by inducing apoptosis. Anticancer Res 19(1A):403–8
- Rodríguez-Burruezo A, Kollmannsberger H, Prohens J, Nitz S, Nuez F (2004) Analysis of the volatile aroma constituents of parental and hybrid clones of pepino (*Solanum muricatum*). J Agric Food Chem 52(18): 5663–9
- Ruiz-Bevia F, Font A, Garcia AN, Blasco P, Ruiz JJ (2002) Quantitative analysis of the volatile aroma components of pepino fruit by purge- and- trap and gas chromatography. J Sci Food Agric 82(10):1182–8
- Sanchez M, Camara M, Prohens J, Ruiz JJ, Torija E, Nuez F (2000) Variation in carbohydrate content during ripening in two clones of pepino. J Sci Food Agric 80: 1985–91
- Şen A, Eryılmaz M, Bayraktar H, Önal S (2011) Purification of α -galactosidase from pepino (*Solanum muricatum*) by three-phase partitioning. Sep Purif Technol 85: 130–6
- Shiota H, Young H, Paterson VJ, Irie M (1988) Volatile aroma constituents of pepino fruit. J Sci Food Agric 43:343–54
- Sudha G, Priya MS, Shree RI, Vadivukkarasi S (2011) Antioxidant activity of ripe pepino fruit (*Solanum muricatum* Aiton). Int J Pharm Pharm Sci 3(3): 257–61
- Yalçın H (2010) Effect of ripening period on composition of pepino (*Solanum muricatum*) fruit grown in Turkey. Afr J Biotechnol 9(25):3901–3

Solanum nigrum

Scientific Name

Solanum nigrum L.

Family

Solanaceae

Synonyms

Solanum cestrophyllum Dunal, *Solanum decipiens* Opiz, *Solanum dillenii* Schult., *Solanum humile* Bernh., *Solanum judaicum* Besser, *Solanum morella* Desv., *Solanum morella* subsp. *nigrum* (L.) Rouy, *Solanum moschatum* J.Presl, *Solanum nigrum* forma *luridum* Wessely, *Solanum nigrum* subsp. *chlorocarpum* (Spenn) Arcangeli,

Solanum nigrum subsp. *dillenii* (Schult.) Nyman, *Solanum nigrum* subsp. *humile* (Bernh.) Marzell, *Solanum nigrum* subsp. *luteovirescens* (C.C.Gmelin) Kirschleger, *Solanum nigrum* subsp. *schultesii* (Opiz) Wessely, *Solanum nigrum* var. *atriplicifolium* G. Mey., *Solanum nigrum* var. *dillenii* (Schult.) A.Gray, *Solanum papilionaceum* Dum.Cours., *Solanum pseudoflavum* Pojark., *Solanum schultesii* Opiz, *Solanum suffruticosum* Schousboe ex Willd., *Solanum vulgare* Hegetschw., *Solanum vulgatum* var. *chlorocarpum* Spenn., *Solanum vulgatum* var. *nigrum* (L.) Spenn.

Common/English Names

Annual Nightshade, Blackberry, Black Berry Nightshade, Black Fruited Nightshade, Black Nightshade, Common Nightshade, Deadly Nightshade, Garden Huckleberry, Garden Nightshade, Harsh, Hound's Berry, Inkberry, Nightshade, Nightshade Black-Berry, Petty Morel, Poisonberry, Potato Bush, Tomato Bush, Wild Currants.

Vernacular Names

Arabic: Anab-UI-Thalab, Anab-Us-Salab, Anb-Us-Salap, Anbulzahalab, 'Enab Edh Dhi'b, 'Enab Eth Tha'lab, Enab-UI-Thalab, Enabus Salab, Makoh, Ribriq;

Argentina: Yerba Mora;

Bangladesh: Gurki;

Brazil: Erva-moura, Maria-preta, Maria-pretinha, Pimenta-De-Galinha;

Burmese: Baung-Laung-Nyo;

Cameroon: Kumbo (Banso), Ngah-nyi kob keh i lah bomnyah (Bali);

Chinese: Long Kui, Lung Kuei, Hei Daun Dou, Hei Tuan Tou;

Columbia: Yerba Mora;

Costa Rica: Yerba Mora;

Czech: Lilek Černý, Lilek Černý Pravý;

Dutch: Zwarte Nachtschade, Zwarte Nachtschade Soort;

Eastonian: Must Maavits;

Egypt: Enab El-Dieb;

El Salvador: Yerba Mora;

Ethiopia: Dime People Eat;

Esperanto: Solano Nigra;

Fijian: Black Nightshade, Boro Ni Veiwere, Boro Ni Yaloki Ni Gata, Malahome;

Finnish: Mustakoiiso;

French: Brède Martin, Crève-Chien, Morelle À Fruits Noirs, Morelle Commune, Morelle Des Jardins, Morelle Noire, Morelle Vert Jaune, Tue-Chien;

Gaelic: Fuath Dubh;

German: Hundebein, Hundsbeere, Hundskraut, Mondscheinkraut, Nachtbeere, Nachtschaden, Nachtkraut, Saukraut, Sautod, Schwarzer Nachtschatten, Teufelskirsch, Wolfstraube;

Ghana: Bachinia (Twi);

Hungarian: Fekete Csucsor, Fekete Ebszölő;

Icelandic: Nátskuggajurt;

India: Lachkochi, Pichkati (Assamese), Gurkamai, Kakmachi (Bengali), Kajmaas Makoi, Kankni, Kayankothi, Pilak (Dogri), Piludi (Gujarati), Chirpoti, Gurkamai, Gurkkamai, Kabaiya, Kala-Mako, Kali-Papotan, Kamuni, Mako, Makoi, Makoy, Mukko, Palpotan, Uda-Mako (Hindu), Ganike, Kakamachi Gida, Kakarundi, Kakmunchi, Kanchi, Kare-Ganike, Kare-Kanchi, Karee Kaachi, Karikaachi Gida, Kempu Kaachi, Sunde Kaachi (Kannada), Karimtakali, Karintakali, Karuppu-Manattakali, Manattakali, Manattakali, Manattan-Kanni, Tudavalam (Malayalam), Leipungkhangga (Manipuri), Ghati, Kamchi, Kamoni, Kangani, Laghukavali, Meko, Nakmachi (Marathi), Anhling (Mizoram), Makhoi (Rajasthan), Bahuphala, Bahutikta, Dhvankshamachi, Ghanaghana, Guchhaphala, Jaghenephala, Kaka, Kakahva, Kakamachi, Kakamaci, Kakamata, Kakini, Kakmachi, Kamatta, Katuphala, Kovidaraha,

Krishnakovidaraha, Kushthaghni, Rasayani, Sarvatikta, Sundari, Svadupaka, Vayasavha, Vayasi (Sanskrit), Cerunti, Ceruntika, Ceruntikaceti, Cirutakkali, Icuvaranaci, Irekulicaceti, Irekulicam, Kakaci, Kakam, Kakamaci, Kakamaral, Kakamaram, Kakamaram, Kakateri, Kali, Kalika, Kalikaceti, Kalikam, Kaliram, Kamaratam, Kamataceti, Kamatam, Kanikam, Kankaicarri, Kannikaceti, Kannikakaliceti, Kannikam, Karceni, Karmanakkali, Karmanittakkali, Karumanattakkali, Karuppu-Manattakkali, Karuppumanattakkali, Katteni, Katuracatti, Kutapalai, Kuttattakkali, Kuttikatakkali, Kuttittakkali, Kuvacavam, Leccukaceti, Manat Takkali, Manatakkali, Manathakali, Manathakkali, Manattak-Kali, Manattakkali, Mancara, Mancarakkaliceti, Mani Thakkaali, Manikkali, Manithakkali, Manittakkali, Milagu-Takkali, Milagutakkali, Milakutakkali, Milakuttakkali, Munatakali, Munna-Takali-Pullum, Nacival, Nakatamani, Nalvarotayam, Narumanattakkali, Narumanattakkaliceti, Nateni, Natenikaceti, Natenikam, Niranamanapalatti, Palakanaikkattal, Palakanaikkattan, Pillaittakkali, Pokitturitaceti, Pokitturittam, Pucitam, Sukitti, Tanalarri, Ukkiram, Ulakamata, Ulakamata, Vatatakali, Vatatakaliceti, Vayacam, Veci, Venmilakutakkali, Venmilakuttakkali, Vennalarri, Vitaikkantam, Vitaikkantam, Yamai, Yampalkantan (Tamil), Gajjucettu, Gajuchettu, Kaachi, Kacci, Kaccipandu, Kachi, Kakamachi, Kamanchi, Kamanchi-Chettu, Kamanci, Kanchi-Chettu, Kanchi-Pandu, Kanchi-Pundu, Kanchipundu, Kasaka, Nalla-Kamanchi-Chettu (Telugu), Ab Makoh, Inab-Us-Salab (Makoh), Kaamuni, Kamuni, Mako, Mako Khushk, Makoh Khushk, Makoh Khushk, Makoh Sabz, Makoh Sabz Ka Pani, Maku, Makuh Khushk (Urdu);

Indonesia: Ranti (Java), Leunca Ayam, Leuca Manuk (Sundanese);

Iraq: Innaib El-Theeb;

Italian: Erba Morella, Morella, Morella Commune, Pomidorella, Solano Nero, Solatro, Solatro Del Frutto Nero, Solatro Ortense;

Jamaica: Black Nightshade, Branched Calalu, Guma;

Japanese: Inuhōzuki;

Korean: Kkamajung;

Malaysia: Ranti, Terung Meranti, Terong Paracicit, Terong Perat, Kelamong Puyuh;

Mangarevan: Tutai Kiore;

Mauritius: Brede Martin;

Mexico: Hierba Mora, Trompillo;

Morocco: Morello Noire;

Niuean: Polokai;

Norwegian: Adventivstøvier, Svartsøtvier;

Pakistan: Kach-Mach, Kamper Makoo, Mako;

Panama: Pintamora;

Persian: Angoor-E-Shifa, Robah Turbuk;

Peru: Yerba Mora;

Philippines: Kuti, Lubi-Lubi (Bikol), Bolagtab, Hulablub, Kuti, Lahkakum, Lubi-Lubi (Bisaya), Amti, Anti (Bontok), Muti (Bukidnon), Amti (Ifugao), Natang-Ni-Aso (Igorot), Nateng (Ivatan), Kamates-Manuk, Malasili (Samar Leyte Bisaya), Muti (Sulu), Anti, Kamkamatisan, Konti, Kunti, Libi-Luib, Onti (Tagalog);

Polish: Psianka Czarna;

Portuguese: Erva-Moira, Erva-Moura;

Russian: Paslen Černyj;

Samoan: Magalo, Māgalo, Magalogalo, Magalogalo, Polo, Polo, Polo Vao;

Slovaščina: Pasje Zelišče;

Solvencina: Lu'ok Čiorny;

Spanish: Hierba Mora, Llague, Pintamora, Tomatillo, Tomatito De Moro, Tomatitos, Trompillo, Yerba Mora;

South Africa: galbessie, nagskade, nastergal (Afrikaans); Black Nightsahde (English), ixa-baxaba (Ndebele), lethotho (Pedi), momoli, sehloabohloko, seshoa-bohloko (Sesotho), musaka (Shona), msobo, umsobo (Swati), muxe (Tshivenda), sheshoabohloko, umsobo, umsobo-sobo (Xhosa), kophe (Xitsonga), isihlalakuhe, udoye, umagqa, umgwaba, umqunbane, umsobo, umsobo-sobo (fruit) (Zulu);

Spanish: Hierba Mora, Tomatillo D, Omatillo Del Diablo, Tomatito;

Swedish: Nattskatta, Vanlig Nattskatta;

Taiwan: Lug-Kwei;

Tanzania: Mwaha-Ka (Kihehe), Suga (Swahili);

Thai: Toem Tok, Ya-Tomtok;

Tibetan: Smon Sne U Dmar Po, Smon Sneu Dmar Po;

Tongan: Polo Kai;

Trinidad: Agouma;

Tunisia: Morelle Noire;

Turkish: Bambilotu, Giritotu, İt Üzüümü, Köpek Memesi, Köpek Üzüümü, Sofur;

Venezuela: Hierba Mora, Yocotoco.

Origin/Distribution

The exact origin of *Solanum nigrum* is uncertain, but it is generally considered to be native to Europe and Asia and possibly also Africa (Jansen 2008). Despite the fact that *Solanum* section has recently been studied extensively, taxonomy of *S. nigrum* is still unresolved and debated because of inter- and intraspecific hybridization, phenotypic plasticity and polyploidization (Poczai and Hyvönen 2011). *Solanum nigrum* (hexaploid) is thought to have been derived from the tetraploid *Solanum villosum* Mill. and the diploid *Solanum americanum* Mill., but the involvement of more taxa cannot be discarded. Poczai and Hyvönen (2011) analyzed the genetic relationships among diploid, tetraploid and hexaploid species of sect. *Solanum*, which were possibly involved in the formation of *Solanum nigrum*, utilizing multi-locus (SCoT, ISSR) markers combined with chloroplast trnL-F sequence data and morphological characters.

S. nigrum is now a very widespread species, having naturalised in many areas throughout the world. It is now found in Europe, Asia, Africa, north and south America, Australia, New Zealand and the Pacific Islands.

Agroecology

S. nigrum occurs as a common weed in gardens, fields, pastures, orchards, plantations, vineyards, roadsides, cultivated land, disturbed sites, waste areas and open forests in temperate, subtropical, topical and semi-arid environments. It thrives in full sun or partial shade, in moist environments, on a wide range of soils from sea level to 3000 m elevation. It is best adapted to soils of high fertility, especially those high in nitrogen and phosphorus. It is also quite drought tolerant.

Edible Plant Parts and Uses

The ripe black or purple black fruit are eaten raw and also used in pies and jams. The leaves and tender young shoots are boiled or stewed and used as a vegetable, potherb or relish (Plate 3). They are also used in soups and sauces.

Botany

An erect, glabrous or weakly pubescent, unarmed annual or short-lived perennial herb, 25–100 cm high. Stem green or purplish-tinged. Leaves ovate to ovate-lanceolate, concolorous, glabrous, up to 13 cm long and 7 cm wide, entire (Plates 1 and 2) or shallowly lobe with obtuse lobes, and cuneate bases, borne on 1–3 cm long petioles. Inflorescence short, 4–12 flowered, peduncle 1–2 cm long with pentamerous, bisexual flowers on 7 mm long pedicels; calyx campanulate 1.5–2.2 mm long with triangular lobes; corolla stellate, with triangular-acute lobes, white, 4–6 mm long, yellow oblong anthers on short filaments; ovary glabrous with erect 3.5–4 mm style and capitate stigma. Berry glabrous, globose 5–9.5 mm diameter, green turning to dull black to purplish-black when mature (Plates 1 and 2). Seeds numerous, flattened and minutely pitted.



Plate 1 Leaves, flowers and fruit



Plate 2 Ripe black and unripe green fruits



Plate 3 Leafy shoots on sale as vegetable in a local PNG market

Nutritive/Medicinal Properties

The dry matter (DM) content of *S. nigrum* seeds was found to be 94.22%, mean lipid content of 34.5–37.5% DM, protein content 17.04% DM and crude ash content 7.18% DM (Dhellit et al. 2006). The principal mineral element was Mg (180 mg/100 g), K 37.12 mg/100 g, Ca 11.1 mg/100 g, Na 7.12 mg/100 g. The seed oil was found to be rich in linoleic acid (18:2 n-6) 67.65%, and also contained 16:0 (palmitic acid)

10.19%, 18:0 (stearic acid) 4.62%, 18:1n-9 (oleic acid) 16.12%, 18:2 n-6 (linoleic acid) 67.65%, 18:3 n-3 (α -linolenic acid) 0.85%, 18:4 n-3 (stearidonic acid) 0.30%. The average fatty acid profile was: 18: 2n-6>18: 1 n-9>16: 0>18: 0. The ratio of PUFA/SFA (polyunsaturated fatty acid/saturated fatty acid) was 4.55; indicating the oil to be unsaturated. The acid value of the oil was about 2.5, saponification value varied between 157.3 and 190.1, peroxide value was low at 5.13 and iodine value was 102.33. Oil viscosity varied between 20 and 35 mPa.s at 25°C. The melting points estimated by Differential Scanning Calorimetry were found to be between -22.0 and -12.0°C for the Soxhlet and Folch-extracted oils. Bligh and Dyer extracted oil had three melting points at -36.2, -15.2 and 33.7°C.

Chweya (1997) reported that leaves of *S. nigrum* with purple fruit had the following nutrient composition: 13.3% dry matter, total phenolics 2,750 mg/100 g DM, total glycoalkaloids 131 mg/100 g FW, β -carotene 31.7 mg/100 g DM, crude protein 36.7% DW, crude fibre 9.2% DW, total ash 17.9% DW, iron 63.4 mg/100 g DW, calcium 275.8 mg/100 g DW. Leaves of green fruit variant had 12.2% dry matter, β -carotene 31.9 mg/100 g DM, crude protein 36.5% DW, crude fibre 9.6% DW, total ash 20.9% DW, iron 106.3 mg/100 g DW, calcium 432.2 mg/100 g DW. The nutrient values may, however, vary with soil fertility, plant age and type (i.e. variant or species). For instance, β -carotene, crude protein, nitrates and phenolic leaf contents were significantly increased while ascorbic acid, crude fibre and oxalate leaf contents were significantly reduced by nitrogen application. Thus, although nitrogen application improved leaf yield and nutritive quality of *S. nigrum*, it led to increased phenolic compounds and accumulation of nitrates in the leaves. *S. nigrum* leaves can provide appreciable amounts of protein and amino acids, minerals including calcium, iron and phosphorus, vitamins A and C, fat and fibre, as well as appreciable amounts of methionine, an amino acid scarce in other vegetables (Fortuin and Omta 1980; FAO 1988). Moreover the berries can apparently yield high amounts of iron, calcium and vitamin B (Fortuin and Omta 1980). The leaves were also

found to contain carotenoids (per 100 g edible portion) lutein 2,888 μ g, β -carotene 7,048 μ g, total RE 1,175 μ g and total carotenoids 9,336 μ g (Tee et al. 1997).

Glew et al. (2009) reported on the nutritional composition of *S. nigrum* leaves used as vegetables. Fatty acids contributed <2% of the dry weight of *S. nigrum* leaves. The leaves contained high percentage of omega 3 fatty acids, α -linolenic (46.7%) and low content of saturated fatty acids. They also contained substantial amount of protein (26%). The leaves were also found rich in Ca, K, Mg, P and Fe. Fatty acid composition of *S. nigrum* leaves was reported as total fatty acids (per g dry weight) 11.3 mg, 14:0 (myristic acid) 2%, 14:1 (myristoleic acid) 0.24%, 16:0 (palmitic acid) 16.8%, 16:1 n-7 (palmitoleic acid) 0.19%, 18:0 (stearic acid) 4.24%, 18:1 n-9 (oleic acid) 2.17%, 18:1 n-7 0.27%, 18:2 n-6 (linoleic acid) 19%, 18:3 n-3 (α -linolenic acid) 46.7%, 20:0 (arachidic acid) 1.14%, 22:0 (behenic acid) 0.98%, 22:1 (erucic acid) 0.37%, and unknown fatty acid 5.78%. Amino acid composition of *S. nigrum* leaves was reported as: total amino acid (per g dry weight) 260 mg, alanine 16.6 mg, arginine 13.0 mg, aspartate 36.7 mg, cysteine 4.25 mg, glutamate 33.8 mg, glycine 14.5 mg, histidine 6.51 mg, isoleucine 13.2 mg, leucine 22.0 mg, lysine 17.0 mg, methionine 1.32 mg, phenylalanine 15.3 mg, proline 20.7 mg, serine 10.4 mg, threonine 11.2 mg, tyrosine 5.77 mg and valine 17.5 mg. Mineral composition of *S. nigrum* leaves (mg/g dry weight) was reported as follows: Ca 23800 mg, Co 0.15 mg, Cr 1.09 mg, Cu 6.61 mg, Fe 330 mg, K 22000 mg, Mg 5050 mg, Mn 39.3 mg, Mo 2.55 mg, Na 472 mg, P 6650 mg, Pb 6.48 mg, Sr 39.2 mg and Zn 209 mg.

Leaves of wild vegetables of South Africa namely *Chenopodium album*, *Sonchus asper*, *Solanum nigrum* and *Urtica urens* were found to have protein contents between 13.25 and 26.44%, fibre content were 16.08–23.08% and mineral (ash) contents were 13.0–27.75%, (Afolayan and Jimoh 2008). The total phenolic contents ranged between 4.58 and 10.53 mg/g. Leaves of *Solanum nigrum* were found to be rich in moisture content, ash content, crude protein, crude lipid, crude fibre

and carbohydrate (Jimoh et al. 2010). Elemental analysis in mg/100 g (DW) indicated that the leaves contained sodium, potassium, calcium, magnesium, iron, zinc, phosphorus, copper, manganese, and nitrogen. The chemical composition in mg/100 g (DW) for alkaloid, saponins, and phytate were moderate. The plant was also rich in polyphenols and had good antioxidant activity.

Fruit of *Solanum* Morellae section including *S. americanum* and *S. nigrum* were found to contain solasonine and solamargine (Briggs et al. 1961). Solasodamine was shown to be solasonine monohydrate and solauricine a mixture of solasonine and solamargine and that solauricidine was probably a mixture of solasodine and its galactoside. Both fruits also contained small amounts of α -solanigrine and β -solanigrine. Significant amounts of diosgenin (1.2%) and solasodine (0.65%) were found in green berries of the Indian diploid '*S. nigrum*' (= *S. americanum*) with lesser amounts of both chemicals in the Indian tetraploid (= *S. villosum*) and hexaploid (= *S. nigrum*) species (Khanna and Rathore 1977). *S. nigrum* fruits were found to contain a saturated steroidal sapogenin identified as tigogenin (Varshney and Sharma 1965).

S. nigrum fruit was found to contain acetylcholine, average content of 250 μ g/g (de melo et al. 1978). Immature fruits of *S. nigrum* were found to have steroidal glycosides, proto-desgalactotigogenin, desgalactotigogenin, tigogenin 3-O- β -D-glucopyranosyl-(1 $\rightarrow$ 2)-[β -D-glucopyranosyl-(1 $\rightarrow$ 3)]- β -D-glucopyranosyl-(1 $\rightarrow$ 4)- β -D-galactopyranoside, together with steroidal alkaloids, solamargine and solasonine (Saijo et al. 1982). *S. nigrum* was found to contain (+)-pinoresinol, (+)-syringaresinol, (+)-medioresinol, scopoletin, tetracosanoic acid and β -sitosterol (Zhao et al. 2010). A new characteristic steroidal glycoside possessing a hydroxyl group at C-23, inunigroside A, was isolated from the withered berries of *Solanum nigrum* (Ohno et al. 2012). Its structure was characterized as (5 α ,22S,23S,25R)-3 β ,23-dihydroxyspirostane 3-O- β -lycotetraoside.

The proximate nutrient composition of *S. nigrum* seeds was reported as protein (17.66 g/100 g, carbohydrate 33.48 g/100 g, ash 7.18% comprising (Ca, K, Na and Mg) (Nzikou et al. 2007). *S. nigrum* seed oil content was

37.12–38.88%, comprising 18:2n-6 (67.77%), 18:1n-9 (14.59%), 16:0 (12.46%) and 18:0 (4.31%) and 18:3n-3(0.63%). The majors TAG (triacylglycerides) in *S. nigrum* seeds oil were oleodilinolein (OLL) at 56.54% of total triacylglycerols followed by palmitooleo-linolein (POL) and dioleolinolein (OOL) varying between 14.79 and 22.04%. The oil extracts exhibited good physicochemical properties and could be useful as edible oils and for industrial applications.

Two steroidal saponins named nigrumnins I and II, desgalactotigogenin and tigogenin 3-O- β -D-glucopyranosyl-(1 $\rightarrow$ 2)-[β -D-glucopyranosyl-(1 $\rightarrow$ 3)]- β -D-glucopyranosyl-(1 $\rightarrow$ 4)- β -D-galactopyranoside were isolated from *S. nigrum* whole plant (Ikeda et al. 2000b). Nigrumnin I was elucidated as (25R)-5 α -spirostan-3 β -ol 3-O- β -D-xylopyranosyl-(1 $\rightarrow$ 3)-[α -L-arabinopyranosyl-(1 $\rightarrow$ 2)]- β -D-glucopyranosyl-(1 $\rightarrow$ 4)-[α -L-rhamnopyranosyl-(1 $\rightarrow$ 2)]- β -D-galactopyranoside, and nigrumnin II was elucidated as (25R)-3 β ,17 α -dihydroxy-5 α -spirostan-12-one 3-O- β -D-xylopyranosyl-(1 $\rightarrow$ 3)-[α -L-arabinopyranosyl-(1 $\rightarrow$ 2)]- β -D-glucopyranosyl-(1 $\rightarrow$ 4)-[α -L-rhamnopyranosyl-(1 $\rightarrow$ 2)]- β -D-galactopyranoside. Six new steroidal saponins, solanigrosides C–H, and one known saponin, degalactotigogenin, were isolated from the whole plant of *Solanum nigrum* (Zhou et al. 2006). Two new pregnane saponins, solanigroside A (1) and solanigroside B (2), along with two known compounds (3 and 4), were isolated from 60% ethanolic extract of the dried herb of *Solanum nigrum* (Zhou et al. 2007). The structures of 1 and 2 were elucidated as 5 α -pregn-16-en-3 β -ol-20-one 3-O- β -D-xylopyranosyl-(1 $\rightarrow$ 3)-O-[α -L-arabinopyranosyl-(1 $\rightarrow$ 2)]-O- β -D-glucopyranosyl-(1 $\rightarrow$ 4)-O-[α -L-rhamnopyranosyl-(1 $\rightarrow$ 2)]-O- β -D-galactopyranoside (1) and 5 α -pregn-16-en-3 β -ol-20-one 3-O- β -D-glucopyranosyl-(1 $\rightarrow$ 2)-O-[β -D-glucopyranosyl-(1 $\rightarrow$ 3)]-O- β -D-glucopyranosyl-(1 $\rightarrow$ 4)-O- β -D-galactopyranoside (2), respectively. Non-saponin compounds isolated from 60% ethanol extract of *S. nigrum* were identified as 6-methoxy-hydroxycoumarin, syringaresinol-4-O- β -D-glucopyranoside, pinoresinol-4-O- β -D-glucopyranoside, 3, 4-dihydroxybenzoic acid, *p*-hydroxybenzoic acid, 3-methoxy-4-hydroxybenzoic

acid and adenosine (Wang et al. 2007). Two novel disaccharides were isolated from *S. nigrum* and their structures elucidated as ethyl β -D-thevetopyranosyl-(1 $\rightarrow$ 4)- β -D-oleandropyranoside (1) and ethyl β -D-thevetopyranosyl-(1 $\rightarrow$ 4)- α -D-oleandropyranoside (2) (Chen et al. 2009).

Quercetin, in its various glycosidic forms, was the only flavonoid detected in *S. nigrum* Complex (Mohy-Ud-Din et al. 2009). Taxa in the *S. nigrum* complex were found to contain the following glycoalkaloids: β -Solamargine, α -solamargine, solasonine and α -solanine and the aglycones solanidine, solasodine in varying concentrations (Mohy-Ud-Din et al. 2010).

Two new quercetin glycosides were identified from *S. nigrum* leaves, namely, quercetin 3-O-(2Gal- α -rhamnosyl)- β -glucosyl (1 $\rightarrow$ 6)- β -galactoside and quercetin 3-O- α -rhamnosyl (1 $\rightarrow$ 2)- β -galactoside together with known compounds: quercetin 3-glucosyl(1 $\rightarrow$ 6)galactoside, 3-gentiobioside, 3-galactoside and 3-glucoside (Nawwar et al. 1989). Leaves of *S. nigrum* (ranti) was found to have 7,048 μ g of β -carotene, total carotenoids of 9936 μ g and total RE of 1175 μ g per 100 g edible portion (Tee et al. 1997).

Solanum nigrum was found to contain the following steroidal glycolalkaloids α -solamargine 5.03 mg/g, solasonine 5.8 mg/g, α -solanine 4.7 mg/g, β -solamargine 1.69 mg/g and the following steroidal glycolalkaloid aglycones solanidine 16.03% and solasodine 75.89% (Mohy-Ud-Din et al. 2010). Among the five taxa of *Solanum nigrum* Complex investigated, *S. nigrum* showed highest level of total flavonoids (2.116%) followed by *S. americanum* 1.667%, *S. retroflexum* 1.204%, *S. villosum* 0.891% and *S. chenopodioides* 0.883% the lowest (Mohy-Ud-Din et al. 2009). In terms of quercetin concentration (mg/100 g of plant), *S. americanum* had the highest 6.46 mg, followed by *S. villosum* 4.91 mg, *S. chenopodioides* 3.81 mg, *S. retroflexum* 3.18 mg and *S. nigrum* 3.06 mg the lowest.

Rao (1978) identified the anthocyanin pigment, petunidin3-(*p*-coumoryl) rhamnosyl glucoside in the Indian forms of both *S. nigrum* and *S. americanum*. Leaf-extracts of all species in *Solanum* sect. *Solanum* (= sect. Morella) including

S. americanum and *S. nigrum* were found to contain diosgenin and tigogenin (Carle 1981). Solasodine was absent in the leaf extracts but was detected in unripe fruits.

One spirostanol glycoside and two furostanol glycosides were isolated from a methanol extract of the stems and roots of *Solanum nigrum* (Sharma et al. 1983). *S. nigrum* was found to cocktail of phytoecdysteroids, of which 20-hydroxyecdysone and polypodine B (5 β , 20-dihydroxyecdysone) were major components (Savchenko et al. 2000). Eltayeb et al. (1997) found that the smallest leaves of *S. nigrum* showed the highest steroidal alkaloid, solasodine concentration. The absolute amount of alkaloid per leaf increased during leaf development whereas the concentration declined. The concentration of solasodine in roots was higher than in the stem. Small unripe fruits of *S. nigrum* had a high concentration of solasodine, but both the concentration and the absolute amount per fruit decreased with fruit maturation.

Studies have reported that *Solanum nigrum* possesses antiviral, antiinflammatory, diuretic, antipyretic and analgesic effects and has been used to cure inflammation, edema, mastitis and hepatic cancer (Shokrzadeh et al. 2010).

Antioxidant Activity

Glycoprotein from *Solanum nigrum* was found to have potent antioxidative potential (Heo and Lim 2004). Under optimal conditions, it exhibited slightly higher scavenging effects on superoxide anion generated by the enzymatic hypoxanthine/xanthine oxidase system than on hydroxyl radicals generated by the Fenton reaction. However, the glycoprotein was more effective against hydroxyl radicals in cell cultures (NIH/3 T3). At 20 μ g/mL, the glycoprotein had a scavenging ability against superoxide anion equivalent to that of ascorbic acid. In contrast, its hydroxyl radical scavenging activity corresponded to 0.1 μ g/mL catalase. Al-Qirim et al. (2008) found that crude extract *S. nigrum* leaf treatment of rats after 6 h of stress exposure was more effective in restoring restraint stress induced changes in rat plasma than using the extract before stress exposure.

The decreased activities of SOD, CAT and GST and the level of glucose caused by stress were restored and the elevated levels of MDA and uric acid were lowered by the extract. The results suggested that *S. nigrum* leaf extract could be given both as a prophylactic and therapeutic supplement for scavenging free radicals.

Anticancer Activity

In-Vitro Studies

Hu et al. (1999) reported that three steroidal glycosides, β 2-solamargine, solamargine, and degalactotigonin, isolated from *Solanum nigrum* displayed in-vitro cytotoxicity on six cultured human solid tumour cell lines HT-29 (colon), HCT-15 (colon), LNCaP (prostate), PC-3 (prostate), T47D (breast), and MDA-MB-231 (breast). The cytotoxic assay indicated that solamargine was the main antineoplastic agent in *S. nigrum*. *Solanum nigrum* extract showed strong cytotoxicity effect on human multiple myeloma U266 cells (Wang and Lu 2005). Its antineoplastic effect could partly be ascribed to its apoptotic inducing effect.

Heo et al. (2004a) found that *Solanum nigrum* glycoprotein inhibited 12-*O*-tetra decanoylphorbol-13-acetate (TPA; 100 nM)-induced DNA-binding activities of NF-kappaB and AP-1, and enhanced NO production in human breast cancer MCF-7 cells. Ethanol extract of *S. nigrum* ripe fruits strongly inhibited the proliferative capacity of MCF-7 breast cancer cells and induced their apoptosis as evidenced by the appearance of DNA laddering, increase in DNA fragmentation, and low fluorescence intensity in nuclei after propidium iodide staining of the cells (Son et al. 2003). The extract was also found to be a potential scavenger of hydroxyl radicals and DPPH radicals rather than superoxide anions. *Solanum nigrum* glycoprotein was found to induce apoptosis through modulation of PKCalpha and NF-kappaB activity in MCF-7 breast cancer cells (Heo and Lim 2005). The apoptotic-inducing effect was indicated by nucleosomal DNA fragmentation and nuclear staining. The results suggested that *S. nigrum* glycoprotein may be a potential natural

anticancer agent because of its ability to induce apoptosis in MCF-7 cells. Solamargine exhibited potent cytotoxic effect comparable with that of cisplatin, methotrexate, 5-fluorouracil, epirubicin and cyclophosphamide against human breast cancer cells (Shiu et al. 2007). Solamargin induced apoptosis of the breast cancer cells by up-regulating the expressions of external death receptors, such as tumor necrosis factor receptor I (TNFR-I), Fas receptor (Fas), TNFR-I-associated death domain (TRADD), and Fas-associated death domain (FADD). Solamargin also enhanced the intrinsic ratio of Bax to Bcl-2 by up-regulating Bax and down-regulating Bcl-2 and Bcl-xL expressions. The combined treatment of solamargin and cisplatin significantly reduced Bcl-2 and Bcl-xL expressions, and enhanced Bax, cytochrome c, caspase-9 and -3 expressions in breast cancer cells and thus may be effective in cisplatin-resistant breast cancer. They also found that solamargin co-modulated HER2/neu and TopoIIalpha expression markedly and enhanced TopoII inhibitor-EPI (epirubicin)-induced cytotoxicity to breast cancer MCF-7 and SK-BR-3 cells (Shiu et al. 2009). Studies by Huang et al. (2010) found that *S. nigrum* leaf extract induced cell death in AU565 breast cancer cells via two distinct antineoplastic activities, the abilities to induce apoptosis and autophagy depending on the exposure concentrations, therefore suggesting that it may provide a useful remedy to treat breast cancer. A low dose of the leaf extract induced autophagy but not apoptosis. Higher doses (>100 µg/mL) could inhibit the level of p-Akt and cause cell death due to the induction of autophagy and apoptosis.

Heo et al. (2004b) found that treating human colon adenocarcinoma HT-29 cells with 60 µg/mL *S. nigrum* glycoprotein induced cytotoxic effect in a time-dependent manner through the inhibition of nuclear factor-kappa B (NF-κB) activation induced by hydroxyl radical-induced DNA-binding activities in HT-29 cells. Lee et al. (2005a) found that the glycoprotein isolated from *S. nigrum* consisted of 69.74% carbohydrate and 30.26%, protein content with >50% hydrophobic amino acids containing glycine and proline. LDH (lactate dehydrogenase) assay indicated that the

glycoprotein at 40 µg/mL for 2 h had distinct cytotoxic and apoptotic effects (>50% cell death) in HT-29 cells. Results showed that the glycoprotein stimulated Bid stimulation resulting in the release of cytochrome c, the stimulation of caspase-8, -9 and -3 activities, and the cleavage of PARP in HCT-116 cells and did not significantly stimulate an increase in levels of intracellular reactive oxygen species (ROS) (Lee et al. 2005a; Lee and Lim 2006a). The results suggested that *S. nigrum* glycoprotein induced apoptosis through the mitochondrial apoptotic signal pathway in HCT-116 cells, rather than through intracellular ROS. Earlier, Lee et al. (2004b) demonstrated that *S. nigrum* glycoprotein showed cytotoxic and apoptotic effects on human colon cancer HCT-116 cells via inhibition of the effects of protein kinase C alpha, nuclear factor-kappa B and inducible nitric oxide in HCT-116 cells. In another paper, they confirmed that the glycoprotein induced apoptosis through the NF-kappaB activation and reduction of inducible nitric oxide (iNO) production in HCT-116 cells (Lee and Lim 2006b). Lim (2005) found that treatment of human colon adenocarcinoma HT-29 cells with *S. nigrum* glycoprotein (60 µg/mL) for 4 h resulted in a cytotoxic effect of more than 60%, compared with the control. The glycoprotein killed HT-29 cells through apoptosis. The amount of DNA fragmentation in HT-29 cells and apoptotic cell numbers increased in a dose-dependent manner after treatment with the glycoprotein. Further the results showed that the activation of PKCalpha, NF-kappaB, and Bax expression by the glycoprotein was possibly involved in the apoptotic process. *S. nigrum* glycoprotein at 80 µg/mL exhibited cytotoxic and apoptotic effects in Hep3B cells (hepatocellular carcinoma cells) (Lee and Lim 2008). The glycoprotein transferred its cell death signal from cytochrome c to caspase 3 by inhibiting NF-kappaB and iNOS activation in Hep3B cells.

Six steroidal saponins, solanigrisides C–H (2–7), and one known saponin, degalactotigonin (1), were isolated from the whole plant of *Solanum nigrum* (Zhou et al. 2006). All seven compounds were tested for their cytotoxicity using four human tumour cell lines (HepG2,

NCI-H460, MCF-7, SF-268). Only compound 1 was cytotoxic, with IC₅₀ values of 0.25–4.49 µM. *Solanum nigrum* water extract suppressed the progression of the hepatoma induced by 2-acetylaminofluorene (AAF)/sodium nitrite in rats and resulted in greater increase in survival rate (Hsu et al. 2009). Supplementation with the extract significantly alleviated the AAF-induced hepatic injury and early hepatocarcinogenesis as well as the AAF/NaNO(2)-induced lethal hepatoma, which may result from the overexpression of glutathione S-transferases, Nrf2, and antioxidant enzymes. Hydroalcoholic extract of *S. nigrum* exhibited cytotoxic effects in normal [Chinese hamster ovarian cells (CHO) and rat fibroblast] and cancer (HepG2 and CT26) cell lines (Shokrzadeh et al. 2010). The results showed that IC₅₀ of *S. nigrum* extract was significantly lower than that of the *C. pepo* extract on all four cell lines. Ji et al. (2008) showed that solanine from *S. nigrum*, induced apoptosis in Hep G2 cells which appeared to be mediated by the inhibition in the expression of Bcl-2 protein. The IC₅₀ for HepG2 was 14.47 µg/mL. *Solanum nigrum* extract induced cell death in hepatoma HepG2 cells via two distinct antineoplastic activities (Lin et al. 2007). Firstly via the induction of apoptosis as evidenced by increases in the expressions of p-JNK and Bax, mitochondrial release of cytochrome c, and caspase activation. Secondly via autophagocytosis as evidenced by increased levels of autophagic vacuoles and LC3-I and LC3-II proteins, specific markers of autophagy. The results suggesting that it may have potential to treat liver cancer.

Water extract of *S. nigrum* reduced the incidence of liver lesions including hepatic cells cloudy swelling, lymphocytes infiltration, hepatic necrosis, and fibrous connective tissue proliferation induced by CCl₄ in rats (Lin et al. 2008). The findings suggested that the water extract of *S. nigrum* could protect liver against the CCl₄-induced oxidative damage in rats, and this hepatoprotective effect might contributed to its modulation on detoxification enzymes and its antioxidant and free radical scavenger effects. Yang et al. (2010) showed that treatment of Hep G2 cells with water

or polyphenol extracts of *S. nigrum* attenuated TPA (12-*o*-tetradecanoylphosphor-13-acetate) -induced migration and invasion. Both extracts reduced TPA-elicited PKC α expression in a dose-dependent manner and obviously inhibited TPA-induced phosphorylation of p38 and ERK, respectively. The results suggested that both extracts may act as promising therapeutic agent for the treatment of hepatocellular carcinoma. *S. nigrum* polyphenolic extract was found to be a potent inhibitory agent for hepatocellular carcinoma HepG(2) targeting G(2)/M arrest and apoptosis induction (Wang et al. 2011). Extract fed mice showed decreased tumour weight and tumour volume by 90%. The extract viability of HepG(2) cells in a dose-dependent manner. The extract induced caspases-3, 8, and 9 cleavages and reduced protein levels of cell CDC25A, CDC25B, and CDC25C. Solamargine, a major steroidal alkaloid glycoside purified from *S. nigrum* exerted potential anticancer activity on human hepatoma SMMC-7721 cells in-vitro by induction of apoptosis and inhibition of hepatoma cell proliferation via activation of caspase-3 and cell cycle arrest at the G2/M phase (Ding et al. 2012).

S. nigrum water extract significantly inhibited melanoma B16-F1 cell migration and invasion in-vitro; >50% reduced tumour weight and lung metastatic nodules were observed in mice fed the 1% extract (Wang et al. 2010). This was associated with reduced serum MMP-9 as well as Akt activity and PKC α , Ras, and NF- κ B protein expressions. Solamargine exhibited potent cytotoxicity in four human lung cancer cell lines H441, H520, H661 and H69 cells with IC₅₀ values of 3, 6.7, 7.2 and 5.8 μ M, respectively (Liu et al. 2004). Solamargine dose-dependently induced apoptosis of these cells and increased sub-G1 fraction. Solamargine modulate the expressions of TNFRs and Bcl-2, and might be a potential anticancer agent for TNFs and Bcl-2 related resistance of human lung cancer cells. The scientists (Liang et al. 2004) further found solamargin induced morphological changes of chromatin condensation, DNA fragmentation, and sub-G(1) peak in a DNA histogram of human A549 lung adenocarcinoma cells. Solamargin

elevated the expressions of TNF-R1 and -R2 and overcame the resistance of A549 cells to TNF- α and - β . In addition, release of cytochrome c from mitochondria, down-expression of Bcl-2 and Bcl-x(L), up-regulation of Bax, and caspase-9 activities were observed in solamargin-treated A549 cells. Combinatorial treatment of solamargin and cisplatin synergistically enhanced caspase-8, -9, and -3 activities in A549 cells. Their results suggested that solamargin may have anticancer potential against TNFs- and cisplatin-resistance lung cancer cells. The combinatorial use of low concentrations of solamargine with low-toxic topoisomerase II inhibitor epirubicin accelerated apoptotic cell death of non-small-cell lung cancer (NSCLC) (Liang et al. 2007). The downregulation of the HER2 and TOP2A (topoisomerase II α) expression by solamargin with epirubicin may partially explain the solamargin and epirubicin cytotoxicity synergy effect in NSCLC. Results of their study suggested that solamargin induced Fas expression and TNFR-induced NSCLC cell apoptosis and reduced HER2 expression. Liang et al. (2008) further reported that solamargin enhanced HER2 and TOP2A expressions in NSCLC large cell carcinoma H661 and small cell lung cancer (SCLC) H69 cells and augmented trastuzumab and epirubicin-induced deaths of lung cancer H661 and H69 cells.

Solanum nigrum polysaccharide exhibited significant growth inhibition on cervical cancer (U14) of tumour-bearing mice (Li et al. 2007). The tumour growth inhibition was associated with the reduction of TNF- α level of blood serum, which resulted in a massive necrosis in tumour tissues and the up-regulation of Bax and down-regulation of Bcl-2 and mutant p53 gene expression, which triggered apoptosis in tumour cells. Fraction 1a of *Solanum nigrum* polysaccharide exhibited growth inhibition effect on U14 cervical cancer and protective effect on thymus tissue of tumour-bearing mice (Li et al. 2010). The polysaccharide increased Bcl-2/Bax ratio in thymus lymphocytes of tumour-bearing mice, which might promote more thymus lymphocytes in suppressing proliferation. Li et al. (2008b) reported that *S. nigrum* extract inhibited the

growth of human cervical cancer HeLa cells in-vitro, inducing cell death by apoptosis. Further they found that the aqueous *S. nigrum* extract could suppress U14 cervical carcinoma via modulating immune response of the tumour-bearing mice and causing tumour cell cycle arrest in G0/G1 phase, as well as inducing apoptosis with little toxicity to the animals (Li et al. 2008a). The extract increased the number of CD4+ T lymphocyte subsets as well as the ratio of CD4+/CD8+ T lymphocyte, and decreased the number of CD8+ T lymphocyte subsets of tumour-bearing mice and PCNA (proliferating cell nuclear antigen) positive cells. Li et al. (2009) showed that the crude polysaccharides isolated from *Solanum nigrum* (SNL-P) exhibited potent antitumour activity against U14 cervical cancer. In-vivo oral administration with SNL-P (90, 180, 360 mg/kg body weight) decreased the number of ascites tumour cells and prolonged the survival time of U14 cervical-cancer-bearing mice. Most of the ascites tumour cells were arrested in G2/M phase of cell cycle and the ratio of CD4+/CD8+ peripheral blood T-lymphocyte subpopulations were restored following treatment of SNL-P. Further, SNL-P also caused a significant increment in IFN- γ and a remarkable decrease in interleukin IL-4. The results suggested that *S. nigrum* polysaccharide may exert antitumor activity via activation of different immune responses in the host rather than by directly attacking cancer cells on the U14 cervical cancer bearing mice.

Nawab et al. (2012) demonstrated that a polyphenolic extract derived from ripe berries of *Solanum nigrum* (SN) differentially caused cell cycle arrest and apoptosis in various human prostate cancer cells without affecting normal prostate epithelial cells. Treatment of CA-HPV-10 cells with the extract increased cytotoxicity, decreased cell viability and induced apoptosis. Similar results were observed in the human prostate cancer LNCaP, 22Rv1, DU145 and PC-3 cell lines. Cell cycle analysis revealed that *S. nigrum* treatment (5–20 $\mu\text{g/mL}$) resulted in a dose-dependent G2/M phase arrest and subG1 accumulation in the CA-HPV-10 but not in the PZ-HPV-7 cell line.

Solamargine, a steroidal alkaloid glycoside from *Solanum nigrum*, was found to induce early

lysosomal rupture of human K562 leukemia within 2 h as assessed by acridine-orange relocation and alkalization of lysosomes (Sun et al. 2010). The lysosomal-mitochondrial death pathway induced by solamargine was mediated via the down-regulation of Bcl-2 and up-regulation of Bax, caspase-3 and caspase-9 activities. Sun et al. (2011) also reported that solamargine induced oncosis in human K562 leukemia and squamous carcinoma KB cells (Sun et al. 2011). It rapidly permeated into tumour cells, induce membrane perturbation and blebbing, leakage of cytoplasmic content and LDH release. Solamargine also disrupted the cytoskeletal systems: degradation of microtubules and actin proteins. Solamargine may offer a novel therapeutic strategy in treatment of cancer.

S. nigrum when used in combination with 20 U/mL of recombinant interferon- γ (rIFN- γ) caused a marked cooperative induction of nitric oxide (an anti-tumour molecule) production via nuclear factor- κB activation in mouse peritoneal macrophages (An et al. 2005). The increase in NO synthesis was reflected as an increased amount of inducible NO synthase (iNOS) protein. Lunasin, a peptide from *Solanum nigrum* inhibited acetylation of core histones H3 and H4 and phosphorylation of retinoblastoma protein (Rb) (Jeong et al. 2007). Lunasin in the crude protein and in the autoclaved crude protein was very stable to pepsin and pancreatin in-vitro digestion, while the synthetic pure lunasin was digested at 2 min after the reaction. The authors concluded that lunasin was a bioactive and bioavailable component in *S. nigrum* lunasin and that its consumption may play an important role in cancer prevention. *S. nigrum* lunasin peptide purified protected DNA from oxidative damage by suppressing the generation of hydroxyl radical via blocking fenton reaction (Jeong et al. 2010). The results suggested that consumption of lunasin may play an important role in the chemoprevention for the oxidative carcinogenesis.

Solanum nigrum methanolic extract exerted significant cytotoxicity effect on HeLa cell line in concentration range between 10 and 0.0196 mg/mL by using SRB assay and also showed that inhibitory action on HeLa cell line in concentration

range between 10 and 0.0196 mg/mL using the MTT assay (Patel et al. 2009). IC₅₀ value and R2 value of *S. nigrum* on *HeLa* cell and *Vero* cell were 847.8 and 0.8724; 9,088 and 0.1017 respectively by SRB assay. IC₅₀ value and R2 value of *S. nigrum* on *HeLa* cell was 265.0 and 0.9496 respectively by MTT assay. IC₅₀ value of *S. nigrum* on *Vero* cell was 6.862 by MTT assay. R2 value of *S. nigrum* was not found by MTT assay. From the performed assay, methanolic extract of *S. nigrum* showed greater activity on *HeLa* cell line and little activity on *Vero* cell line indicating *S. nigrum* could be used as anticancer agent.

Antiviral Activity

Methanol and chloroform extracts of *Solanum nigrum* seeds exhibited 37% and more than 50% inhibition of Hepatitis C virus respectively at non toxic concentration (Javed et al. 2011). Further, the chloroform extract decreased the expression or function of Hepatitis C virus NS3 protease in a dose- dependent manner and GAPDH (glyceraldehyde 3-phosphate dehydrogenase) remained constant.

Hepatoprotective Activity

Crude extract of *S. nigrum* plant exhibited hepatoprotective effect (Sultana et al. 1995). Presence of the plant extract in the reaction mixture containing calf thymus DNA and free radical generating system protected DNA against oxidative damage to its deoxyribose sugar moiety. The effect was concentration dependent. Raju et al. (2003) reported that the ethanol extract of dried fruits of *S. nigrum* showed appreciable hepatoprotective effect against carbon tetrachloride-induced hepatic damage in rats. Lin et al. (2008) found that treatment of rats with water extract of *S. nigrum* for 6 weeks significantly lowered carbon tetrachloride-induced serum levels of hepatic enzyme markers (GOT, GPT, ALP, and total bilirubin), superoxide and hydroxyl radical. The hepatic content of GSH, and activities and expressions of SOD, GST A1, and GST Mu that were

reduced by CCl₄ were reverted to control levels by the extract. Liver histopathology showed that the extract reduced the incidence of liver lesions including hepatic cells cloudy swelling, lymphocytes infiltration, hepatic necrosis, and fibrous connective tissue proliferation induced by CCl₄ in rats. In another study, oral administration of *Solanum nigrum* extract 3 times/week for 12 weeks significantly reduced thioacetamide-induced hepatic fibrosis in mice (Hsieh et al. 2008), probably through the reduction of transforming growth factor-beta1 secretion. The extract also reduced the hepatic hydroxyproline and alpha-smooth muscle actin protein levels of thioacetamide-treated mice.

Simultaneous administration of *Solanum nigrum* and *Cichorium intybus* extract to hepatotoxic rats induced by CCl₄ significantly controlled the toxic effect of CCl₄ by maintenance of structural integrity of hepatocyte cell membrane and normalisation of functional status of liver (Subash et al. 2011). Histology of liver sections from *S. nigrum* and *C. intybus*+CCl₄ treated rats revealed moderate centrilobular hepatocytes degeneration, few areas of congestion with mild fatty changes. The extract of *S. nigrum* and *C. intybus* possessed significant hepatoprotective activity in comparison to standard drug silymarin.

Hypocholesterolemic/Antihyperlipidemic Activity

Lee et al. (2005b) showed that when mice were treated with either Triton WR-1339 or corn oil in the presence of *S. nigrum* 150 kDa glycoprotein, the plasma lipoprotein levels (TG, TC and LDL) were significantly reduced; in the absence of the glycoprotein the number of plasma lipoproteins [triglyceride (TG), total cholesterol (TC) and low density lipoprotein (LDL)] increased. Also, the activities of superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx) were remarkably increased after treatment with the glycoprotein. Further, the activity of hepatic 3-hydroxy-3-methylglutaryl coenzyme A (HMG-CoA) reductase was reduced by the glycoprotein in cholestyramine-treated mice. Taken together,

these results indicated that *S. nigrum* 150 kDA glycoprotein could enhance the activities of detoxicant enzymes and bring about the inhibition of HMG-CoA reductase activity in-vivo. They suggested that *S. nigrum* glycoprotein could be used as a cholesterol lowering agent even at low concentrations. In another study, *S. nigrum* fruit extract exhibited antioxidant and antihyperlipidemic activity against ethanol-induced toxicity in rats (Arulmozhi et al. 2010). The extract improved the antioxidant status by decreasing the elevated levels of thiobarbituric acid reactive substances (TBARS) and altering the elevated lipid profiles of total cholesterol (TC), triglycerides (TG), low density lipoproteins (LDL), very low density lipoproteins (VLDL), free fatty acids (FFA), and phospholipids to near normal.

Antiinflammatory Activity

Methanol extract of dried pulverised berries of *S. nigrum* exhibited significant and dose-dependent antiinflammatory activity against carrageenan-induced paw edema (Ravi et al. 2009b). The air-dried powdered leaf extract of *S. nigrum* produced significant dose-independent antiinflammatory and antipyretic activities when assessed using the carrageenan-induced paw edema and brewer's yeast-induced pyrexia tests (Zakaria et al. 2006, 2009). Another research reported that the ethanolic extract of *S. nigrum* produced significant antiinflammatory and anticonvulsant effect in dose dependent manner in animals using carrageenan paw edema and supramaximal electric shock (MES) methods (Ravi et al. 2009a). The flavonoids present in the berries was postulated to be responsible for this activity. Lomash et al. (2010) found ethanol extract of *Solanum nigrum* leaves to exhibit antihistamine and antiinflammatory activities. The extract exhibited significant decrease in permeability response at an early stage (0–2 min) of histamine as well as in carrageenan induced inflammatory lesions. There was a significant suppression in the emigration of heterophils, monocytoïd cells, basophils and total leukocytosis in *Solanum nigrum* pretreated chicken skin lesions as compared to the

control. Kang et al. (2011) demonstrated that the chloroform fraction of *S. nigrum* inhibited inducible NO synthase (iNOS) and tumour necrosis factor- α in lipopolysaccharide-stimulated mouse peritoneal macrophages through inhibition of p38, JNK and ERK1/2. The results indicated that the antiinflammatory components of *S. nigrum* existed preferentially in the nonpolar fraction, ruling out the possibility that diosgenin and α -solanine were the likely candidates.

Ethanolic and aqueous extracts of *S. nigrum* flowers (300 mg/kg) exhibited maximum antiinflammatory activity as assayed by the cotton pellet granuloma method in rats (Elango et al. 2012).

Osteoclastogenesis Inhibitory Activity

S. nigrum was found to exhibit showed inhibitory effects in RANKL (receptor activator of nuclear factor NF- κ B ligand)-induced osteoclast differentiation (Youn et al. 2008). Bone resorption and loss are generally attributed to osteoclasts and the differentiation of osteoclasts is regulated by RANKL, a member of tumour necrosis factor family.

Antiasthmatic Activity

The petroleum ether extract of *S. nigrum* berries inhibited clonidine-induced catalepsy significantly but not haloperidol-induced catalepsy (Nirmal et al. 2012). Petroleum ether extract significantly inhibited increased leukocyte and eosinophil count due to milk allergen and displayed maximum protection against mast cell degranulation by clonidine. Petroleum ether extract also resisted contraction induced by histamine better than other extracts. Active petroleum ether extract showed presence of antiasthmatic compound, β -sitosterol.

Cytoprotective Activity

Solanum nigrum whole plant ethanol whole extract displayed cytoprotective effect against gentamicin-induced kidney cell (Vero cells)

damage in-vitro (Kumar et al. 2001). The plant extract also exhibited significant hydroxyl radical scavenging potential, thus suggesting its probable mechanism of cytoprotection.

Antinociceptive Activity

The aqueous *S. nigrum* leaf extract exhibited significant dose-independent antinociceptive activity when assessed in animal models using the abdominal constriction, hot plate and formalin tests (Zakaria et al. 2006, 2009).

Antipyretic Activity

The aqueous *S. nigrum* leaf extract produced significant, concentration-dependent antipyretic activity in animal model when assessed using the brewer's yeast-induced pyrexia tests (Zakaria et al. 2009).

Antiulcerogenic/Gastroprotective Activity

Solanum nigrum (aerial parts) powder and its methanolic extract decreased the ulcer index significantly in rats with ulcers induced by aspirin (Akhtar and Munir 1989). The activity may be due to inhibition of acid and pepsin secretions and/or their in-vitro ability to bind these. Jainu and Devi (2006) found that treatment of rats with *S. nigrum* fruit extract at higher dose significantly inhibited the gastric lesions induced by cold restraint stress (76.6%), indomethacin (73.8%), pyloric ligation (80.1%) and ethanol (70.6%), respectively, with equal or higher potency than omeprazole. The extract showed concomitant attenuation of gastric secretory volume, acidity and pepsin secretion in ulcerated rats. additionally, the extract (200 and 400 mg/kg body weight) accelerated the healing of acetic acid induced ulcers after the treatment for 7 days. The extract significantly inhibited H(+)K(+)ATPase activity and decreased the gastrin secretion in ethanol-induced ulcer model. These results further suggested that the extract possessed antiulcerogenic

as well as ulcer healing properties, which might also be due to its antisecretory activity.

Jainu and Devi (2004) found that the decreased levels of antioxidant enzymes and increased mucosal injury in rats induced by aspirin reverted to near normal status upon pretreatment with methanol *S. nigrum* fruit extract suggesting that the extract may exert its gastroprotective effect by a free radical scavenging action.

Angiogenesis Inhibition Activity

S. nigrum was found to inhibit the angiogenesis in the chick chorioallantoic membrane (Xu et al. 2008). The angiogenesis area was significantly smaller in the chick chorioallantoic membrane treated with *S. nigrum* than that in the control group.

Estrogenic Activity

The glycoside fraction of *Solanum nigrum* fruit exhibited both in-vitro and in-vivo estrogenic activity (Jisha et al. 2011). At low concentration (40 µg/mL), the fraction induced a dose-dependent increase in MCF-7 cell proliferation, while higher extract concentrations (80–320 µg/mL) caused progressive cell growth inhibition. The competitive binding assay using hydroxy apatite suggested that this effect was mediated by estrogen receptor. Mouse uterotrophic assay revealed a classical uterotrophic response in ovariectomized mice in response to *S. nigrum* glycoside fraction. The fraction at a dose of 100 mg/kg of body weight induced the maximum height of luminal epithelial cells which indicated an increase of 30.8% over control with a correlated increase in uterine wet weight (150% increase over control). Higher doses (250 and 500 mg/kg body wt) of the fraction did not induce any uterotrophic effect.

Antimalarial Activity

Studies by Chen et al. (2010) showed that the *Solanum* glycoalkaloids with chacotriose (chacanine and solamargine) showed higher antimalarial activity against *Plasmodium yoelii* in mice than

those with solatriose (solanine and solasonine). Chaconine was the most active among the five glycoalkaloids. The authors postulated that the activity was dependent upon non-specific carbohydrate interactions with the 6-OH of chaconine being important for antimalarial activity.

Mosquito Larvicidal Activity

S. nigrum leaf extract exhibited potent larvicidal activity against 3 mosquito species: *Anopheles culicifacies* Giles vector of malaria, *Culex quinquefasciatus* Say vector of filariasis and *Aedes aegypti* Linn a vector of dengue and dengue hemorrhagic fever (Singh et al. 2001). Hundred per cent larval mortality was observed within 24 h of exposure period in all 3 species at a concentration of 0.2%. The LC_{50} values of the water extract for *Anopheles culicifacies* instars I/II was 0.0167%, instars III/IV was 0.027%. The LC_{50} values of the water extract for *Culex quinquefasciatus* instars I/II was 0.019%, instars III/IV was 0.027 and that for *Aedes aegypti* instars III/IV was 0.032%. In another study, the 70% ethanol extract of *S. nigrum* leaves showed larvicidal activity against larvae of two mosquito species, *Aedes caspius* and *Culex pipiens*, (LC_{50} 51.29 and 125.89 mg/l within 24 h, and 21.38 and 38.11 mg/l within 48 h, respectively) (Ahmed et al. 2001). Hexane extract of *S. nigrum* dried fruit showed good mosquito larvicidal efficacy against five mosquito species namely *Anopheles culicifacies* species A, *Anopheles culicifacies* species C, *Anopheles stephensi*, *Culex quinquefasciatus* and *Aedes aegypti* than that of the aqueous extract (Raghavendra et al. 2009). The calculated LC_{90} for the extract for different species was below 100 ppm and could be effective for comprehensive control of disease vectors.

Of all the crude extracts of *S. nigrum* leaves, the ethyl acetate extract of *S. nigrum* provided the most potent mosquito larvicidal activity against *Culex quinquefasciatus* (Rawani et al. 2010). The mortality rates at 0.5% concentration were highest amongst all concentrations of the crude extracts tested against all the larval instars at 24, 48 and 72 h of exposure. Mortality rate with ethyl

acetate extract was significantly higher than other extracts when 50-ppm doses were used. The corresponding LC_{50} value of acetone, absolute alcohol, petroleum ether, chloroform: methanol (1:1 v/v), benzene and ethyl acetate extracts were 72.91 ppm, 59.81 ppm, 54.11 ppm, 32.69 ppm, 27.95 ppm and 17.04 ppm, respectively, after 24 h of exposure period.

Antimutagenic and Cytotoxic Activities

Among several edible plant species consumed as leafy vegetables, *S. nigrum* and *Sechium edule* extracts showed the strongest inhibitory effect towards the mutagenicity of 2-amino-3-methyl-imidazo[4,5-f]quinoline (IQ) in *Salmonella typhimurium* TA98 and TA100; the ID_{50} was less than 1 mg/plate (Yen et al. 2001). The immature fruit extracts of *S. nigrum* exhibited strong dose-dependent cytotoxicity and induced significant DNA damage in human lymphocytes based on the comet assay. For a direct mutagen, 4-nitroquinoline-N-oxide (NQNO), only *S. nigrum* extracts showed strong inhibitory effects in *Salmonella typhimurium* TA100 system.

Molluscicidal and Cercaricidal Activities

Water extract of *S. nigrum* leaves was found to have molluscicidal and cercaricidal activities against three Egyptian snail species (*Biomphalaria alexandrina*, *Bulinus truncatus* and *Lymnaea natalensis*), each an intermediate host of parasites causing human schistosomiasis or fascioliasis. (Ahmed and Ramzy 1997). The extract exhibited high molluscicidal activity, with median lethal concentrations (LC_{50}) of 18.6 mg/l for *Biomphalaria alexandrina*, 14.5 mg/l for *Bulinus truncatus* and 17.7 mg/l for *Lymnaea natalensis*. When *Biomphalaria alexandrina* infected with *Schistosoma mansoni* were exposed to the extract (20 or 25 mg/l), they shed significantly fewer cercariae than unexposed snails. The cercaricidal properties of the extract against *Schistosoma haematobium*,

Schistosoma mansoni and *Fasciola gigantica* cercariae followed a time-concentration relationship; the concentrations needed to kill all cercariae (LC_{100}) within 30 min of exposure were 30 mg/l for both *S. haematobium* and *S. mansoni* and 40 mg/l for *F. gigantica*. *Solanum nigrum villosum* exhibited molluscicidal and antiparasitic activities against the snail, *Galba truncatula* infected or uninfected with *Fasciola hepatica* (Hammami and Ayadi 2008). The unripe fruit extract (LC_{50} = 41.2 mg/l) was more toxic than the leaf (LC_{50} = 132.5 mg/l) and the ripe fruit (LC_{50} = 172.8 mg/l) extracts on the snail after 48 h of treatment. The unripe fruit extract was more toxic than the leaf and the ripe fruit extracts on larval stages of *F. hepatica*. Maximum deterioration rates were obtained with the unripe fruit extract: 65.6% for rediae, 77.8% for cercariae and 27.6% for intraredial germinal masses after 48 h of treating the snails. The hydro-methanol (MeOH-H₂O) immature *S. nigrum* fruit extract was found to possess the highest molluscicidal activity (LC_{50} = 3.96 mg/l) against the mollusca gastropoda *Galba truncatula* intermediate host of *Fasciola hepatica*, compared with other tested compounds (Hammami et al. 2011). The methanolic extract fraction isolated from the immature fruits was the richest in alkaloids and was the most toxic (LC_{50} = 1.65 mg/l). The fractions richest in saponosides obtained from the hydromethanolic and methanolic extracts of immature fruits showed interesting molluscicidal activities (LC_{50} = 6.15 mg/l and LC_{50} = 7.91 mg/l, respectively). The observed molluscicide activity could be attributed to the presence of alkaloids or saponosides in *S. nigrum* fruit.

The snail, *Biomphalaria arabica*, intermediate host for *Schistosoma mansoni*, treated with sublethal concentration of *S. nigrum*, generated cytotoxic ROS and antioxidants for protection of the tissue against the cytotoxicity (Al-Daihan et al. 2010). malondialdehyde, and the antioxidants glutathione (GSH) and catalase were significantly increased in *Solanum*-treated snails compared to controls and glutathione peroxidase decreased. The 70% ethanol extract of *S. nigrum* leaves showed the highest molluscicidal activity against *Biomphalaria alexandrina*, (LC_{50} 3.37 mg/l)

within 24 h (Ahmed et al. 2001). (El-Sherbini et al. 2009) found that *S. nigrum* mature leaf extract had the highest molluscicidal activity against *Biomphalaria alexandrina*, followed by *Solanum sinaicum* and the less one was *Solanum villosum*. When the mortality of different solvent extracts was compared, the maximum mortality was recorded at a concentration of 90 ppm of ethanol extract of *S. nigrum*. Ahmed and Rifaat (2004) found that binary (1:1) and tertiary combinations (1:1:1) of *Acanthus mollis* with *Solanum nigrum* and *Iris pseudacorus* gave good additive effects against *Biomphalaria alexandrina*. The use of sublethal concentration of (LC_{25}) of dry powdered leaves *S. nigrum* exhibited molluscicidal activity in the snail, *Biomphalaria arabica*, molluscan host to *Schistosoma mansoni* (Al-Daihan 2010). The plant molluscicide was potent in inhibiting ectonucleotidases (NTPdases) (ADPase & ATPase), sodium/potassium adenosine triphosphatase (Na⁺/K⁺ + ATPase) and creatine kinase (CK) enzymes presenting a percentage inhibition range between 45 and 55%. The results indicated that disturbing the biochemical profile of the snail hosts could be a promising and safe strategy to control schistosomiasis disease. Pre-treatment of Swiss female mice with *S. nigrum* leaf crude water extract prior to *Schistosoma mansoni* cercariae infection caused a significant reduction in cercarial penetration at 7.5 and 10 mg/l concentrations (Ahmed and Rifaat 2005). The mean number of worm burden declined from 28.5 worms/ mouse in untreated group to 4.4 worms/mouse with 7.5 mg/l treatment and a concentration of 10 mg/l, mice had no adult worm. The reduction in schistosome egg count (per gram liver) in hepatic tissue in treated mice was significant at 5 and 7.5 mg/l. The treatment with *Solanum* water extract had no effect on female mice fecundity.

Neuropharmacological Activity

S. nigrum ethanol fruit extract was found to possess potential CNS-depressant activity Perez et al. (1998). On intraperitoneal injection, the extract significantly prolonged pentobarbital-induced

sleeping time, produced alteration in the general behavior pattern, reduced exploratory behavior pattern, suppressed the aggressive behavior, affected locomotor activity and reduced spontaneous motility of the experimental animals.

The presence of acetylcholine in aqueous extracts of the fruit of *Solanum nigrum* was confirmed from the following pharmacological tests: (a) isotonic contraction of the isolated toad rectus abdominis; (b) negative chronotropic and inotropic action on the isolated toad heart; (c) isotonic contraction of the isolated guinea pig's ileum; (d) isotonic contraction of the rat's isolated jejunum; (e) decrease on the cat's arterial blood pressure; (f) secretory effects on the rat's submaxillary gland (de Melo et al. 1978). These actions were selectively blocked by curate or atropine and disappeared after incubation of the extract at 37°C with plasma.

Anticonvulsant Activity

The aqueous leaf extract of *S. nigrum* produced a significantly dose dependent protection against electrically-induced seizure in chicks and rats, pentylenetetrazole-induced seizure and picrotoxin-induced in mice and rats (Wannang et al. 2008). The anti-seizure property of the extract was potentiated by amphetamine.

Neuroprotective Activity

The oral administration of *S. nigrum* aqueous leaf extract for 30 days to lead acetate affected mice significantly increased the levels of antioxidants (SOD, CAT, GPx) and decreased the level of lipid peroxidation (LPO), protecting against lead acetate induced neurotoxicity in brains of albino mice (Chinthana and Ananthi 2012).

Traditional Medicinal Uses

All parts of *S. nigrum* plant have been used in traditional folkloric medicine mainly in Asia and Africa for a diverse array of disorders and

ailments (Watt and Breyer-Brandwijk 1962; Grieve 1971; Chopra et al. 1986; Burkill 1966; Saijo et al. 1982; Akhtar and Munir 1989; Schilling et al. 1992; Edmonds and Chweya 1997; Dokosi 1998; Singh et al. 2001; Hebbar et al. 2004; Kokwaro 2009; Mohamed Saleem et al. 2009; Jain et al. 2011; Stuart 2012; Gogoi and Islam 2012; Ding et al. 2012). The plants has been traditionally used as an analgesic, antispasmodic, antiseptic, antidysentric, antinarcotic, cardiogenic, digestive, diuretic, laxative, expectorant, antiasthmatic, diaphoretic, sedative, emollient, diuretic, tonic, soporific, anticancer, antiulcer and for disorders of neuro-vegetative system etc. These medicinal properties are mainly attributed to the steroidal glycoalkaloidal contents of the plants. The plant is used as a remedy for treating cardiopathy, leprosy, haemorrhoids, nephropathy, ophthalmopathy, dropsy, cough, asthma, swellings and general debility. The roots have been reported useful for otopathy, ophthalmopathy, rhinopathy and hepatitis. The leaves are employed as a poultice for rheumatic, arthritic and gouty joints, skin diseases, and used as a cure for tuberculosis. Leaves are employed in dropsy, nausea and nervous disorders. Decoction of flowers and fruits are used to treat cough, erysipelas, pulmonary tuberculosis and bronchitis. The juice of the berries is used as an antidiarrhoea, ophthalmopathy and hydrophobia. It is also used in anasarca and heart disease. Berries are used also as tonic, diuretic and for this cathartic properties. Seeds are useful in giddiness, dipsia and for treating skin diseases and inflammations.

In various parts of Africa, the plant is used as cure for malaria, dysentery and blackwater fever. A plant infusion is employed as an enema for abdominal disorders in children and plant sap or decoction is employed as an ointment for foul ulcers. The plant extract is also used for disinfecting anthrax-infected meat. The plant is also used as an emetic, diuretic and for treating headaches. Burnt and powdered roots are applied to the back for lumbago, and roots boiled in milk are administered to children as a tonic. Raw roots are also taken in raw to relieve stomach upsets. Pounded leaves are fermented in water and used to treat ulcers, boils and swollen glands. Leaves

are used in soup to treat jaundice, and also used as purgative and diuretic. Leaf sap extract is used to relieve chronic conjunctivitis and related inflammations. Individuals with heart pains eat the leaves raw. A poultice made from leaves is applied externally to treat Guinea worm. Pounded leaf infusion is used for tonsillitis. Leaves boiled with milk are employed for sudden stomach ache, to boost the health of expectant women and to relax the uterus of both pregnant and lactating mothers. The same leaf mixture is used to relieve muscular pains among the elderly and those with arthritis, and for strengthening weak bodies and to prevent skin eruptions. Infusion of pounded leaves and seeds are rubbed onto the gum of children with crooked teeth. Raw fruit are chewed and swallowed as a remedy for stomach ulcers and abdominal disorders. Unripe berries are used as a treatment for ringworm and are applied to aching teeth and babies' gums to relieve pain during teething.

In India, the plant has been extensively used in traditional ethnomedicine to cure liver disorders, chronic skin ailments (psoriasis and ringworm), inflammatory conditions, painful periods, fevers, diarrhoea, eye diseases, hydrophobia, ocular diseases, toothache, stomach disorders, cough and jaundice. The plant is noted for its antiseptic and antidyenteric properties and is given internally for cardalgia and gripe. Freshly prepared plant extracts are used for the treatment of cirrhosis of the liver and also serve as an antidote to opium poisoning. An alcoholic extract of leaves is active against bacteria such as *Staphylococcus aureus* and *Escherichia coli*. A liquid extract of the leaves and stems is employed in dropsy, in heart diseases, skin diseases, piles, gonorrhoea, inflammatory swellings, and chronic enlargement of the liver and spleen. A syrup of it is used as a cooling drink in fevers, and to promote perspiration. The heated leaves are applied to painful and swollen testicles. In Hindu medicine, the berries are tonic, diuretic, and useful in anasarca and heart diseases. The juice from the berries is laxative and diuretic and may be applied as dropsy and for domestic treatments of fevers, ulcers and heart disease. A decoction of the berries and flowers is said to be useful in coughs, and

consumption. The seeds are reportedly used to treat gonorrhoea and dysuria.

In the Philippines, the leaves, when prepared in poultices, are said to have sedative and healing properties, and when prepared as an alcoholate, are said to alleviate neuralgic pains. The fruit is reputed, to be a remedy for diabetes. The leaf extract has been reported to be useful to restore body skin pigment. In the Philippines and Malaysia the leaf decoction is used as a lotion for yaws. *Solanum nigrum* is used as a traditional Chinese medicinal herb endowed with diuretic, antipyretic and hepatoprotective effects, has been used as a major ingredient of folk prescriptions for anticancer treatment in China. The leaves, shoots and root are applied to wounds and sores. the juice of the leaves is used to alleviate the pain in inflammation of the kidneys and bladder and in virulent gonorrhoea. The leaves are used as a vegetable, yielding a heat-clearing effect and as a febrifugal or detoxicant drug. Whole plant can be used for treating inflammation, dissipating blood stasis, and promoting the subsidence of swelling, also clearing away heat and detoxifying. Dried aerial parts of plants were used as a diuretic, anti-hypertensive and anticancer agent for infections of the urinary system, hypertension and cancer of the digestive system.

In Mexico, a decoction of the plant is reported to be employed externally as a cooling agent, as a vulnerary in the form of fomentations, and for vaginal irrigation. In Sinaloa, the roots are reported to be used as a cure for bubonic plague. Pounded fresh leaves and juice are used to cure eye inflammation and other skin afflictions. Boiled young shoots are eaten and are believed to be corrective, cooling, and tonic to men for increasing virility and women with menstrual disorders. The fruit is a domestic cure for erysipelas and a paste of the immature fruit is employed to treat ringworm. In Hawaii, the plant has been reported to be used in disorders of the respiratory tract, skin eruptions, cuts, wounds and trachoma. In Ecuador, the flowers and leaves have been reported to be used to alleviate fever and combat the effects of alcoholic excesses.

In Europe, the plant has been used as a remedy for convulsions, and has been administered as a

soporific in Germany especially for children, with leaves being placed in babies' cradles to promote sleep. The pounded fresh leaves used externally are reputed to relieve pain and reduce inflammation; they are applied to burns and ulcers by the Arabs. Leaf juice has also been used for ringworm, gout and earache, and is also deemed to be an effective gargle and mouthwash when mixed with vinegar.

Other Uses

In various parts of Africa, the plant has been reported to be used as a fodder by browsing animals including cattle, goats and sheep. However, eating large quantities has been suggested to be toxic to cattles.

S. nigrum has fungicidal activity. A full-length 910 bp cDNA encoding osmotin-like protein with an open reading frame of 744 bp encoding a protein of 247 amino acids with a calculated molecular mass of 26.8 kDa was cloned from *Solanum nigrum* (Jami et al. 2007). The recombinant protein purified from overexpressed *Escherichia coli* cells showed hyphal growth inhibition in phytopathogens *Rhizoctonia batitcola* and *Sclerotinia sclerotiorum* but without any endo- β -1,3-glucanase activity. An ethanol extract of *Solanum nigrum* was found to inhibit spore germination of *Alternaria brassicicola*, the causative agent of cabbage black leaf spot disease. (Lin et al. 2011). At a concentration of 500 mg/l, this ethanol extract also caused the germ tubes to become completely swollen. Further, an n-butanol fraction of the ethanol extract exhibited strong antifungal activity; at a concentration of 25 mg/l, a derived subfraction (Bu-11-13) powder showed complete inhibition of spore germination and was identified as degalactotiginin.

Comments

Blackberry nightshade (*Solanum nigrum*) is regarded as an environmental weed in Victoria, Western Australia, New South Wales, Queensland and the Northern Territory.

Selected References

- Afolayan AJ, Jimoh FO (2008) Nutritional quality of some wild leafy vegetables in South Africa. *Int J Food Sci Nutr* 26:1–8
- Ahmed AH, Ramzy RM (1997) Laboratory assessment of the molluscicidal and cercaricidal activities of the Egyptian weed, *Solanum nigrum* L. *Ann Trop Med Parasitol* 91(8):931–937
- Ahmed AH, Rifaat MM (2004) Molluscicidal and cercaricidal efficacy of *Acanthus mollis* and its binary and tertiary combinations with *Solanum nigrum* and *Iris pseudacorus* against *Biomphalaria alexandrina*. *J Egypt Soc Parasitol* 34(3):1041–1050
- Ahmed AH, Rifaat MM (2005) Effects of *Solanum nigrum* leaves water extract on the penetration and infectivity of *Schistosoma mansoni* cercariae. *J Egypt Soc Parasitol* 35(1):33–40
- Ahmed AH, Kamal IH, Ramzy RM (2001) Studies on the molluscicidal and larvicidal properties of *Solanum nigrum* L. leaves ethanol extract. *J Egypt Soc Parasitol* 31(3):843–852
- Akhtar MS, Munir M (1989) Evaluation of the gastric antiulcerogenic effects of *Solanum nigrum*, *Brassica oleracea* and *Ocimum basilicum* in rats. *J Ethnopharmacol* 27(1–2):163–176
- Al Chami L, Méndez R, Chataing B, O'Callaghan J, Usubillaga A, LaCruz L (2003) Toxicological effects of alpha-solamargine in experimental animals. *Phytother Res* 17(3):254–258
- Al-Daihan S (2010) Effect of plant molluscicides on selected enzymes related to energy metabolism in *Biomphalaria arabica* snails molluscan hosts to *Schistosoma mansoni* in Saudi Arabia. *J Egypt Soc Parasitol* 40(1):187–195
- Al-Daihan S, Kaggwa JS, El-Ansary AK (2010) The effect of a sublethal concentration of *Solanum nigrum* on some antioxidants in *Biomphalaria arabica*. *J Egypt Soc Parasitol* 40(1):205–214
- Al-Qirim T, Zaidi SM, Shahwan M, Shattat G, Banu N (2008) Effect of *Solanum nigrum* on immobilization stress induced antioxidant defense changes in rat. *Res J Biol Sci* 3(12):1426–1429
- An HJ, Kwon KB, Cho HI, Seo EA, Ryu DG, Hwang WJ, Yoo SJ, Kim YK, Hong SH, Kim HM (2005) *Solanum nigrum* produces nitric oxide via nuclear factor-kappaB activation in mouse peritoneal macrophages. *Eur J Cancer Prev* 14(4):345–350
- Arulmozhi V, Krishnaveni M, Karthishwaran K, Dhamodharan G, Mirunalini S (2010) Antioxidant and antihyperlipidemic effect of *Solanum nigrum* fruit extract on the experimental model against chronic ethanol toxicity. *Pharmacogn Mag* 6(21):42–50
- Bean AR (2006) *Solanum* species of Eastern Australia. <http://delta-intkey.com/solanum/www/intro.htm>. Queensland Herbarium, Toowong
- Briggs LH, Cambie RC, Hoare JL (1961) *Solanum* alkaloids. Part XV. The constituents of some *Solanum* species and a reassessment of solasodamine and solauricine. *J Chem Soc* 1961:4645–4649

- Bromilow C (1995) Problem plants of south Africa. Briza Publications, Pretoria, 315 pp
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula, Revised reprint, 2 vols. Ministry of agriculture and co-operatives, Kuala Lumpur, pp 1–1240, 1241–2444, vol 1 (A–H), vol 2 (I–Z).
- Carle R (1981) Investigations on the content of steroidal alkaloids and sapogenins within *Solanum* sect. *Solanum* (= sect. *Morella*) (Solanaceae). Plant Syst Evol 138(1–2):61–71
- Chen R, Feng L, Li HD, Zhang H, Yang F (2009) Two novel oligosaccharides from *Solanum nigrum*. Carbohydr Res 344(13):1775–1777
- Chen Y, Li S, Sun F, Han H, Zhang X, Fan Y, Tai G, Zhou Y (2010) In vivo antimalarial activities of glycoalkaloids isolated from Solanaceae plants. Pharm Biol 48(9):1018–1024
- Chinthana P, Ananthi T (2012) Protective Effect of *Solanum nigrum* and *Solanum trilobatum* aqueous leaf extract on lead induced neurotoxicity in albino mice. J Chem Pharm Res 4(1):72–74
- Chopra RN, Nayar SL, Chopra IC (1986) Glossary of Indian medicinal plants (Including the supplement). Council Scientific Industrial Research, New Delhi, 330 pp
- Chweya JA (1997) Genetic enhancement of indigenous vegetables in Kenya. In Guarino L (ed) Traditional African vegetables. Promoting the conservation and use of underutilized and neglected crops. 16. In: Proceedings of the IPGRI international workshop on genetic resources of traditional vegetables in Africa: conservation and use, 29–31 Aug 1995, ICRAF-HQ, Nairobi, Kenya. Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute, Rome, Italy, pp 90–99
- Conn BJ (2007) *Solanum nigrum* L. New South Wales flora online. PlantNET – The plant information network system of Botanic Gardens Trust. <http://plantnet.rbg Syd.nsw.gov.au>. Royal Botanic Gardens and Domain Trust, Sydney
- de Melo AC, Perec CJ, Rubio MC (1978) Acetylcholine-like activity in the fruit of the black nightshade (Solanaceae). Acta Physiol Lat Am 28(4–5):19–26
- Dhellot JR, Matouba E, Maloumbi MG, Nzikou JM, Dzondo MG, Linder M, Parmentier M, Desobry S (2006) Extraction and nutritional properties of *Solanum nigrum* L seed oil. Afr J Biotechnol 5(10):987–991
- Ding X, Zhu FS, Li M, Gao SG (2012) Induction of apoptosis in human hepatoma SMMC-7721 cells by solamargine from *Solanum nigrum* L. J Ethnopharmacol 139(2):599–604
- Dokosi OB (1998) Herbs of Ghana. Ghana University Press, Accra, 746 pp
- Edmonds JM, Chweya JA (1997) Black nightshades, *Solanum nigrum* L., and related species, Promoting the conservation and Use of underutilized and neglected crops 15. IPGRI/IPK, Rome/Gatersleben, 113 pp
- Elango V, Oliver C, Raghu PS (2012) Anti-inflammatory activity of the flower extracts of *Solanum nigrum* in rats. Hygeia J D Med 4(1):59–62
- El-Sherbini GT, Zayed RA, El-Sherbini ET (2009) Molluscicidal activity of some *Solanum* species extracts against the snail *Biomphalaria alexandrina*. J Parasitol Res 2009 (2009), Article ID 474360
- Eltayeb EA, Al-Ansari AS, Roddick JG (1997) Changes in the steroidal alkaloid solasodine during development of *Solanum nigrum* and *Solanum incanum*. Phytochemistry 46(3):489–494
- FAO (1988) Traditional food plants. A resource book for promoting the exploitation and consumption of food plants in arid, semi-arid and sub-humid lands of Eastern Africa, FAO food and nutrition paper 42. FAO, Rome, pp 458–466
- Fortuin FTJM, Omta SWP (1980) Growth analysis and shade experiment with *Solanum nigrum* L., the black nightshade, a leaf and a fruit vegetable in West Java. Neth J Agric Sci 28(4):199–210
- Foundation for Revitalisation of Local Health Traditions (2008) FRLHT Database. <http://envis.frlht.org>
- Fox FW, Norwood Young ME (1982) Food from the veld: edible wild plants of Southern Africa. Delta Books, Johannesburg, 399 pp
- Glew RS, Amoako-Atta B, Ankar-Brewoo G, Presley J, Chuang LT, Millson M, Smith BR, Glew RH (2009) Non-cultivated plant foods in West Africa: nutritional analysis of the leaves of three indigenous leafy vegetables in Ghana. Food 3(1):39–42
- Gogoi P, Islam M (2012) Ethnomedicinal study of *Solanum nigrum* L and *S. myriacanthus* Dunal used by tribals and non-tribals from districts of Upper Assam, India. Asian J Exp Biol Sci 3(1):73–81
- Grieve M (1971) A modern herbal. Penguin, 2 vols. Dover publications, New York, 919 pp
- Hammami H, Ayadi A (2008) Molluscicidal and antiparasitic activity of *Solanum nigrum* villosum against *Galba truncatula* infected or uninfected with *Fasciola hepatica*. J Helminthol 82(3):235–239
- Hammami H, Mezghani-Jarraya R, Damak M, Ayadi A (2011) Molluscicidal activity of various solvent extracts from *Solanum nigrum* var. *villosum* L. aerial parts against *Galba truncatula*. Parasite 18(1):63–70
- Hebbbar SS, Harsha VH, Shripathi V, Hegde GR (2004) Ethnomedicine of Dharwad district in Karnataka, India – plants used in oral health care. J Ethnopharmacol 94(2–3):261–266
- Henderson RJF (1974) *Solanum nigrum* L. (Solanaceae) and related species in Australia. Contrib Qld Herb 16:1–78
- Heo KS, Lim KT (2004) Antioxidative effects of glycoprotein isolated from *Solanum nigrum* L. J Med Food 7(3):349–357
- Heo KS, Lim KT (2005) Glycoprotein isolated from *Solanum nigrum* L. modulates the apoptotic-related signals in 12-O-tetradecanoylphorbol 13-acetate-stimulated MCF-7 cells. J Med Food 8(1):69–77
- Heo KS, Lee SJ, Ko JH, Lim K, Lim KT (2004a) Glycoprotein isolated from *Solanum nigrum* L. inhibits the DNA-binding activities of NF-kappaB and AP-1, and increases the production of nitric oxide in TPA-stimulated MCF-7 cells. Toxicol In Vitro 18(6):755–763

- Heo KS, Lee SJ, Lim KT (2004b) Cytotoxic effect of glycoprotein isolated from *Solanum nigrum* L. through the inhibition of hydroxyl radical-induced DNA-binding activities of NF-kappa B in HT-29 cells. *Environ Toxicol Pharmacol* 17(1):45–54
- Holm LG, Plucknett DL, Pancho JV, Herberger JP (1977) The world's worst weeds: distribution and biology. East-west Center, University Press of Hawaii, Honolulu, 609 pp
- Hsieh CC, Fang HL, Lina WC (2008) Inhibitory effect of *Solanum nigrum* on thioacetamide-induced liver fibrosis in mice. *J Ethnopharmacol* 119(1):117–121
- Hsu JD, Kao SH, Tu CC, Li YJ, Wang CJ (2009) *Solanum nigrum* L. extract inhibits 2-acetylaminofluorene-induced hepatocarcinogenesis through overexpression of glutathione S-transferase and antioxidant enzymes. *J Agric Food Chem* 57(18):8628–8634
- Hu SY (2005) Food plants of China. The Chinese University Press, Hong Kong, 844 pp
- Hu K, Kobayashi H, Dong A, Jing Y, Iwasaki S, Yao X (1999) Antineoplastic agents III: steroidal glycosides from *Solanum nigrum*. *Planta Med* 65:35–38
- Huang HC, Syu KY, Lin JK (2010) Chemical composition of *Solanum nigrum* Linn extract and induction of autophagy by leaf water extract and its major flavonoids in AU565 breast cancer cells. *J Agric Food Chem* 58(15):8699–8708
- Ikeda T, Ando J, Miyazono Zhu XH, Tsumagari H, Nohara T, Yokomizo K, Uyeda M (2000a) Anti-herpes virus activity of *Solanum* steroidal glycosides. *Biol Pharm Bull* 23(3):363–364
- Ikeda T, Tsumagari H, Nohara T (2000b) Steroidal oligoglycosides from *Solanum nigrum* L. *Chem Pharm Bull* 48(7):1062–1064
- Itoh T, Tamura T, Matsumoto T (1977a) 4-desmethylsterols in the seeds of Solanaceae. *Steroids* 30(3):425–433
- Itoh T, Tamura T, Matsumoto T (1977b) Triterpene alcohols in the seeds of Solanaceae. *Phytochemistry* 16(11):1973–1976
- Itoh T, Ishii T, Tamura T, Matsumoto T (1978) Four new and other 4 α -methylsterols in the seeds of Solanaceae. *Phytochemistry* 17(5):971–977
- Jain R, Sharma A, Gupta S, Sarethy IP, Gabrani R (2011) *Solanum nigrum*: current perspectives on therapeutic properties. *Altern Med Rev* 16(1):78–85
- Jainu M, Devi CSS (2004) Antioxidant effect of methanolic extract of *Solanum nigrum* berries on aspirin induced gastric mucosal injury. *Indian J Clin Biochem* 19(1):57–61
- Jainu M, Devi CSS (2006) Antiulcerogenic and ulcer healing effects of *Solanum nigrum* (L.) on experimental ulcer models: possible mechanism for the inhibition of acid formation. *J Ethnopharmacol* 104(1–2):156–163
- Jami SK, Swathi Anuradha T, Guruprasad L, Kirti PB (2007) Molecular, biochemical and structural characterization of osmotin-like protein from black nightshade (*Solanum nigrum*). *J Plant Physiol* 164(3):238–252
- Jansen PCM (2008) *Solanum nigrum* L. [Internet] Record from Protabase. In: Schmelzer GH, Gurib-Fakim A (eds) PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen. <http://database.prota.org/search.htm>
- Javed T, Ashfaq UA, Riaz S, Rehman S, Riazuddin S (2011) In-vitro antiviral activity of *Solanum nigrum* against Hepatitis C Virus. *Virol J* 8:26
- Jeong JB, Jeong HJ, Park JH, Lee SH, Lee JR, Lee HK, Chung GY, Choi JD, de Lumen BO (2007) Cancer-preventive peptide lunasin from *Solanum nigrum* L. inhibits acetylation of core histones H3 and H4 and phosphorylation of retinoblastoma protein (Rb). *J Agric Food Chem* 55(26):10707–10713
- Jeong JB, De Lumen BO, Jeong HJ (2010) Lunasin peptide purified from *Solanum nigrum* L. protects DNA from oxidative damage by suppressing the generation of hydroxyl radical via blocking fenton reaction. *Cancer Lett* 293(1):58–64
- Ji YB, Gao SY, Ji CF, Zou X (2008) Induction of apoptosis in HepG2 cells by solanine and Bcl-2 protein. *J Ethnopharmacol* 115(2):194–202
- Jimoh FO, Adedapo AA, Afolayan AJ (2010) Comparison of the nutritional value and biological activities of the acetone, methanol and water extracts of the leaves of *Solanum nigrum* and *Leonotis leonorus*. *Food Chem Toxicol* 48(3):964–971
- Jisha S, Sreeja S, Manjula S (2011) In vitro & in vivo estrogenic activity of glycoside fractions of *Solanum nigrum* fruit. *Indian J Med Res* 134(3):369–374
- Kang H, Jeong HD, Choi HY (2011) The chloroform fraction of *Solanum nigrum* suppresses nitric oxide and tumor necrosis factor- α in LPS-stimulated mouse peritoneal macrophages through inhibition of p38, JNK and ERK1/2. *Am J Chin Med* 39(6):1261–1273
- Khanna P, Rathore AK (1977) Diosgenin and solasodine from *Solanum nigrum* L. complex. *Indian J Exp Biol* 15:808–809
- Kokwaro JO (2009) Medicinal plants of east Africa, 3rd edn. University of Nairobi Press, Nairobi, 534 pp
- Kumar PV, Shashidhara S, Kumar MM, Sridhara BY (2001) Cytoprotective role of *Solanum nigrum* against gentamicin-induced kidney cell (Vero cells) damage in vitro. *Fitoterapia* 72(5):481–486
- Kuo KW, Hsu SH, Li YP, Lin WL, Liu LF, Chang LC, Lin CC, Lin CN, Sheu HM (2000) Anticancer activity evaluation of the *solanum* glycoalkaloid solamargine. Triggering apoptosis in human hepatoma cells. *Biochem Pharmacol* 60(12):1865–1873
- Kwon YI, Apostolidis E, Shetty K (2008) In vitro studies of eggplant (*Solanum melongena*) phenolics as inhibitors of key enzymes relevant for type 2 diabetes and hypertension. *Bioresour Technol* 99(8):2981–2988
- Lee SJ, Lim KT (2006a) Apoptosis induced by glycoprotein (150-kDa) isolated from *Solanum nigrum* L. is not related to intracellular reactive oxygen species (ROS) in HCT-116 cells. *Cancer Chemother Pharmacol* 57(4):507–516

- Lee SJ, Lim KT (2006b) 150 kDa glycoprotein isolated from *Solanum nigrum* Linne stimulates caspase-3 activation and reduces inducible nitric oxide production in HCT-116 cells. *Toxicol In Vitro* 20(7):1088–1097
- Lee SJ, Lim KT (2008) Cell death signal by glycine- and proline-rich plant glycoprotein is transferred from cytochrome c and nuclear factor kappa B to caspase 3 in Hep3B cells. *J Nutr Biochem* 19(3):166–174
- Lee SJ, Oh PS, Ko JH, Lim K, Lim KT (2004) A 150-kDa glycoprotein isolated from *Solanum nigrum* L. has cytotoxic and apoptotic effects by inhibiting the effects of protein kinase C alpha, nuclear factor-kappa B and inducible nitric oxide in HCT-116 cells. *Cancer Chemother Pharmacol* 54(6):562–572
- Lee SJ, Ko JH, Lim KT (2005a) Glycine- and proline-rich glycoprotein isolated from *Solanum nigrum* Linne activates caspase-3 through cytochrome c in HT-29 cells. *Oncol Rep* 14(3):789–796
- Lee SJ, Ko JH, Lim K, Lim KT (2005b) 150 kDa glycoprotein isolated from *Solanum nigrum* Linne enhances activities of detoxicant enzymes and lowers plasmic cholesterol in mouse. *Pharmacol Res* 51(5):399–408
- Li J, Li QW, Feng T, Zhang T, Li K, Zhao R, Han Z, Gao D (2007) Antitumor activity of crude polysaccharides isolated from *Solanum nigrum* Linne on U14 cervical carcinoma bearing mice. *Phytother Res* 21(9):832–840
- Li J, Li QW, Feng T, Li K (2008a) Aqueous extract of *Solanum nigrum* inhibit growth of cervical carcinoma (U14) via modulating immune response of tumor bearing mice and inducing apoptosis of tumor cells. *Fitoterapia* 79(7–8):548–556
- Li J, Li QW, Gao DW, Han ZS, Li K (2008b) Antitumor effects of total alkaloids isolated from *Solanum nigrum* in vitro and in vivo. *Pharmazie* 63(7):534–538
- Li J, Li QW, Gao DW, Han ZS, Lu WZ (2009) Antitumor and immunomodulating effects of polysaccharides isolated from *Solanum nigrum* Linne. *Phytother Res* 23(11):1524–1530
- Li J, Li QW, Peng Y, Zhao R, Han Z, Gao D (2010) Protective effects of fraction 1a of polysaccharides isolated from *Solanum nigrum* Linne on thymus in tumor-bearing mice. *J Ethnopharmacol* 129(3):350–356
- Liang CH, Liu LF, Shiu LY, Huang YS, Chang LC, Kuo KW (2004) Action of solamargine on TNFs and cisplatin-resistant human lung cancer cells. *Biochem Biophys Res Commun* 322(3):751–758
- Liang CH, Shiu LY, Chang LC, Sheu HM, Kuo KW (2007) Solamargine upregulation of Fas, downregulation of HER2, and enhancement of cytotoxicity using epirubicin in NSCLC cells. *Mol Nutr Food Res* 51:999–1005
- Liang CH, Shiu LY, Chang LC, Sheu HM, Tsai EM, Kuo KW (2008) Solamargine enhances HER2 expression and increases the susceptibility of human lung cancer H661 and H69 cells to trastuzumab and epirubicin. *Chem Res Toxicol* 21(2):393–399
- Lim KT (2005) Glycoprotein isolated from *Solanum nigrum* L. kills HT-29 cells through apoptosis. *J Med Food* 8(2):215–226
- Lin HM, Tseng HC, Wang CJ, Chyau CC, Liao KK, Peng PL, Chou FP (2007) Induction of autophagy and apoptosis by the extract of *Solanum nigrum* Linn in HepG2 cells. *J Agric Food Chem* 55(9):3620–3628
- Lin HM, Tseng HC, Wang CJ, Lin JJ, Lo CW, Chou FP (2008) Hepatoprotective effects of *Solanum nigrum* Linn extract against CCl4-induced oxidative damage in rats. *Chem Biol Interact* 171(3):283–293
- Lin TC, Fan MC, Wang SY, Huang JW (2011) Identification of the *Solanum nigrum* extract component involved in controlling cabbage black leaf spot disease. *J Agric Food Chem* 59(5):1667–1672
- Liu LF, Liang CH, Shiu LY, Lin WL, Lin CC, Kuo KW (2004) Action of solamargine on human lung cancer cells—enhancement of the susceptibility of cancer cells to TNFs. *FEBS Lett* 577(1–2):67–74
- Lomash V, Parihar SK, Jain NK, Katiyar AK (2010) Effect of *Solanum nigrum* and *Ricinus communis* extracts on histamine and carrageenan-induced inflammation in the chicken skin. *Cell Mol Biol (Noisy-le-Grand)* 56(Suppl):OL1239–OL1251
- Milner SE, Brunton NP, Jones PW, O' Brien NM, Collins SG, Maguire AR (2011) Bioactivities of glycoalkaloids and their aglycones from *Solanum* species. *J Agric Food Chem* 59(8):3454–3484
- Mohamed Saleem TS, Chetty CM, Ramkanth S, Alagusundaram M, Gnanaprakash K, Thiruvengada Rajan VS, Angalaparameswari S (2009) *Solanum nigrum* Linn.- a review. *Pharmacogn Rev* 3:342–345
- Mohy-Ud-Din A, Khan Z-U-D, Ahmad M, Kashmiri MA, Yasmin S, Mazhar H (2009) Chemotaxonomic significance of flavonoids in the *Solanum nigrum* complex. *J Chil Chem Soc* 54(4):486–490
- Mohy-Ud-Din A, Khan Z-U-D, Ahmad M, Kashmiri MA (2010) Chemotaxonomic value of alkaloids in *Solanum nigrum* complex. *Pak J Bot* 42(1):653–660
- Nawab A, Thakur VS, Yunus M, Ali Mahdi A, Gupta S (2012) Selective cell cycle arrest and induction of apoptosis in human prostate cancer cells by a polyphenol-rich extract of *Solanum nigrum*. *Int J Mol Med* 29(2):277–284
- Nawwar MAM, El-Mousallamy AMD, Barakat HH (1989) Quercetin 3-glycosides from the leaves of *Solanum nigrum*. *Phytochemistry* 28(6):1755–1757
- Nirmal SA, Patel AP, Bhawar SB, Pattan SR (2012) Antihistaminic and antiallergic actions of extracts of *Solanum nigrum* berries: possible role in the treatment of asthma. *J Ethnopharmacol* 142(1):91–97
- Nzikou JM, Mvoula-Tsieri M, Matos L, Matouba E, Ngakegni-Limbili AC, Linder M, Desobry S (2007) *Solanum nigrum* L. seeds as an alternative source of edible lipids and nutriment in Congo Brazzaville. *J Appl Sci* 7:1107–1115
- Ochse JJ, van den Brink RC B (1980) *Vegetables of the Dutch Indies*, 3rd edn. Ascher & Co, Amsterdam, 1016 pp
- Ohno M, Murakami K, El-Aasr M, Zhou JR, Yokomizo K, Ono M, Nohara T (2012) New spirostanol glycosides from *Solanum nigrum* and *S. jasminoides*. *J Nat Med* 66(4):658–663

- Pacific Island Ecosystems at Risk (PIER) (2006) *Solanum nigrum* Cav., Solanaceae. http://www.hear.org/pier/species/solanum_nigrum.htm
- Patel S, Gheewala N, Suthar A, Shah A (2009) In-vitro cytotoxicity activity of *Solanum nigrum* extract against hela cell line and vero cell line. *Int J Pharm Pharm Sci* 1(1):38–46
- PBI Solanum Project (2011) Solanaceae Source. May 2011. <http://www.nhm.ac.uk/solanaceaesource/>
- Perez RM, Perez JA, Garcia LM, Sossa H (1998) Neuropharmacological activity of *Solanum nigrum* fruit. *J Ethnopharmacol* 62(1):43–48
- Poccai P, Hyvönen J (2011) On the origin of *Solanum nigrum*: can networks help? *Mol Biol Rep* 38(2):1171–1185
- Porcher MH et al (1995–2020) Searchable World Wide Web multilingual multiscrypt plant name database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Raghavendra K, Singh SP, Subbarao SK, Dash AP (2009) Laboratory studies on mosquito larvicidal efficacy of aqueous & hexane extracts of dried fruit of *Solanum nigrum* Linn. *Indian J Med Res* 130(1):74–77
- Raju K, Anbuganapathi G, Gokulakrishnan V, Rajkapoor B, Jayakar B, Manian S (2003) Effect of dried fruits of *Solanum nigrum* Linn against CCl₄-induced hepatic damage in rats. *Biol Pharm Bull* 26(11):1618–1619
- Rao GR (1978) Role of fruit pigments in understanding the inter-relationships and mechanism of evolution of higher chromosomal forms of the species of the *Solanum nigrum* L. complex. *Acta Bot Indic* 6(Suppl):41–47
- Ravi V, Saleem TSM, Maiti PP, Gauthaman K, Ramamurthy J (2009a) Phytochemical and pharmacological evaluation of *Solanum nigrum* Linn. *Afri J Pharm Pharmacol* 3(9):454–457
- Ravi V, Saleem TSM, Patel SS, Raamamurthy J, Gauthaman K (2009b) Anti-inflammatory effect of methanolic extract of *Solanum nigrum* Linn berries. *Int J Appl Res Nat Prod* 2(2):33–36
- Rawani A, Ghosh A, Chandra G (2010) Mosquito larvicidal activities of *Solanum nigrum* L. leaf extract against *Culex quinquefasciatus* Say. *Parasitol Res* 107(5):1235–1240
- Saijo R, Murakami K, Nohara T, Tomimatsu T, Sato A, Matsuoka K (1982) Studies on the constituents of *Solanum* plants. II. On the constituents of the immature berries of *Solanum nigrum* L. *Yakugaku Zasshi* 102(3):300–305, In Japanese
- Sánchez-Mata MC, Yokoyama WE, Hong YJ, Prohens J (2010) Alpha-solasonine and alpha-solamargine contents of gbmoma (*Solanum macrocarpon* L.) and scarlet (*Solanum aethiopicum* L.) eggplants. *J Agric Food Chem* 58(9):5502–5508
- Savchenko T, Whiting P, Germade A, Dinan L (2000) Ecdysteroid agonist and antagonist activities in species of the Solanaceae. *Biochem Syst Ecol* 28(5):403–419
- Schilling EE, Ma QS, Anderson RN (1992) Common names and species identification in blacknightshades, *Solanum* sect. *Solanum* (Solanaceae). *Econ Bot* 46:223–225
- Sharma SC, Chand R, Sati OP, Sharma AK (1983) Oligofurostanosides from *Solanum nigrum*. *Phytochemistry* 22(5):1241–1244
- Shiu LY, Chang LC, Liang CH, Huang YS, Sheu HM, Kuo KW (2007) Solamargine induces apoptosis and sensitizes breast cancer cells to cisplatin. *Food Chem Toxicol* 45(11):2155–2164
- Shiu LY, Liang CH, Chang LC, Sheu HM, Tsai EM, Kuo KW (2009) Solamargine induces apoptosis and enhances susceptibility to trastuzumab and epirubicin in breast cancer cells with low or high expression levels of HER2/neu. *Biosci Rep* 29(1):35–45
- Shokrzadeh M, Azadbakht M, Ahangar N, Hashemi A, Saeedi Saravi SS (2010) Cytotoxicity of hydro-alcoholic extracts of *Cucurbita pepo* and *Solanum nigrum* on HepG2 and CT26 cancer cell lines. *Pharmacogn Mag* 6(23):176–179
- Siemonsma JS, Jansen PCM (1994) *Solanum americanum* Miller. In: Siemonsma JS, Piluek K (eds) Plant resources of South-East Asia, no. 8. Vegetables. Prosea Foundation, Bogor, pp 252–255
- Singh SP, Raghavendra K, Singh RK, Subbarao SK (2001) Studies on larvicidal properties of leaf extract of *Solanum nigrum* Linn. (family Solanaceae). *Curr Sci* 81(12):1529–1530
- Son YO, Kim J, Lim JC, Chung Y, Chung GH, Lee JC (2003) Ripe fruit of *Solanum nigrum* L. inhibits cell growth and induces apoptosis in MCF-7 cells. *Food Chem Toxicol* 41(10):1421–1428
- Stuart GU (2012) Philippine alternative medicine. Manual of some Philippine medicinal plants. <http://www.stu-artschange.org/OtherHerbals.html>
- Subash KR, Ramesh KS, Chariar BV, Britto F, Jagan Rao N, Vijaykumar S (2011) Study of hepatoprotective activity of *Solanum nigrum* and *Cichorium intybus*. *Int J Pharmacol* 7(4):504–509
- Sultana S, Perwaiz S, Iqbal M, Athar M (1995) Crude extract of hepatoprotective plants *Solanum nigrum* and *Cichorium intybus* inhibit free radical mediated damage in free radical-mediated DNA damage. *J Ethnopharmacol* 45(3):189–192
- Sun L, Zhao Y, Li X, Yuan H, Cheng A, Lou H (2010) A lysosomal-mitochondrial death pathway is induced by solamargine in human K562 leukemia cells. *Toxicol In Vitro* 24(6):1504–1511
- Sun L, Zhao Y, Yuan H, Li X, Cheng A, Lou H (2011) Solamargine, a steroidal alkaloid glycoside, induces oncosis in human K562 leukemia and squamous cell carcinoma KB cells. *Cancer Chemother Pharmacol* 67(4):813–821
- Thorne HV, Clarke GF, Skuce R (1985) The inactivation of herpes simplex virus by some Solanaceae glycoalkaloids. *Antiviral Res* 5(6):335–343
- Tropicos Org (2011) Nomenclatural and specimen database of the Missouri Botanical Garden. <http://www.tropicos.org/Home.aspx>
- Van Wyk B, Gericke N (2000) People's plants. A guide to useful plants of Southern Africa. Briza Publications, Pretoria, 351 pp

- Varshney IP, Sharma SC (1965) Saponins and sapogenins-XXIX: The sapogenin of *Solanum nigrum* L. berries. *Phytochemistry* 4(6):967–968
- Wang W, Lu DP (2005) An in vitro study of cytotoxic and antineoplastic effect of *Solanum nigrum* L extract on U266. *Beijing Da Xue Xue Bao* 37(3):240–244 (In Chinese)
- Wang LY, Wang NL, Yao XS (2007) Non-saponins from *Solanum nigrum* L. *Zhong Yao Cai* 30(7):792–794 (In Chinese)
- Wang HC, Wu DH, Chang YC, Li YJ, Wang CJ (2010) *Solanum nigrum* Linn. water extract inhibits metastasis in mouse melanoma cells in vitro and in vivo. *J Agric Food Chem* 58(22):11913–11923
- Wang HC, Chung PJ, Wu CH, Lan KP, Yang MY, Wang CJ (2011) *Solanum nigrum* L. polyphenolic extract inhibits hepatocarcinoma cell growth by inducing G2/M phase arrest and apoptosis. *J Sci Food Agric* 91(1):178–185
- Wannang NN, Anuka JA, Kwanashie HO, Gyang SS, Auta A (2008) Anti-seizure activity of the aqueous leaf extract of *Solanum nigrum* Linn (Solanaceae) in experimental animals. *Afr Health Sci* 8(2):74–79
- Watt JM, Breyer-Brandwijk MG (1962) The medicinal and poisonous plants of southern and eastern Africa, 2nd edn. E. and S. Livingstone, Edinburgh, 1457 pp
- Xu Y, Pan RL, Chang Q, Qin M, Liu Y, Tang JT (2008) Experimental study of *Solanum nigrum* on inhibiting angiogenesis in chick chorioallantoic membrane. *Zhongguo Zhong Yao Za Zhi* 33(5):549–552, In Chinese
- Yang MY, Hsu LS, Peng CH, Shi YS, Wu CH, Wang CJ (2010) Polyphenol-rich extracts from *Solanum nigrum* attenuated PKC alpha-mediated migration and invasion of hepatocellular carcinoma cells. *J Agric Food Chem* 58(9):5806–5814
- Yen GC, Chen HY, Peng HH (2001) Evaluation of the cytotoxicity, mutagenicity and antimutagenicity of emerging edible plants. *Food Chem Toxicol* 39(11):1045–1053
- Youn YN, Lim E, Lee N, Kim YS, Koo MS, Choi SY (2008) Screening of Korean medicinal plants for possible osteoclastogenesis effects in vitro. *Gen Nutr* 2(4):375–380
- Zakaria ZA, Gopalan HK, Zainal H, Mohd Pojan NH, Morsid NA, Aris A, Sulaiman MR (2006) Antinociceptive, anti-inflammatory and antipyretic effects of *Solanum nigrum* chloroform extract in animal models. *Yakugaku Zasshi* 126(11):1171–1178
- Zakaria ZA, Sulaiman MR, Morsid NA, Aris A, Zainal H, Pojan NH, Kumar GH (2009) Antinociceptive, anti-inflammatory and antipyretic effects of *Solanum nigrum* aqueous extract in animal models. *Methods Find Exp Clin Pharmacol* 31(2):81–88
- Zhang ZY, Lu AM, D'Arcy WG (1994) Solanaceae A. L. Jussieu. In: Wu ZY, Raven PH, Hong DY (eds) *Flora of China*, vol 17 (Verbenaceae through Solanaceae). Science Press/Missouri Botanical Garden Press, Beijing/St. Louis
- Zhao Y, Liu F, Lou HX (2010) Studies on the chemical constituents of *Solanum nigrum*. *Zhong Yao Cai* 33(4):555–556 (In Chinese)
- Zhou X, He X, Wang G, Gao H, Zhou G, Ye W, Yao X (2006) Steroidal saponins from *Solanum nigrum*. *J Nat Prod* 69(8):1158–1163
- Zhou XL, He XJ, Zhou GX, Ye WC, Yao XS (2007) Pregnane glycosides from *Solanum nigrum*. *J Asian Nat Prod Res* 9(6–8):517–523

Solanum quitoense

Scientific Name

Solanum quitoense Lam.

Ecuador: Naranjilla;

French: Morelle De Quito, Naranjille, Orange De Quito;

German: Quito-Nachtschatten;

Spanish: Lulo, Naranjilla;

Swedish: Naranjilla.

Synonyms

Solanum angulatum Ruiz & Pav., *Solanum macrocarpon* Molina, *Solanum macrocarpon* Pav. ex Dunal in DC. nomen nudum, *Solanum nollanum* Britton, *Solanum quitense* Kunth, *Solanum quitoense* f. *septrionale* (R.E.Schult. & Cuatrec.) D'Arcy, *Solanum quitoense* var. *septrionale* R.E.Schult.

Origin/Distribution

Naranjilla is indigenous to the Andean countries of Columbia and Ecuador. The fruit is widely cultivated in Ecuador and Columbia and was also introduced to Central America where it is becoming a successful weed in montane regions of Costa Rica, Guatemala and Panama (Heiser 1972).

Family

Solanaceae

Agroecology

In its native range, naranjilla is found and cultivated at elevations of 1,500–2,400 m where the mean temperatures is 17–19°C and mean annual precipitation 1,500–2,500 mm uniformly distributed trough out the year. Naranjilla is intolerant of temperatures above 30°C. It thrives best in partial shade and wind-protected areas.

Common/English Names

Lulo, Naranjilla, Quito-Orange.

Vernacular Names

Columbia: Lulo, Naranjilla;

Naranjilla does best in well-drained rich organic soil but will also grown on poor, stony soils and calcareous soils.

Edible Plant Parts and Uses

Ripe naranjillas has a sweet-tart, refreshing flavour. Ripe naranjillas, freed of hairs, can be eaten out-of-hand by halving the fruit and squeezing the contents into the mouth or scooping with a spoon and ingesting the flesh. Some locals eat the fruit with a tinge of salt. The ripe flesh with embedded seeds, may be scooped out and added to ice-cream mix, made into a sauce for various native cuisine or used in pies and other cooked desserts. Naranjilla jelly and marmalade are produced on a small scale in Cali, Colombia. The empty fruit hulls can be stuffed with a mixture of mashed bananas and other ingredients and baked. In its native countries, lulo is primarily and popularly used for its delicious and nutritious juice '*jugo de lulo*', in particular *refrescos* or naranjilla smoothies, made by blending the flesh then strained, sweetened and served with ice-cubes. Sherbet is also prepared by mixing strained naranjilla juice with sugar or corn syrup, water, a dash of lime juice, then partially freezing followed by blending to a froth and freezing again.

Botany

An erect, spreading herbaceous perennial 1–2.5 m tall with thick, lignescent, pubescent (with purple stellate trichomes) stem, prickly in the wild, unarmed in cultivated plant. Leaves, alternate, simple, elliptic to oblong ovate, large, 13–60 by 11–45 cm, thin-texture, woolly-pubescent adaxially, stellate woolly abaxially, apex acute, base truncate or shallowly cordate, margin coarsely dentate with 5–6 deltoid, acute- or obtuse tipped lobes, major veins spineless or sparsely spiny, petiole 5–15 cm, pubescent, prickly or unarmed (Plate 1). Flowers fragrant, pentamerous, strongly andromonoecious in short axillary inflorescence of 1–20 flowers. Staminate flowers abundant in distal pro-



Plate 1 Naranjilla plant with large coarsely dentate leaves (A. Gonzalez)

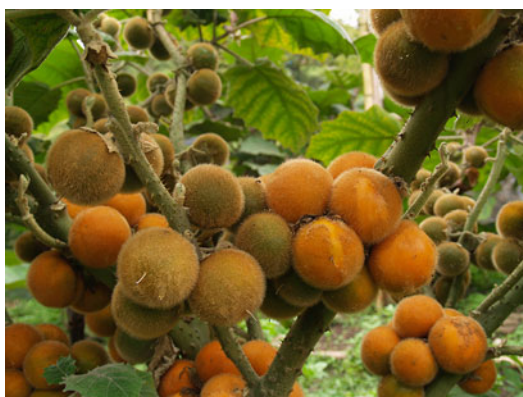


Plate 2 Densely hirsute unripe and ripe fruits (A. Gonzalez)

duced inflorescences. Calyx broadly campanulate with 5 ovate to broadly ovate lobes, persistent; corolla with 5 ovate-lanceolate, white petals, purple pubescent beneath, stamens with 5 yellow anthers; ovary globose, 4-loculed, densely pubescent with a cylindrical straight style and capitate stigma. Fruits 1–4 per inflorescence, globose, 3–6.5 cm across, brownish-green turning to orange when ripe, densely hirsute (Plate 2), trichomes easily removed by rubbing to expose a bright-orange to deep orange, smooth leathery, thick peel (Plate 3). Seeds numerous, small, lenticular, flat, minutely pitted, buff-coloured, 2.5–3.5 mm diameter (Plate 4).



Plate 3 Harvested ripe, globose fruit with hairs (trichomes) removed (A. Gonzalez)



Plate 4 Ripe fruit halved to show the seeds (A. Gonzalez)

Nutritive/Medicinal Properties

The proximate nutrient composition of naranjilla fruit per 100 g edible portion had been reported by Lorenzi et al. (2006) in Brazil as: energy 25.7 cal, water 89.15 g, protein 0.35 g, fat 0.17 g, carbohydrate 5.7 g, ash 0.7 g, Ca 9.15 mg, P 27.8 mg, Fe 0.49 mg, vitamin A 0.15 mg, vitamin B1 0.06 mg, vitamin B2 0.03 mg, niacin 1.47 mg and vitamin C 57.4 mg. Morton (1987) reported results of analyses (per 100 g) performed on fresh naranjilla fruits in Colombia and Ecuador as moisture 85.8–92.5, protein 0.107–0.6 g, fat 0.1–0.24 g, carbohydrate 5.7 g, dietary fibre 0.3–4.6 g, ash 0.61–0.8 g, energy 23 kcal, Ca 5.9–12.4 mg,

P 12.0–43.7 mg, Fe 0.34–0.64 mg, carotene 0.071–0.232 mg (600 I.U.), thiamine 0.04–0.094 mg, riboflavin 0.03–0.047 mg, niacin 1.19–1.76 mg and vitamin C 31.2–83.7 mg.

Proximate nutrient composition of naranjilla fruit per 100 g edible portion was reported by Acosta et al. (2009) in Costa Rica as: moisture 90.6 g, protein 0.7 g, available carbohydrates 3.8 g, dietary fibre 1.4 g, sugars 3 g, sucrose 1.6 g, glucose 0.68 g, fructose 0.7 g, ash 0.92 g and energy 18 kcal. Total titratable acidity was 2.63 g citric acid equivalent / 100 g and total soluble solids amounted to 9.1 °Brix. Its antioxidant H-ORAC (hydrophilic – Oxygen radical absorbance capacity) value was 17 µmol Trolox equivalent/g, total phenolic content was 48 mg gallic acid equivalent/100 g and ascorbic acid content was 12.5 mg/100 g. Carotenoid content of the whole fruit and pulp was 33.3 and 7.2 µg/g, respectively. The carotenoids identified in the whole fruit was β-carotene 58.4%, lutein 32.2%, *cis*-β-carotene 6.1% and violaxanthin 3.2%.

The following bioactive antioxidant carotenoids and phenolic compounds were identified in lulo fruit: all-*trans*-β-carotene, 13-*cis*-β-carotene, and 9-*cis*-β-carotene and the lutein (carotenoids); chlorogenic acids and their hexosides in the flesh and placental tissues, and flavonol glycosides in the skin (phenolic compounds); and many dihydrocaffeoyl spermidines in all three parts of the fruit (Gancel et al. 2008).

The main aroma constituents found in naranjilla fruit in Ecuador were esters of butanoic acid and ethyl acetate (reported as area percent in gas chromatograms): ethyl butanoate 26.7%, methyl butanoate 12.1%, butanoic acid 0.4%, methyl benzoate 0.3%, methyl hexanoate 0.4%, methyl (*E*)-2-butenate 0.9%, methyl 3-hydroxyhexanoate <0.1%, γ-hexalactone 8.2%. Aroma impact compounds could not be found. Acosta et al. (2009) also found all the above volatiles and two new compounds in fruit from Costa Rica: ethyl butanoate 4.02%, methyl butanoate 54.30%, butanoic acid 8.38%, methyl benzoate 5.75%, methyl hexanoate 3.81%, methyl (*E*)-2-butenate 3.4%, methyl 3-hydroxyhexanoate 2.87%, γ-hexalactone

2.33%, 4-hydroxy-4-methyl-2-pentanone 13.25% and 2-methyl-2-pentenal 1.90%.

As the result of enzymatic hydrolysis with an exogenous commercial enzyme (emulsin), C13-norisoprenoid glycosides isolated from lulo leaves produced only the aglycone (glycosidically bound volatile) (Osorio et al. 2003). In contrast, enzymatic hydrolysis of glycosides, using endogenous enzymes (lulo fruit glycosidases), generated additional volatile compounds, some recognisable as components of fruit flavour. Some of the novel volatiles generated included: 2-cyclohexen-1-one, 4-(3-hydroxy-1-butenyl)-3,5,5-trimethyl-; vomifoliol; 3-hydroxy-7,8-dihydro- β -ionol; 3-hydroxy-4,7,9-megastigmatrien-3-one; 3-hydroxy-5,6-epoxy- β -ionol; 13-hydroxy-3-oxo- α -ionol; 3,4-dihydro-8-hydroxy-4,4,7-trimethyl-2(1 H)-naphthalenone; 3-hydroxy-7,8-didehydro- β -ionol; (6E,8Z)-4,6,8-megastigmatrien-3-one; (6Z,8E)-4,6,8-megastigmatrien-3-one; (6E,8E)-4,6,8-megastigmatrien-3-one; (6Z,8Z)-4,6,8-megastigmatrien-3-one; (7E)-4,7,9-megastigmatrien-3-one; and megastigmatrien-3-one.

From *S. quitoense* leaves, three C(13)-norisoprenoid glucoconjugates were isolated and elucidated as (6R,9R)-13-hydroxy-3-oxo- α -ionol 9-*O*- β -D-glucopyranoside (4a), the uncommon (3S,5R,8R)-3, 5-dihydroxy-6,7-megastigmadien-9-one 5-*O*- β -D-glucopyranoside (citroside A) (5a), and the known (6S,9R)-vomifoliol 9-*O*- β -D-glucopyranoside (6a) (Osorio et al. 1999). Enzymatic treatment of compound 5a yielded 3-hydroxy-7,8-didehydro- β -ionone, an important lulo peeling volatile, which after chemical reduction and heated acid catalyzed rearrangement generated β -damascenone and 3-hydroxy- β -damascone.

Physiologically mature fruits could be maintained green for 9 days in good condition at ambient temperature in a sealed polyethylene bag of high gas permeability, or for 15 days if an ethylene absorber was added, 25 days if stored at 7.5°C and 50 days if the 3 methods were combined (Arango et al. 1999). They recommended that to increase the shelf life of naranjilla, fruits for the local market should be packed in high permeability plastic film, while refrigeration at 7.5°C or addition of an ethylene absorber should be

used if a longer storage period is required for foreign markets.

Other Uses

Naranjilla is used as a source for *Solanum* hybridisation and breeding work.

Comments

Naranjilla can be easily propagated from seeds or by air-layering or by cuttings of mature wood.

Selected References

- Acosta O, Pérez AM, Vaillant F (2009) Chemical characterization, antioxidant properties, and volatile constituents of naranjilla (*Solanum quitoense* Lam.) cultivated in Costa Rica. Arch Latinoam Nutr 59(1):88–94
- Arango H, Vaillant F, Vélez C, Millan P, Reynes M (1999) Evaluation of post-harvest performance of naranjilla (*Solanum quitoense* Lam.) fruits packed under modified atmosphere. Fruits 54(4):261–270
- Bohs L (2004) A chloroplast DNA phylogeny of *Solanum* section *Lasiocarpa* (Solanaceae). Syst Bot 29:177–187
- Bohs L (2005) Major clades in *Solanum* based on *ndhF* sequences. In: Keating RC, Hollowell VC, Croat TB (eds) A festschrift for William G. D'Arcy: the legacy of a taxonomist, vol 104, Monographs in systematic botany from the Missouri Botanical Garden. Missouri Botanical Garden Press, St. Louis, pp 27–49
- Brunke EJ, Mair P, Hammerschmidt FJ (1989) Volatiles from naranjilla fruit (*Solanum quitoense* Lam.). GC/MS analysis and sensory evaluation using sniffing GC. J Agric Food Chem 37(3):746–748
- Gancel AL, Alter P, Dhuique-Mayer C, Ruales J, Vaillant F (2008) Identifying carotenoids and phenolic compounds in naranjilla (*Solanum quitoense* Lam. var. Puyo hybrid), an Andean fruit. J Agric Food Chem 56(24):11890–11899
- Heiser CB Jr (1972) The relationships of the naranjilla, *Solanum quitoense*. Biotropica 4(2):77–84
- Heiser CB Jr (1985) Ethnobotany of the naranjilla (*Solanum quitoense*) and its relatives. Econ Bot 39:4–11
- Lorenzi H, Bacher L, Lacerda M, Sartori S (2006) Brazilian fruits & cultivated exotics (for consuming in natura). Instituto Plantarum de Etodos da Flora Ltda, Brazil, 740 pp
- Miller JS, Diggle PK (2003) Diversification of andromonoecy in *Solanum* section *Lasiocarpa* (Solanaceae):

- the roles of phenotypic plasticity and architecture. *Am J Bot* 90(5):707–715
- Morton J (1987) Naranjilla. In: *Fruits of warm climates*. Julia F. Morton, Miami, pp 425–428
- Munier R (1962) La Culture du lulo en Colombia. *Fruits* 17:91–92
- Osorio C, Duque C, Fujimoto Y (1999) C(13)-Norisoprenoid glucoconjugates from lulo (*Solanum quitoense* L.) leaves. *J Agric Food Chem* 47(4):1641–1645
- Osorio C, Duque C, Batista-Viera F (2003) Studies on aroma generation in lulo (*Solanum quitoense*): enzymatic hydrolysis of glycosides from leaves. *Food Chem* 81(3):333–340
- Schultes RE, Romero-Castañeda R (1962) Edible fruits of *Solanum* in Colombia. *Bot Mus Leaflet* 19:235–286
- Whalen MD, Costich DE, Heiser CB Jr (1981) Taxonomy of *Solanum* section *Lasiocarpa*. *Gentes Herb* 12:41–129

Solanum sessiliflorum

Scientific Name

Solanum sessiliflorum Dunal.

Hungarian: Orinoco-Paradicsom;

Peru: Cocona, Kukush;

Spanish: Topiro;

Swedish: Topiro;

Venezuela: Pupú (*Arecuna*), Tupiru.

Synonyms

Solanum alibile R.E.Schult., *Solanum arecunarium* Pittier (nom.nud.), *Solanum topiro* Dunal.

Family

Solanaceae

Common/English Names

Cocona, Orinoco Apple, Peach Tomato, Topiro.

Vernacular Names

Brazil: Cocona, Cubiu, Maná, Tomate-De-Indio (Portuguese);

Columbia: Be-Tá-Ka (Kubeo), Cocona, De-Twá (Taiwano, Tatuya), Coconilla, Lulo, Tupiru;

French: Tomate Chauve Souris;

Guyana: Orinoco Apple;

Origin/Distribution

Cocona is not known in the wild, having been observed only in cultivation in swiddens and surrounds of human abodes in the upper Amazon Basin of southern Colombia, Ecuador, and northern Peru, cultivated sporadically in settlements along the Amazon and Orinoco River systems of Brazil and Venezuela as far east as Belém. Cocona has been partially domesticated by Amazonian Indians (Piaroas and other native tribes) of the Upper Orinoco Basin in Venezuela (Volpato et al. [2004](#)).

Agroecology

Cocona is a lowland tropical species, usually growing between 0 and 600 m but occasionally cultivated at somewhat higher elevations of 900–1,200 m. It thrives in areas with mean annual temperatures of 18–30°C and average relative humidity of 85%. It thrives in full sun, in soils of medium fertility, on latisols and sandy soils. It will also

grow on poor clayey and calcareous (scarified limestone) soils provided drainage is good.

Edible Plant Parts and Uses

The ripe fruit has a pleasant acidulous flavour liken to citrus. They are eaten fresh, peeled, out of hand or in fruit salads. They also can be used in cooking, in fish and meat dishes, in making sauces and fillings for pies. Cocona is eaten in compotes or cakes as a substitute for apples. Cocona is also prized for processing into jam, marmalade, paste, and jelly, and is sometimes pickled or candied. The fruit is also make in juice, sweetened with sugar which is a refreshing cool drink in Brazil or other beverages. The young leaves are cooked and eaten.

Botany

Cocona is an erect, much branched, unarmed, lignescent perennial shrub 1–2 m high with pubescent stems and densely pubescent twigs. Leaves are simple, broadly ovate, 25–45 cm by 20–39 cm, thin-textured, with obtuse to acute apex, asymmetrical truncated base and coarsely dentate margins, with 5–7 major lateral veins, sparsely to densely sericeous on the adaxial surface and borne on pubescent petioles, 4–15 cm long. Inflorescences are extra-axillary, 3–10 cm long, unbranched with short 5 mm peduncle and 6–16 flowers on 2–7 mm pedicels, lowermost 2–5 flowers are usually perfect. Calyx campanulate, tube 4–6.5 mm, lobes ovate, acute-tipped. Corolla 2–3 cm across, white or greenish-white, tube 1–5 mm, lobes ovate to ovate lanceolate and spreading. Stamens with linear-lanceolate anthers. Ovary with pubescent, cylindrical style and capitate stigma. Fruits 1–3 per inflorescence, 2.5–9.5 cm across, 4–6 locular, globose or ovoid, glabrous, golden yellow, burnt-orange, orange red, red to purple-red, flesh yellow with numerous, thin, flat, ovate – reinform, 3.2–4 × 2.1–2.7 mm. cream-coloured seeds (Plates 1–2).

Nutritive/Medicinal Properties

Cocona fruits are mostly globose, 31–92 mm long, 33–77 mm in longitudinal diameter, 1.5–19.5 mm of pulp thickness and 18.5–30.1 g of mass (Silva Filho et al. 2005). Cocona had been reported to be a low-calorie food with carbohydrates and lipids ranging from 1.3 to 27.2% and 58.5 to 87.3% per 100 g of pulp, respectively with high concentrations of potassium (54.6 mg to 463.5 mg per 100 g of pulp) and iron (97.3–352.0 µg per 100 g of pulp). The proximate nutrient composition of cocona fruit per 100 g edible portion had been reported by Lorenzi et al. (2006) in Brazil as: protein 0.6 g, carbohydrate 5.7 g, Ca 12 mg, P 14 mg, Fe 0.6 g, vitamin A 0.14 mg, vitamin B1 0.25 mg and niacin 500 mg. Another analysis conducted in Brazil was reported by Morton (1987) per 100 g edible portion as: protein 0.6 g, carbohydrate 5.7 g, fibre 0.4 g, Ca 12 mg, P 14 mg, Fe 0.6 g, carotene 140 µg, thiamine 25 µg and niacin 500 µg. Cocona fruit also contained 1.1–2% citric acid (Souza et al. 2008), 1.22% citric acid and soluble solids of 6.62° Brix (Silva et al. 2011). Morton (1987) reported that Venezuelan studies reported cocona to contain 142 mg tannin. Marx et al. (1998) reported the pulp of ripe cocona fruit to contain the following chemical composition per 100 g dry weight basis: water 90.5 g, fat 3.15 g, myristic acid 0.01 g, palmitic acid 1.00 g, palmitoleic 0.08 g, stearic acid 0.09 g, oleic acid 1.53 g, linoleic acid 0.16 g, linolenic acid 0.13 g, tetracosanoic acid 0.01 g, available carbohydrate 32.10 g, glucose 18.4 g, fructose 7 g, sucrose 3.8 g, starch 2.87 g, inositol traces, total organic acids 254.4 mval/100 g, citric acid 14.10 g, malic acid 0.36 g, Ca 99 mg, Mg 1,988 mg, P 383 mg, Fe 2.5 mg, Mn 0.64 mg, Zn 1.08 mg, Se 0.13 mg, valine 25.60 mg, leucine 17.20 mg, isoleucine 23.60 mg, lysine 30.40 mg, threonine 22.80 mg, methionine 4.40 mg, phenylalanine 60.80 mg, tyrosine 7.60 mg, aspartic acid 64.40 mg, asparagine 366.80 mg, serine 321.00 mg, glutamic acid 74.80 mg, glutamine 172.80 mg, proline 12.00 mg, glycine 7.60 mg, alanine 5.60 mg, histidine 18.80 mg, arginine 34.80 mg, β-alanine 21.60 mg, non-amino acids:



Plate 1 Harvested cocona fruits (J. Ugarte-Guerra)



Plate 2 Close-up of ripe cocona fruit (J. Ugarte-Guerra)

γ -aminobutyric acid 298 mg, α -aminobutyric acid 1.60 mg, α -aminoadipic acid 0.4 g, hydroxylysine 2 mg, biogenic amines: taurine traces, ethanolamine 1.60 mg and ornithine 3.20 g.

In the water volatile distillate, Marx et al. (1998) found safrole (40.34%), methyl salicylate (8.73%), and palmitic acid (18.20%) to be most abundant, with the former two being major contributors to the fresh aroma of the fruit. Other volatile compounds included 1-dodecanol (6.09%), (Z)-3-hexen-1-ol (4.23%), guaiazulene (3.51%), apiole (2.38%), 1-hexanol (1.62%), phenylacetaldehyde 1.28%, spathulenol 1.19%, myristicin 1.17%, eugenol methyl ether 1.05%, dodecanone 0.87%, 1-nonanol 0.68%, myristic acid 0.68%, elemicin 0.65%, dodecanoic acid

0.58%, α -bisabolol 0.53%, eugenol 0.40%, and undecane 0.39%.

A total of 76 volatile compounds were identified in cocona fruit comprising of 29 esters, 13 terpenes, 12 carbonyls, 10 alcohols, 5 acids, 3 lactones, 2 phenols and 2 hydrocarbons; in immature green fruits 39 compounds were identified (Quijano and Pino 2006). Carbonyl compounds (2.36 mg/kg) occurred in the highest concentration in green fruit, whereas esters showed the highest level in mature and ripe fruits (2.18 and 2.68 mg/kg, respectively). The content of C6-aldehydes, including (Z)-3-hexenal, (Z)-2-hexenal, (E)-2-hexenal and hexanal significantly decreased with maturity of the fruit. The amount of terpenes, alcohols, acids, phenols and lactones increased with maturation of the fruit. The major volatile constituents in green fruit were (Z)-2-hexenal (0.90 mg/kg), (Z)-3-hexenal (0.48 mg/kg), hexanal (0.36 mg/kg) and (E)-2-hexenal (0.29 mg/kg). Due to their green notes, it postulated that the hexenals had the major impact on the flavour of green fruits. In contrast, the most abundant volatile were methyl salicylate (0.76 mg/kg), (Z)-2-hexenal (0.59 mg/kg) and (Z)-3-hexenal (0.43 mg/kg) in mature fruit; whereas methyl salicylate (0.85 mg/kg), α -terpineol (0.42 mg/kg), (Z)-3-hexenal (0.40 mg/kg), (Z)-2-hexenal (0.35 mg/kg), geranyl acetate (0.26 mg/kg), benzyl acetate (0.18 mg/kg) hexyl hexanoate (0.17 mg/kg) and butyl acetate (0.0165 mg/kg) showed the highest concentration in the ripe fruits. Some constituents (Z)-3-hexenal, linalool (0.19 mg/kg) and α -terpineol were also common to other species in the Solanaceae family. The identified lactones (concentrations in ripe fruits) γ -octalactone (0.035 mg/kg), γ -decalactone (0.056 mg/kg) and δ -undecalactone (0.085 mg/kg), and the identified phenols 4-vinylguaiacol (0.045 mg/kg) and eugenol (0.16 mg/kg) were reported for the first time in *Solanum* species.

Total phenols content in cocona seeds ranged from 557 to 788 mg gallic acid equivalents (GAE)/100 g dried weight (dw), and in the pulp from 1,031 to 1,392 mg gallic acid equivalents (gAE)/100 dw (Rincón et al. 2011). All the fractions viz. pulp, peel and seeds exerted high DPPH scavenging activity. Total phenolic content

correlated strongly with antioxidant activity ($R^2=0.9156$).

Cocona extract inhibited growth of *Helicobacter pylori* in-vitro (Pardo Sandoval 2010). This inhibitory effect was superior to the antibiotics tested amoxycycline, tetracycline, claritromycine and amikacine.

Traditional Medicinal Uses

Cocona is used by the Amazonian Indians to treat diabetes, burns, skin mycoses and also to lower uric acid and cholesterol levels (Silva Filho et al. 2003; Pardo Sandoval 2004). The powdered seeds are said to be employed by Taiwano Indians in lowland Colombia to relieve irritation of the mouth caused by chewing coca. The juice is used by native Indians to make the hair bright and the leaves and roots are used as medicine (Marx et al. 1998).

Other Uses

Cocona can also be grown as an indoor ornamental plant in temperate climates.

Comments

Cocona is readily propagated from seeds but it can also be vegetatively propagated by using air-layers and cuttings of mature wood which have been reported to root successfully.

Selected References

- Bohs L (2004) A chloroplast DNA phylogeny of *Solanum* section *Lasiocarpa* (Solanaceae). *Syst Bot* 29: 177–187
- Bohs L (2005) Major clades in *Solanum* based on *ndhF* sequences. In: Keating RC, Hollowell VC, Croat TB (eds) *A festschrift for William G. D'Arcy: the legacy of a taxonomist*, vol 104, Monographs in systematic botany from the Missouri Botanical Garden. Missouri Botanical Garden Press, St. Louis, pp 27–49
- Heiser CB Jr (1985) Ethnobotany of the naranjilla (*Solanum quitoense*) and its relatives. *Econ Bot* 39:4–11
- Kennard WC, Winters HF (1960) Some fruits and nuts for the tropics. USDA Agric Res Serv Misc Publ 801:1–135
- Lorenzi H, Bacher L, Lacerda M, Sartori S (2006) Brazilian fruits & cultivated exotics (for consuming in natura). Instituto Plantarum de Etodos da Flora Ltda, Brazil, 740 pp
- Marx F, Andrade EHA, Maia JAG (1998) Chemical composition of the fruit of *Solanum sessiliflorum*. *Zeitsch Lebensm Unters Forsch A* 206:364–366
- Morton JF (1987) Cocona. In: *Fruits of warm climates*. Julia F. Morton, Miami, pp 428–430
- Pardo Sandoval MA (2004) Efecto de *Solanum sessiliflorum* Dunal sobre el metabolismo lipídico y de la glucose. *Ciencia e Invest* 7(2):43–48
- Pardo Sandoval MA (2010) Efecto in vitro del extracto de *Solanum sessiliflorum* “cocona” sobre el crecimiento de *Helicobacter pylori*. *Ciencia e Invest* 13(1):30–33
- Quijano CE, Pino JA (2006) Changes in volatile constituents during the ripening of cocona (*Solanum sessiliflorum* Dunal) fruit. *Rev CENIC Cienc Quím* 37(3):133–136
- Rincón A, González D, Rached LB, Emaldi U, Padilla FC (2011) Actividad antioxidante y contenido de polifenoles en frutos de túpiro (*Solanum sessiliflorum* Dunal) provenientes del Amazonas venezolano. *Revist Fac Farm* 74(1):41–45. (Antioxidant activity and polyphenols content of tupiro fruits (*Solanum sessiliflorum* Dunal) from Venezuelan Amazonas)
- Schultes RE (1958) A little-known cultivated plant from northern South America. *Bot Mus Leaf* 18:229–244
- Schultes RE, Romero-Castañeda R (1962) Edible fruits of *Solanum* in Colombia. *Bot Mus Leaf* 19:235–286
- Silva Filho DF, Noda H, Yuyama LKO, Aguiar JPL, Machado FM (2003) Cubiu (*Solanum sessiliflorum*, Dunal): Uma planta medicinal nativa da Amazônia em processo de seleção para o cultivo e Manaus, Amazonas, Brasil. *Rev Bras Plantas Med* 5(2):65–70. (Cubiu (*Solanum sessiliflorum*, Dunal): a medicinal plant from Amazonia in the process of selection for cultivation in Manaus, Amazonas, Brasil)
- Silva Filho DF, Yuyama LKO, Aguiar JP, Oliveira MC, Martins LHP (2005) Caracterização e avaliação do potencial agrônomo e nutricional de etnovarietades de cubiu (*Solanum sessiliflorum* Dunal) da Amazônia. *Acta Amazon* 35:399–406. (Characterization and evaluation of the agronomic and nutritional potential of ethnovarieties of cubiu (*Solanum sessiliflorum* Dunal) in Amazonia)
- Silva DFP, Rocha RHC, Salomão LCC (2011) Postharvest quality of cocona (*Solanum sessiliflorum* Dunal) stored under ambient condition. *Rev Ceres (Impr)* 58(4):476–480
- Souza LT, Zonta JB, Zonta JH, Braun H, Martins Filho S (2008) Caracterização física e química de cúbio

- (*Solanum sessiliflorum* Dunal) durante o seu desenvolvimento. *Revis Ciênc Agron* 39:449–454
- Suárez M, Duque C (1992) Change in volatile compounds during lulo (*Solanum vestissimum* D.) fruit maturation. *J Agric Food Chem* 40:647–649
- Volpato G, Marcucci R, Tornadore N, Paoletti MG (2004) Domestication process of two *Solanum* section *Lasiocarpa* species among Amerindians in the Upper Orinoco, Venezuela, with special focus on Piaroa Indians. *Econ Bot* 54:184–194
- von der Pahlen A (1977) Cubiu (*Solanum topiro* Humb. & Bonpl.), uma fruteira da Amazônia. *Acta Amazon* 7:301–307
- Whalen MD, Costich DE, Heiser CB Jr (1981) Taxonomy of *Solanum* section *Lasiocarpa*. *Gentes Herb* 12:41–129

Solanum torvum

Scientific Name

Solanum torvum Swartz.

Synonyms

Solanum acanthifolium Hort. Par. ex Dunal, *Solanum daturifolium* Dunal, *Solanum ferrugineum* Jacq, *Solanum ficifolium* Ortega, *Solanum largiflorum* C. White, *Solanum maccai* L.C. Rich. ex Spreng., *Solanum mannii* Wright, *Solanum mayanum* Lundell, *Solanum stramonifolium* Lam. *Solanum torvum* var. *daturifolium* (Dunal) Schulz, *Solanum torvum* var. *typicum* Hochr., *Solanum verapazense* Standl. & Steyerl.

Family

Solanaceae

Common/English Names

Cherry Eggplant, Devil's Fig, Green-Fruited Pea Eggplant, Gully Bean, Pea Aubergine, Pea Eggplant, Plate Brush, Susumba, Susumber, Thai Pea Eggplant, Thai Cultivated Nightshade, Thornapple, Turkey Berry, Water Nightshade, Wild Eggplant.

Vernacular Names

Bangladesh: Gotha Begun, Hat Begun, Tit Begun (Bengali), Bigal Biji (Chalma), Kajo-Ba, Khaja (Marma), Kurka Plawo (Murong), Titar Berul (Tanchangan);

Brazil: Jurubeba (Portuguese);

Burmese: Hkawhkam-Kaju, Kazaw-Kha, Magwikaju, Mai-Mak-Hku-Sum, Myobyet-Khayan;

Cameroon: Top Na Aka (Batoufam);

China: Dian Qie Zi, Ci Qie, Qing Qie, Shui Qie, Shan Dian Qie, Wan Tao Hua;

Danish: Ærtenatskygge;

Fijian: Kaisurisuri, Katai, Kausoni, Kauvotovotua, Soni;

French: Aubergine Sauvage Épineuse, Fausse Aubergine, Aubergine Sauvage D'asie, Aubergine Pois, Mélongène-Diable, Bellangère Bâtarde;

German: Teufels-Nachtschatten;

Guatemala: Güis;

India: Bhi Tita, Hatibhekuri (Assamese), Gota Begun, Gothbegun, Titabaigun, Tita Bagoon (Bengali), Bhankatiya, Bhurat, Katai, Tit-Baigun (Hindu), Borasunde, Bovasonde, Bovasunde, Busende, Busunde, Chinde, Chundai, Chunde, Kaada Kallatti, Kaadu Badane, Kaadu Kadane, Kaadu Kallate, Kaadu Kallunte, Kaadu Sonde, Kadakadana, Kadakallate, Kadchunde, Kadubadene, Kadusonde, Karase, Karashe, Katukallante, Shundakkayi, Sonde, Sonde Gida,

Sundekkayi (Kannada), Anachunda, Chunda, Chunde, Cunta, Kadchunde, Katchunde, Kattucunta, Puttaricunta (Malayalam), Shingkhanga (Manipuri), Dhoravaange, Doralee, Marang (Marathi), Tawkpui (Mizoram), Brihati (Sanskrit), Amarakkay, Cenkuro-nikacceti, Cenkuronikam, Chundai, Cularkay, Cularkaycceti, Cuntai, Cuntai Varral, Cuntankay, Curacica, Curapakam, Curuntaikkay, Curutkay, Cuvacakacokkini, Cuvucakacakkinipokki1, Iruttiyakuttam, Kancakacceti, Kancakam, Katikipalam, Kottukkattari, Malaiccuntai, Malasundai, Nattucuntai, Pasanamaini, Pitiratakacceti, Pitiratakam, Pittalam, Pittatincam, Sundai, Sundaikai, Sundakkai, Tottitanaipparpamakki (Tamil), Chundai Kai, Konda Vusti, Kondavuste, Kottuvastu, Usti (Telugu);

Indonesia: Pokak, Poka, Terongan, Terungan, Cepoka, Cong Belut, Cuka Wana (Javanese), Pokak, Cepokak (Madurese), Terong Pipit (Sumatra), Takolak (Sundanese);

Italian: Morella Della Giamaica;

Japanese: Suzume Nasubi;

Khmer: Trap Put Lum្អ៊ាច្រ;

Laotian: Kh'èngz Faaz, Kh'eenz Saph'au;

Malaysia:

Nepali: Tokrakur;

Pakistan: Khana Pakana;

Papua New Guinea: Podopodo Kai Ra T Aba Rau;

Philippines: Taogotan, Talongon, Terongan, Talimbolo, Balbalusa (Bisayan), Balbalusa (Bontok), Taogotan (Panay Bisaya), Gambol (Subanun), Dagutung, Talungkia (Sulu), Talongon, Talong-Talongan, Tandang-Aso, Talampay, Talimbolo (Tagalog);

Portuguese: Bellangère Bâtarde;

Puerto Rico: Berenjena Cimarrona;

Saint Lucia: Béléjenn Djab;

Samoan: Lapiti;

Spanish: Berenjena De Gallina, Berenjena Silvestre;

Thailand: Makhua-Phuang, Makhua Phuong, Makhwaeng;

Tongan: Tisaipale;

Vanuatu: Piko;

Vietnam: Cà Dai Hoa Trang, Cà Hoang, Cà Nong;

Yapese: Rawelnagafi.

Origin/Distribution

The plant is indigenous to Central and South America, where it is found from Mexico to Brazil and Peru, and is widespread in the Caribbean. It is now a common pantropical weed but cultivated as a small-scale vegetable in southern and eastern Asia, and is especially popular in Thailand and Indonesia.

Agroecology

Solanum torvum is found in the open or under partial shade in disturbed places, roadsides, wastelands, ravines, valleys, thickets, plantations, wet places near villages in areas that receive more than 2,000 mm rainfall annually. It is also found in riparian zones in drier areas with less than 600 mm rainfall. It is also quite drought tolerant and is adaptable on a wide range of soils from near sea level to 2,000 m altitude.

Edible Plant Parts and Uses

The young immature pale green fruit is used as vegetable. In Thailand, it can be eaten fresh or dip in *Nam prik* (a spicy chilli paste with pounded shrimps or dried fish and is equivalent to the Indian sambar or Malay Sambal). *Nam prik* is served as a condiment with rice, vegetables, meats, poultry and fish but can also be served as a dip. The young fruits are also cooked in red or green curry, and the popular Thai dish *kaeng kai* (Thai chicken curry casserole). In the Ivory coast the young fruits are used in soups and sauces as are chopped together with eggplant fruits or tomatoes. In Indonesia, the young fruits are used as *lalab*, raw or cooked, or eaten in sayur lodeh, a Javanese dish called *Trantjam*, or the Sundanese



Plate 1 (a) and (b) Fruit and leaves

Karedok. *Karedok* is a side dish made of pounded fruits, mixed with roasted red onions, lombok, chekur and jahe (Ginger), *tarasi* (spicy pounded shrimp based chilli paste) and salt. In India, Tamil Nadu, the young fruit is consumed directly or cooked in dishes like *Sundaikkai Sambar*, *Sundaikkai Poriyal*, *Sundaikkai Aviyal* and *Sundaikkai vattral*. *Sundaikkai Aviyali* is also esteemed in Kerala cuisine and is a mixture of vegetables including turkey berry (*Sundaikkai*), curd, coconut and seasoned with coconut oil and *Murraya* curry leaves. *Sundaikkai vattral* is prepared by soaking vegetables like *manathakkali* (black-nightshade), *sundaikkai* (turkey berry), *kothavaranga* (cluster beans) in buttermilk, salt and dried in sunlight. Then frying the product in oil with Thoor dhal, tamarind, sambar onion and season with spices like dry red chilli powder, dry coriander powder, pepper powder, cumin powder, turmeric powder, garlic cloves, mustard seeds and a few curry leaves.

Botany

An erect, branched, slender perennial shrub, 1–3 m tall, sparingly armed, densely pubescent overall with many- greyish stellate hairs. Stems densely tomentose with stout, recurved, reddish or pale-yellow prickles. Leaves simple, alternate, solitary or in pairs; petiole 2–4 cm; leaf blade ovate to



Plate 2 Harvested fruit on sale in a local market

elliptic, 6–19 by $\times$ 4–13 cm, densely tomentose, armed or unarmed, with an acute tip and rounded to oblique base, margin sinuate or usually 5-7-lobed (Plate 1a, b). Inflorescences extra-axillary, many-flowered racemose panicles. Flowers andromonoecious, pentamerous, pedicel, slender, 5–12 mm densely tomentose, Calyx cup-shaped, with ovate-lanceolate lobes 3–4 mm long; corolla white, rotate, 2.5 cm across, short tube with 5 short ovate-lanceolate lobes, 8–10 mm; stamens five, yellow, epipetalous, and erect with connivent anthers, ovary superior, globose, pubescent; style 6–8 mm long with capitate stigma. Fruit a many seeded, smooth, glabrous, globose berry turning green (Plates 1–3) to yellowish-green when mature, glabrous, 1–1.5 cm in diameter and borne on 1–2 cm, pedicel thickened upwards. Seeds discoid, brown, 1.5–2 mm in diameter.

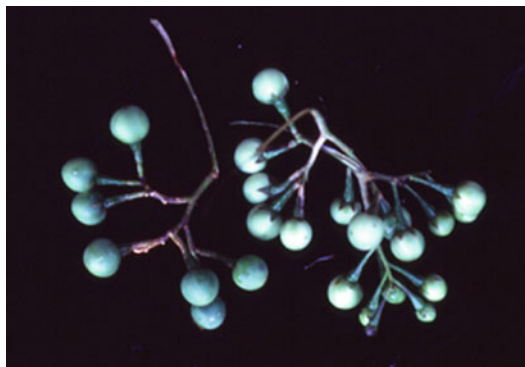


Plate 3 Clusters of pea eggplant

Nutritive/Medicinal Properties

The proximate nutrient composition of the fruit per 100 g edible portion was reported as: moisture 81.9 g, energy 47 cal, fat 0.6 g, crude fibre 6.1 g, protein 2.8 mg, Ca 158 mg, P 110 mg, Fe 7.1 mg, Vitamin A 554 I.U., Vitamin B1 0.17 mg, Vitamin B2 0.06 mg, niacin 2.6 mg and Vitamin C 4 mg (Ministry of Public Health, Thailand 1970). Another analysis reported the young fruit to contain per 100 g edible portion, the following values: water 85.4 g, energy 197 kJ (47 kcal), protein 2.4 g, fat 0.4 g, carbohydrate 10.7 g, fibre 6.1 g, Ca 104 mg, P 70 mg, Fe 4.6 mg, β -carotene 390 μ g, thiamin 0.12 mg, riboflavin 0.09 mg, niacin 2.6 mg and ascorbic acid 4 mg (Leung et al. 1972).

The fruit was found to contain the steroidal alkaloid solasonine (Fayez and Saleh 1967). The fruit also contained torvogenin and chlorogenin (Doepke et al. 1975).

Chlorogenone {(25R)-5 α -spirostane-3,6-dione} and its 25S-epimer, neochlorogenone, were extracted from unripe fruit of *S. torvum* (Cuervo et al. 1991). The C-4 sulfated isoflavonoid, torvanol A and the steroidal glycoside, torvoside H, together with the known glycoside, torvoside A, were isolated from a methanol extract of *Solanum torvum* fruits (Arthan et al. 2002). Upon enzymatic hydrolysis with β -glucosidase, torvoside A and torvoside H yielded the corresponding acetal derivatives aglycone torvoside A and aglycone torvoside H, respectively. Three 22- β -O-23-hydroxy-(5 α)-spirostanol glycosides namely

torvoside J, torvoside K and torvoside L were isolated from the fruits of *Solanum torvum* (Iida et al. 2005). Smith et al. (2008) isolated solasonine and solamargine from the fruits.

From the leaves, nitrogen-free steroidal saponins neochlorogenin and paniculogenin were isolated (Schreiber and Ripperger 1968) and also chlorogenin (Doepke et al. 1975). The following non-alkaloidal compounds were isolated from the leaves: 2,3,4-trimethyltriacontane, octacosanyl triacontanoate and 5-hexatriacontanone (Mahmood et al. 1983a). Triacontanol, 3-tritriacontanone, tetratriacontanoic acid, sitosterol, stigmasterol and campesterol were also isolated and identified. Mahmood et al. (1983b) isolated neochlorogenin, neosolaspigenin, and solaspigenin from *Solanum torvum* leaves. From leaves, a steroidal saponin torvonin-A, was isolated and its structure elucidated as neochlorogenin-3-O- β -L-rhamnopyranosyl (1 $\rightarrow$ 2) β -L-rhamnopyranoside neochlorogenin-3-O- β -L-rhamnopyranosyl (1 $\rightarrow$ 2) β -L-rhamnopyranoside (Mahmood et al. 1985). A β -glucosidase, torvosidase (Furostanol glycoside 26-O- β -glucosidase) was isolated from the leaves (Arthan et al. 2006). Purified torvosidase was found to be a monomeric glycoprotein, with a native molecular weight of 87 kDa. The enzyme showed strict specificity for the β -D-glucosyl bond when tested for glycone specificity. Torvosidase hydrolysed only torvosides and dalcochinin-8- β -glucoside, but did not hydrolyse other natural substrates of the GH1 β -glucosidases or of the GH3 β -glucosidase families. Torvosidase also hydrolysed C5-C10 alkyl- β -glucosides, with a rate of hydrolysis increasing with longer alkyl chain length.

The stem was found to contain steroidal alkaloids: solasodine, solasodiene and from the roots, neochlorogenin and chlorogenin (Doepke et al. 1975). From the roots the steroidal alkaloid glycoside, jurubine [(25S)-3 β -amino-5-amino-5 α -furostane-22-furostan-22 α .26-diol O(26)-O.26-diol (26)- β -D-glucopyranoside] was isolated (Schreiber and Ripperger 1968).

Torvonin-B. (neosolaspigenin 3-O- β -D-fucopyranosyl-(1 $\rightarrow$ 2)- β -D-quinovopyranoside) was isolated from *Solanum torvum* (Agrawal et al. 1989). From the aerial plant parts and roots of *Solanum torvum*, seven steroidal glycosides,

named torvosides A-G were isolated (Yahara et al. 1996). Their structures were characterized as (25S)-26-O-(β -D-glucopyranosyl)-5 α -furostan-3 β ,6 α ,22 ξ ,26-tetraol-6-O-[α -L-rhamnopyranosyl-(1 $\rightarrow$ 3)- β -D-quinovopyranoside]; (25S)-26-O-(β -D-glucopyranosyl)-22 α -methoxy-5 α -furostan-3 β ,6 α ,26-triol-6-O-[β -D-xylopyranosyl-(1 $\rightarrow$ 3)- β -D-quinovopyranoside]; neosolaspigenin 6-O-[α -L-rhamnopyranosyl-(1 $\rightarrow$ 3)- β -D-quinovopyranoside]; neosolaspigenin 6-O-[β -D-xylopyranosyl-(1 $\rightarrow$ 3)- β -D-quinovopyranoside]; (25S)-26-O-(β -D-glucopyranosyl)-6 α ,26-dihydroxy-22 α -methoxy-5 α -furostan-3-one-6-O-(β -D-quinovopyranoside); (25S)-26-O-(β -D-glucopyranosyl)-6 α ,26-dihydroxy-22 α -methoxy-5 α -furostan-3-one-6-O-[β -D-xylopyranosyl-(1 $\rightarrow$ 3)- β -D-quinovopyranoside]; and (25S)-26-hydroxy-22 α -methoxy-5 α -furostan-3-one-6-O-(β -D-glucopyranoside), respectively. The total amount of steroidal glycoalkaloids found in *Solanum torvum* was (0.038%) and two glycosylated compounds derived from solasodine, solasonine (0.0043%) and solamargine (0.0028%), were determined (Perez-Amador et al. 2007). These two glycosylated compounds of solasodine could be used as a substrate for the production of important steroids in pharmacology.

Two new siprostanol glycosides: neosolaspigenin 6-O- β -D-quinovopyranoside and solagenin 6-O-[β -D-xylopyranosyl-(1 $\rightarrow$ 3)-O- β -D-quinovopyranoside] were identified from *Solanum torvum* (Lu et al. 2008). Two novel C-22 steroidal lactone saponins, namely solanolactoside A, solanolactoside B and two new spirostanol glycosides, namely torvoside M and torvoside N were isolated from ethanol extract of aerial parts of *Solanum torvum* (Lu et al. 2009). Their structures were characterized as solanolide 6-O-[α -L-rhamnopyranosyl-(1 $\rightarrow$ 3)-O- β -D-quinovopyranoside]; solanolide 6-O-[β -D-xylopyranosyl-(1 $\rightarrow$ 3)-O- β -D-quinovopyranoside]; yamogenin 3-O-[β -D-glucopyranosyl-(1 $\rightarrow$ 6)-O- β -D-glucopyranoside]; and neochlorogenin 3-O-[β -D-glucopyranosyl-(1 $\rightarrow$ 6)-O- β -D-glucopyranoside]. Six triterpenes were isolated from aerial parts of *S. torvum* and identified as 3 β -acetyloleanolic acid (1), 3-O-acetyl-11 α ,12 α -epoxy-oleanan-28,13 β -olide (2), oleano-

lic acid (3), ursolic acid (4), 2 α -hydroxy-oleanolic acid (5), and 2 α ,3 β -dihydroxyursolic acid (6) (Zhou et al. 2011).

Nine known compounds including neochlorogenin 6-O- β -D-quinovopyranoside; neochlorogenin 6-O- β -D-xylopyranosyl-(1 $\rightarrow$ 3)- β -D-quinovopyranoside; neochlorogenin 6-O- α -L-rhamnopyranosyl-(1 $\rightarrow$ 3)- β -D-quinovopyranoside; solagenin 6-O- β -D-quinovopyranoside; solagenin 6-O- α -L-rhamnopyranosyl-(1 $\rightarrow$ 3)- β -D-quinovopyranoside; isoquercetin; rutin; kaempferol; and quercetin were isolated from *S. torvum* (Lu et al. 2011).

Antioxidant Activity

A purified protein with a molecular weight of ~28 kDa was obtained from *S. torvum* seeds (Sivapriya and Srinivas 2007). The purified protein, at 0.8 μ M, inhibited deoxyribose degradation induced by generation of hydroxyl radicals by 90% and scavenged DPPH (1,1-diphenyl-2-picrylhydrazyl) radicals by 76%. The reducing power and chelating power of the purified protein, at 0.8 μ M, were found to be 72% and 85%, respectively. The protein, at 0.8 μ M, also offered significant protection to calf thymus DNA damage induced by H₂O₂ (1 mM). The results demonstrated, the novel protein from the water extract of Sundakai seeds to be an excellent antioxidant. The chloroform, acetone, and methanol extracts of *Solanum torvum* leaves and fruit exhibited in-vitro antioxidant activity as evaluated using ferric reducing antioxidant power, DPPH, ABTS+, iron chelation, and antihemolytic activity (Loganayaki et al. 2010). Among the various solvents used, the maximum yield was obtained in chloroform followed by acetone and methanol. The total phenolics were also significantly higher in the chloroform extracts and the in-vitro antioxidant activity was shown to be highly dependant on the total phenolic content. The results reported implied leaves and fruits of *S. torvum* could be considered as health supplements and nutraceuticals/functional foods. Compared to pomegranate seed extract, *S. torvum* seed extract was more potent as it exhibited outstanding

reducing power, scavenging activity against DPPH and hydrogen peroxide and showed a significant linear correlation with phenolic and flavonoid contents (Waghulde et al. 2011). The total flavonoid content of ethanol -extract and methanol extract of *S. torvum* seeds was found to be 85.26 µg and 65.69 µg rutin equivalent/ mg of extract respectively and the total phenolic content was found to be 99.52 µg and 78. µg gallic acid equivalent/mg of extract respectively. However, Wetwitayaklung and Phaechamud (2011) reported low antioxidant activity of *S. torvum* (Ma Khuea Phuang) fruit with IC₅₀ of 1,440 µg TEAC (Trolox Equivalent Antioxidant capacity) and total phenolic content of 2.33 g/100 g crude extract gallic acid.

Anticancer Activity

Compounds 1–5 isolated from *S. torvum* fruit namely torvanol A, torvoside A, torvoside H, aglycone torvoside A and aglycone torvoside H showed no cytotoxicity (at 50 µg/mL) against BC (breast cancer), and KB (oral-cavity cancer) and Vero cell lines (Arthan et al. 2002). Two new spirostanol glycosides from *S. torvum* aerial plant parts , torvoside M and torvoside N exhibited significant cytotoxic activity towards a panel of human cancer cell lines (Lu et al. 2009). BEC, a standard mixture of solasodine glycosides significantly inhibited murine sarcoma 180 (S180) in mice, whereas the aglycone solasodine at equimolar concentrations was ineffective (Cham and Daunter 1990). The efficacy of BEC against S180 in-vivo was inhibited by rhamnose. Mice which were in their terminal stage with S180 could tolerate and become symptom-free of cancer by single dose administration of BEC at concentrations of BEC three times the LD100 for normal mice. These observations suggested that the binding of solasodine glycosides on tumour cells may be mediated through the monosaccharide rhamnose, which formed part of solasonine, solamargine and di-glycosides of solasodine in BEC. In addition, the results provided evidence that BEC selectively destroyed tumour cells relative to normal cells in-vivo.

Antiviral Activity

Torvanol A, torvoside H and compound aglycone torvoside H isolated from *S. torvum* fruit exhibited antiviral activity (Herpes simplex virus type 1) with IC₅₀ values of 9.6, 23.2 and 17.4 µg/mL, respectively (Arthan et al. 2002).

Antimicrobial Activity

The methanolic extract of *Solanum torvum* fruit showed a wide spectrum of antimicrobial activities against human and animal clinical isolates (Chah et al. 2000). The methanol extract of the fruits of *S. torvum* was found to exhibit interesting growth-inhibiting activity against bacteria commonly associated with pyogenic infections. Wiart et al. (2004) found *S. torvum* (methanol extracts of various plant parts) was one of several plants screened that displayed broadest spectrum of antimicrobial activity.

Water and ethanol aqueous extracts of Sundakai (*S. torvum*) fruit coat exhibited strong antibacterial activity against *Escherichia coli*, *Vibrio cholera*, *Staphylococcus aureus*, *Bacillus subtilis*, *Salmonella cibrium*, *Salmonella typhimurium* and *Pseudomonas* sp (Sivapriya et al. 2011).

The water, acetone, chloroform and methanol extracts of *Solanum torvum* inhibited the growth of *Helicobacter pylori* and showed better activities against antibiotic resistance strains than the reference strain (Hsu et al. 2010). *Helicobacter pylori* infection is associated with an increased risk for development of duodenal ulcers, gastric ulcers, gastric adenocarcinomas and gastric lymphomas. Of the extracts, the chloroform extract possessed the strongest ability to inhibit *H. pylori* growth. *H. pylori*-induced apoptosis in human gastric epithelial cells could also be efficiently suppressed by the chloroform extract.

Methanol root extract of *S. torvum* exhibited promising antibacterial and antifungal effects with MIC of 64–128 µg/mL. (Bari et al. 2010). Order of antimicrobial activity was in the order root > stem > inflorescence > leaf. The following bacteria: *Bacillus cereus*, *Bacillus subtilis*,

Streptococcus β -haemolyticus, *Salmonella typhi*, and *Shigella dysenteriae* were inhibited. Both methanol and chloroform root extracts were inhibitory to fungi *Aspergillus fumigatus*, *Fusarium vasinfectum*, and *Candida albicans*. Chloroform extract of roots was more toxic (LC_{50} 35.463 ppm) than other extracts in the brine shrimp nauplii test indicating they were biologically active.

Antiinflammatory and Analgesic Activities

Aqueous leaf extract of *S. torvum* administered orally to rats suppressed acetic-acid-induced and pressure-induced pains (Ndebia et al. 2007). The extract also inhibited carrageenan-induced inflammation in rats at various doses of the extract. The aqueous extract of *S. torvum* induced dose dependant analgesic effect against the writhing syndrome indicating its peripheral effect. The findings also suggested that *S. torvum* extract may act by suppressing the later phase of the inflammatory process by the inhibition of cyclooxygenase, the enzyme involved in the formation of prostaglandins. Solasonine inhibited cotton ball granuloma and carrageenan-induced hind paw swelling in the rat (Basu and Lahiri. 1977).

Immunostimulatory and Erythropoietic Activities

Solanum torvum extract showed a concentration-dependent immunostimulant and erythropoietic activity (Koffuor et al. 2011). The aqueous *Solanum torvum* extract and levamisole significantly enhanced delayed type hypersensitivity response, increased hemagglutinating antibody titer and white blood cells count, while dexamethasone significantly decreased delayed type hypersensitivity response, did not increase hemagglutinating antibody titer, and did not enhance white blood cells profile. The extract and Feroglobin, the reference heamatinic, were able to reverse phenylhydrazine-induced anemia, and increase the red blood cells and haemoglobin

concentration above baseline values within 24 days.

Hypotensive and Antiplatelet Activities

This plant is also used for its haemostatic properties. Aqueous extracts of turkey berry were found to be lethal to mice by depressing the number of erythrocytes, leukocytes and platelets in their blood. Recent studies using animal models reported that both methanolic and aqueous extracts of *S. torvum* fruit possessed hypotensive activity which may partially result from their bradycardic effect (Nguelefack et al. 2008b). The aqueous fruit extract dose-dependently inhibited the aggregation effect induced by thrombin and adenosine diphosphate. These results supported the use of the plant in the traditional treatment of arterial hypertension and haemostatic ailments. Studies suggested that oral chronic administration of aqueous extract from dried *Solanum torvum* fruits induced potentiation of arterial hypertension and cardiac hypertrophy in L-NAME (nitro-L-arginine methyl ester hydrochloride) treated rats but not in normotensive animals (Nguelefack et al. 2009). The extract increased the sensitivity to noradrenaline in normotensive and significantly reduced it in hypertensive animals. The extract significantly increased urinary volume and sodium excretion in L-NAME treated animals while reducing the sodium excretion in normotensive. These effects were suggested to result from a reduction in sensitivity to vasorelaxant agents and increase in hypersensitivity to contractile factors. The extract possessed potent in vitro vasocontractile activity that may result from activation of both alpha(1)-adrenergic pathway and calcium influx. In another study, the ethanolic extract of *Solanum torvum* reduced systolic blood pressure, vascular reactivity changes to catecholamines and reversed the metabolic alterations induced by fructose (Mohan et al. 2009). The results suggested that the ethanol extract of *Solanum torvum* could prevent the development of high blood pressure induced by a diet rich in fructose probably by reversing the metabolic alterations induced by fructose.

Antiacetylcholine Activity

Solasonine inhibited isolated cat heart contraction and contraction of the isolated guinea pig ileum and cat trachea induced by acetylcholine (Basu and Lahiri 1977). It also had contracting effect on isolated rabbit aural blood vessels, and could induce contraction and spontaneous activities of isolated rat uterus.

Platelet Aggregating Activity

Moriyama et al. (2003) found that *Solanum torvum* plant extracted with 50% ethanol exhibited a more potent platelet aggregating effect than the aqueous extracts. The results suggested that platelet aggregation activating constituents in the plant may be more ethanol soluble than water soluble.

Antiulcerogenic Activity

The aqueous and methanol leaf extracts of *Solanum torvum* was found to have antiulcerogenic properties (Nguelefack et al. 2008a). The methanol extract at the dose of 750 mg/kg produced 98.12, 99.16, 98.70 and 96.03% inhibition when gastric ulcerations were induced by HCl/ethanol, indomethacin, pylorus ligation and stress, respectively. The aqueous extract at the same dose produced 96.55, 96.86, 98.63 and 98.63% inhibition on ulcerations induced respectively by HCl/ethanol, indomethacin, pylorus ligation and stress. All the fractions of the methanol extract significantly inhibited ulcer formation. Fraction F which contained flavonoids and triterpenes was the most active and exhibited an inhibitory percentage of 84.74. Both extracts significantly increased mucus production and reduced gastric acid secretion.

Nephroprotective Activity

Studies showed that *S. torvum* exerted a the protective effect on doxorubicin-induced nephrotoxicity

in Wistar rats (Mohan et al. 2010). Treatment with *S. torvum* (100 mg/kg and 300 mg/kg) significantly decreased the levels of serum creatinine and blood urea nitrogen and significantly increased the anti-oxidant defence enzyme levels of superoxide dismutase and catalase. Histopathological changes showed that doxorubicin caused significant structural damages to kidneys like tubular necrosis, renal lesions and glomerular congestion which was reversed with *S. torvum*.

Antidiabetic Activity

After 1 month of dry Sundakai powder supplementation, no significant changes were observed with respect to glucose, lipid profile, glycated proteins, total amino acids and uronic acid levels in non-insulin dependent diabetes mellitus patients (Iyer et al. 1992). Studies found *S. torvum* extracts to be a natural source of polyphenolic antioxidants (phenol, flavonoids and tannin) and to have cytochrome P450 2E1 (CYP2E1) enzyme inhibiting in human liver microsomes and free radical scavenging properties, as related to lipid peroxidation and superoxide anion activity (Kusirisin et al. 2009). Cytochrome P450 2E1 enzymes (CYP2E1) are involved in drug metabolism in the liver and metabolism of DNA-reaction generating intra-mitochondrial ROS, which leads to micro- and macro-vascular pathology in diabetes. The IC_{50} value of CYP2E1 catalytic inhibiting activity level was 5.14 mg/mL by concentration in a dependent manner. One gram of concentrated ST extract had an antioxidant activity index of 3.68 mg of Trolox and 360.53 mg of ascorbic acid equivalent. Effects on free radical-scavenging, as measured by TBARS and superoxide anion, showed IC_{50} values of 20.60 and 10.26 μ g/mL, respectively. The results suggested that *S. torvum* could potentially be used for reducing oxidative stress in diabetes.

Oral administration of *S. torvum* fruit methanol extract at 200 and 400 mg/kg to streptozotocin induced diabetic rats for 30 days reduced blood glucose level by 17.04% and 42.10%, respectively in diabetic rats (Gandhi et al. 2011a). The levels and/or activities of other biochemical

parameters: glucose, insulin, total protein, hemoglobin, glycated hemoglobin, liver glycogen and marker enzymes of carbohydrate metabolism, hepatic function and antioxidants were restored significantly compared to diabetic control rats due to treatment with fruit extract. Histology of liver and pancreas in fruit extract treated groups substantiated the cytoprotective action of the drug. Immunohistochemical observation of islets in extract treated diabetic rats showed apparent β -cells regeneration. *S. torvum* fruit extract contained high levels of phenolic compounds, mainly rutin (1.36%w/w), caffeic acid (12.03%w/w), gallic acid (4.78%w/w) and catechin (0.46%w/w). The findings suggested *S. torvum* fruit containing phenolic compounds had great potential as a natural source of antidiabetic and antioxidant drug.

S. torvum fruit was found to contain methyl caffeate, an α -glucosidase inhibitor with potential antidiabetic usage (Takahashi et al. 2010). They showed that methyl caffeate had a most favourable structure for both sucrase and maltase inhibition. Gandhi et al. (2011b) found that methyl caffeate isolated from *S. torvum* fruit at 40 mg/kg significantly prevented the increase in blood glucose level after glucose administration at 60 min in comparison to the hyperglycemic control group. In streptozotocin induced diabetic rats, methyl caffeate produced significant reduction in blood glucose and increased body weight. The levels and/or activities of other biochemical parameters were near normal due to treatment with methyl caffeate. Methyl caffeate treated diabetic rats showed upregulation of GLUT4 and regeneration of β -cells in the pancreas. The results substantiated that methyl caffeate possessed hypoglycemic effect and its traditional use for treating diabetes.

Antidepressant Activity

The methanolic extract of *Solanum torvum* seeds and its ethyl acetate fraction dose dependently inhibited the immobility period, increased norepinephrine, serotonin and dopamine levels in mice and inhibited the monoamine oxidase enzymes in forced swim test and tail suspension test (Momin

and Mohan 2011). The study provided evidence for antidepressant actions of *S. torvum*.

Antimelanogenesis Activity

Studies found that *S. torvum* root extract (300 μ g/mL) strongly inhibited the melanin production of B16 melanoma cells without significant cytotoxicity (Arung et al. 2009).

Antimalarial/Larvicidal Activity

The leaf and seed methanol extracts of *S. torvum* exhibited larvicidal effects against fourth instar larvae of malaria vector, *Anopheles subpictus* and Japanese encephalitis vector, *Culex tritaeniorhynchus* (Kamaraj et al. 2009). They also found the leaf methanol extract of *S. torvum* exhibited high larvicidal activity against the fourth instar larvae of malaria vector, *Anopheles stephensi* and lymphatic filariasis vector, *Culex quinquefasciatus* and may have potential for use to control mosquitoes (Kamaraj et al. 2010b). More recently they found the leaf extract of *S. torvum* exhibited moderate antimalarial activity against the chloroquine-resistant (INDO) strains of *Plasmodium falciparum* (Kamaraj et al. 2011a).

Adverse Effects

Inclusion of dried powdered leaves of *Solanum torvum* in the diet of rats induced hypercalcaemia rapidly and hyperphosphataemia more slowly and soft tissue calcification was most evident in the kidney and lung (Morris et al. 1979). The authors suggested that *Solanum torvum* may be a causative agent of enzootic calcinosis in cattle in Papua, New Guinea. Oral feeding of Swiss mice with salted, sun-dried and oil fried Sundakkai (*Solanum torvum*) at 100 mg/animal/day for 12 months was found to cause hepatic haemangiomas (Balachandran and Sivaramkrishnan 1995). Smith et al. (2008) reported two geographically, temporally disparate outbreaks of poisoning by susember berries (*Solanum torvum*) and on detection of

alkaloids not present in non-toxic berries. Five family members in New York City suffered gastrointestinal distress, dizziness, slurred speech, cranial nerve deficits, and ataxia the next morning after consumption of an evening meal containing susumber berries. The most seriously afflicted patient developed hypertension, confusion, proximal upper extremity weakness, and hypercapnic respiratory failure requiring prolonged mechanical ventilation. In another case in Toronto, six patients who consumed unripe susumber berries developed varying degrees of diarrhea, weakness, facial paralysis, slurred speech, ataxia, early hypertension, and proximal weakness 14 h post-consumption. Two patients had ventilatory decompensation; one required intubation. The researchers isolated solasonine, larger amounts of solamargine, and other steroidal glycoalkaloids in the toxic berry strains. The findings suggested that *S. torvum* poisoning could produce significant neurological and gastrointestinal effects which appeared to be mediated by steroidal glycoalkaloids present in the berries.

Traditional Medicinal Uses

Various part of the plant have been utilised in traditional folkloric medicine and have been regarded to be antipyretic, anti-rheumatic, antiphlogistic, anti-infectious, anti-contusion, anti-inflammation, diuretic and analgesic (Burkill 1966; Burkill 2000; Jain and Borthakur 1986; Sivarajan and Balachandran 1994; Stuart 2010). The plant was used by the Mayans in ancient Mexico to treat infections, rheumatism, vaginal bleeding occurring outside menstrual cycle and as analgesic (Dominguez and Alcorn 1985). In the Philippines, the dried roots in decoction, or processed into syrup or alcoholic suspension have been used as treatment for stomach ache, indigestion, gastric pain, amenorrhea and rheumatism. The dried pounded roots are used for poultice of cracking sole in Malaysia, seeds are smoked in Malaysia for curing toothache. In China the plant is used as antitussive to disperse extravasated blood and to relieve pain. In India, the plant is used as antidote to snakebite and insect stings, the fruit

to relieve stomach pain and leaves are dried and ground to powder, which is used as medicine for diabetic patients. Studies on the effect of dried leaf powder in India showed no significant changes with respect to glucose, lipid profile, glycated proteins, total amino acids and uronic acid levels in non-insulin dependent diabetes mellitus patients. As an Ayurvedic herb it is used in many Ayurvedic treatments in connection with its sedative, diuretic and digestive properties. It is used in the treatment for coughs and cold and a tonic for liver. The young fruits are employed medicinally for improving eyesight; the leaves are used for treating skin diseases – sores, pimples. The plant is used in Cameroonian folk medicine for the treatment of fever, wounds, and tooth decay and for the management of pain and inflammation (Ndebia et al. 2007). In Sierra Leone, a decoction of the fruit is given to children as a cough medicine, and in Senegal the plant is taken to treat sore throat and stomach-ache.

In Tripura and West Bengal, fruits are crushed or cooked with dry fish (sidhol) and taken with warm rice to cure rheumatic pain (Arif and Fareed 2011). The fruit has been used ethnomedicinally as a tonic and haematopoietic, anti-microbial agent and for the treatment of pain. A decoction of fruits is given for cough ailments and is considered as useful in liver and spleen enlargement. The fruit has sedative, diuretic and digestive in action.

The antimicrobial properties of the leaves have been known for some time in Central America and India, and also in Gabon people apply the leaves to cuts and wounds. In Tamil Nadu, sundaikkai leaf juice is taken orally to reduce body heat (Muthu et al. 2006). *Solanum torvum* is used as a herbal remedy for the treatment of malaria in the Dangme West District of Ghana (Asase et al. 2010). The leaves are boiled and administered orally.

Other Uses

Solanum torvum is used as a disease resistant rootstock against *Meloidogyne* nematodes for *Solanum quitoense* in Colombia and Ecuador,

and for *Solanum melongena* in southeast Asia and Cuba and against bacterial wilt in tomatoes.

Methanol extract of *S. torvum* exerted 100% egg hatching and larvicidal inhibition in-vitro against the sheep gastrointestinal nematode *Haemonchus contortus* and the effect was similar to positive control of Albendazole (0.075 mg/mL) and Ivermectin (0.025 mg/mL) (Kamaraj et al. 2011b). The leaf and seed methanol extracts of *S. torvum* exhibited antiparasitic activities against the larvae of cattle tick *Rhipicephalus (Boophilus) microplus*, nymph of goat-lice *Damalinia caprae*, adult of cattle tick *Haemaphysalis bispinosa*, hematophagous fly *Hippobosca maculata*, and the seed methanol extract of *S. torvum* against the adult of sheep parasite *Paramphistomum cervi* (Kamaraj et al. 2010a).

Comments

The plant is used horticulturally as a rootstock for eggplant, *Solanum melongena*.

Selected References

- Agrawal PK, Mahmood U, Thakur RS (1989) Torvonin B, a spirostane saponin from *Solanum torvum*. *Heterocycles* 29(10):1895–1900
- Arif M, Fareed S (2011) Pharmacognostical studies and evaluation of total phenolic and flavonoid contents of traditionally utilized fruits of *Solanum torvum* Sw. *Indian J Nat Prod Resour* 2(2):218–224
- Arthan D, Svasti J, Kittakoop P, Pittayakhachonwut D, Tanticharoen M, Thebtaranonth Y (2002) Antiviral isoflavonoid sulfate and steroidal glycosides from the fruits of *Solanum torvum*. *Phytochemistry* 59(4):459–463
- Arthan D, Kittakoop P, Esen A, Svasti J (2006) Furostanol glycoside 26-O- β -glucosidase from the leaves of *Solanum torvum*. *Phytochemistry* 67(1):27–33
- Arung ET, Kusuma IW, Christy EO, Shimizu K, Kondo R (2009) Evaluation of medicinal plants from Central Kalimantan for antimelanogenesis. *J Nat Med* 63(4):473–480
- Asase A, Akwetey GA, Achel DG (2010) Ethnopharmacological use of herbal remedies for the treatment of malaria in the Dangme West District of Ghana. *J Ethnopharmacol* 129(3):367–376
- Badola KC, Mohinder P, Bhandari HCS, Pal M (1993) Vegetative propagation of ranbaigan (*Solanum torvum* Sw.) by rooting branch cuttings. *Indian For* 119(12):1027–1028
- Balachandran B, Sivaramkrishnan VM (1995) Induction of tumours by Indian dietary constituents. *Indian J Cancer* 32(3):104–109
- Bari MA, Islam W, Khan AR, Mandal A (2010) Antibacterial and antifungal activity of *Solanum torvum* (Solanaceae). *Int J Agric Biol* 12:386–390
- Basu A, Lahiri SC (1977) Some pharmacological actions of solasonine. *Indian J Exp Biol* 15(4):285–289
- Boonkerd T, Na Songkhla B, Thephuttee W (1994) *Solanum torvum* Swartz. In: Siemonsma JS, Piluek K (eds) *Plant resources of South-East Asia*, no. 8. Vegetables. Prosea Foundation, Bogor, pp 258–260
- Burkill IH (1966) *A dictionary of the economic products of the Malay Peninsula*, Revised reprint, 2 vols. Ministry of Agriculture and Co-operatives, Kuala Lumpur, Malaysia, pp 1–1240, 1241–2444, vol 1 (A–H), 2 (I–Z)
- Burkill HM (2000) *Useful plants of west tropical Africa*, vol 5. Families S–Z/Royal Bot. Gardens, Kew, 686 pp
- Chah KF, Muko KN, Oboegbulem SI (2000) Antimicrobial activity of methanolic extract of *Solanum torvum* fruit. *Fitoterapia* 71:187–189
- Cham BE, Daunter B (1990) Solasodine glycosides. Selective cytotoxicity for cancer cells and inhibition of cytotoxicity by rhamnose in mice with sarcoma 180. *Cancer Lett* 55(3):221–225
- Cuervo AC, Blunden G, Patel AV (1991) Chlorogenone and neochlorogenone from the unripe fruits of *Solanum torvum*. *Phytochemistry* 30(4):1339–1341
- Doepke W, Nogueiras C, Hess U (1975) Steroid alkaloid and saponin contents of *Solanum torvum*. *Pharmazie* 30(11):755
- Dominguez XA, Alcorn JB (1985) Screening of medicinal plants used by Huastec Mayans of Northeastern Mexico. *J Ethnopharmacol* 13:139–156
- Fayez MB, Saleh AA (1967) Constituents of local plants. XIII. Steroidal constituents of *Solanum torvum*. *Planta Med* 15(4):430–433
- Foundation for Revitalisation of Local Health Traditions (2008) FRLHT Database. <http://envis.frlht.org>
- Gandhi GR, Ignacimuthu S, Paulraj MG (2011a) *Solanum torvum* Swartz. fruit containing phenolic compounds shows antidiabetic and antioxidant effects in streptozotocin induced diabetic rats. *Food Chem Toxicol* 49(11):2725–2733
- Gandhi GR, Ignacimuthu S, Paulraj MG, Sasikumar P (2011b) Antihyperglycemic activity and antidiabetic effect of methyl caffeate isolated from *Solanum torvum* Swartz. fruit in streptozotocin induced diabetic rats. *Eur J Pharmacol* 670(2–3):623–631
- Henty EE, Pritchard GH (1973) Weeds of New Guinea and their control, Bot bull no 7. Department of Forests/Division of Botany, Lae, pp 149–151
- Herzog F, Gautier-Béguin D, Müller K (1996) Uncultivated plants for human nutrition in Côte d'Ivoire. In: Domestication and commercialization of non-timber forest products in agroforestry systems, Non-wood forest products no 9. Food and Agriculture Organization (FAO), Rome

- Hsu YM, Weng JR, Huang TJ, Lai CH, Su CH, Chou CH (2010) *Solanum torvum* inhibits *Helicobacter pylori* growth and mediates apoptosis in human gastric epithelial cells. *Oncol Rep* 23(5):1401–1405
- Iida Y, Yanai Y, Ono M, Ikeda T, Nohara T (2005) Three unusual 22-beta-*O*-23-hydroxy-(5 α)-spirostanol glycosides from the fruits of *Solanum torvum*. *Chem Pharm Bull*(Tokyo) 53(9):1122–1125
- Iyer UM, Mehta NC, Mani I, Mani UV (1992) Studies on the effect of dry Sundakai (*Solanum torvum*) powder supplementation on lipid profile, glycosylated proteins and amino acids in non-insulin dependent diabetic patients. *Plant Foods Hum Nutr* 42(2):175–182
- Jain SK, Borthakur SK (1986) Solanaceae in Indian tradition, folklore, and medicine. In: D'Arcy WG (ed) *Solanaceae: biology and systematics*. Columbia University Press, New York, pp 577–583, 603 pp
- Kamaraj C, Bagavan A, Rahuman AA, Zahir AA, Elango G, Pandiyan G (2009) Larvicidal potential of medicinal plant extracts against *Anopheles subpictus* Grassi and *Culex tritaeniorhynchus* Giles (Diptera: Culicidae). *Parasitol Res* 104(5):1163–1171
- Kamaraj C, Rahuman AA, Bagavan A, Elango G, Rajakumar G, Zahir AA, Marimuthu S, Santhoshkumar T, Jayaseelan C (2010a) Evaluation of medicinal plant extracts against blood-sucking parasites. *Parasitol Res* 106(6):1403–1412
- Kamaraj C, Rahman AA, Bagavan A, Zahir AA, Elango G, Kandan P, Rajakumar G, Marimuthu S, Santhoshkumar T (2010b) Larvicidal efficacy of medicinal plant extracts against *Anopheles stephensi* and *Culex quinquefasciatus* (Diptera: Culicidae). *Trop Biomed* 27(2):211–219
- Kamaraj C, Kaushik NK, Mohanakrishnan D, Elango G, Bagavan A, Zahir AA, Rahuman AA, Sahal D (2011a) Antiplasmodial potential of medicinal plant extracts from Malaiyur and Javadhu hills of South India. *Parasitol Res* 111(2):703–715
- Kamaraj C, Rahuman AA, Elango G, Bagavan A, Zahir AA (2011b) Anthelmintic activity of botanical extracts against sheep gastrointestinal nematodes, *Haemonchus contortus*. *Parasitol Res* 109(1):37–45
- Koffuor GA, Amoateng P, Andey TA (2011) Immunomodulatory and erythropoietic effects of aqueous extract of the fruits of *Solanum torvum* Swartz (Solanaceae). *Pharmacogn Res* 3(2):130–134
- Kusirisin W, Jaikang C, Chaiyasut C, Narongchai P (2009) Effect of polyphenolic compounds from *Solanum torvum* on plasma lipid peroxidation, superoxide anion and cytochrome P450 2E1 in human liver microsomes. *Med Chem* 5(6):583–588
- Leung W-TW, Butrum RR, Chang FH (1972) Food composition table for use in East Asia. Department of Health/Education and Welfare, Bethesda, 334 pp
- Liogier HA (1995) Descriptive flora of Puerto Rico and adjacent Islands, vol 4. Editorial de la Universidad de Puerto Rico, Río Piedras, 617 pp
- Loganayaki N, Siddhuraju P, Manian S (2010) Antioxidant activity of two traditional Indian vegetables: *Solanum nigrum* L. and *Solanum torvum* L. *Food Sci Biotechnol* 19(1):121–127
- Lu YY, Luo JG, Xu DR, Huang XF, Kong LY (2008) Characterization of spirostanol saponins in *Solanum torvum* by high-performance liquid chromatography/evaporative light scattering detector/electrospray ionization with multi-stage tandem mass spectrometry. *Rapid Commun Mass Spectrom* 22(16):2447–2452
- Lu YY, Luo JG, Huang XF, Kong LY (2009) Four new steroidal glycosides from *Solanum torvum* and their cytotoxic activities. *Steroids* 74(1):95–101
- Lu YY, Luo JG, Kong LY (2011) Chemical constituents from *Solanum torvum*. *Chinese J Nat Med* 9(1):30–32
- Mahmood U, Shukla YN, Thakur RS (1983a) Non-alkaloidal constituents from *Solanum torvum* leaves. *Phytochemistry* 22(1):167–169
- Mahmood U, Thakur RS, Blunden G (1983b) Neochlorogenin, neosolaspigenin, and solaspigenin from *Solanum torvum* leaves. *J Nat Prod* 46(3):427–428
- Mahmood U, Agrawal PK, Thakur RS (1985) Torvonin-A, a spirostane saponin from *Solanum torvum* leaves. *Phytochemistry* 24(10):2456–2457
- Ministry of Public Health (1970) Tables of nutrition values in Thai food per 100 g of edible portion. Office of the Prime Minister, Royal Thai Government, Bangkok
- Mohan M, Jaiswal BS, Kasture S (2009) Effect of *Solanum torvum* on blood pressure and metabolic alterations in fructose hypertensive rats. *J Ethnopharmacol* 126(1):86–89
- Mohan M, Kamble S, Gadhi P, Kasture S (2010) Protective effect of *Solanum torvum* on doxorubicin-induced nephrotoxicity in rats. *Food Chem Toxicol* 48(1):436–440
- Momin R, Mohan M (2011) Involvement of central noradrenaline, serotonin and dopamine system in the antidepressant activity of fruits of *Solanum torvum* (Solanaceae). *Nat Prod Res* 1:1–7
- Moriyama H, Iizuka T, Nagai M, Hoshi K, Murata Y, Taniguchi A (2003) Platelet aggregatory effects of *Nasturtium officinale* and *Solanum torvum* extracts. *Nat Med* 57(4):133–138
- Morris KM, Simonite JP, Pullen L, Simpson JA (1979) *Solanum torvum* as a causative agent of enzootic calcinosis in Papua, New Guinea. *Res Vet Sci* 27(2):264–266
- Muthu C, Ayyanar M, Raja N, Ignacimuthu S (2006) Medicinal plants used by traditional healers in Kancheepuram District of Tamil Nadu, India. *J Ethnobiol Ethnomed* 2:Article 43
- Ndebja EJ, Kamgang R, Nkeh-Chungag Anye BN (2007) Analgesic and anti-inflammatory properties of aqueous extract from leaves of *Solanum torvum* (Solanaceae). *Afr J Tradit Complement Altern Med* 4(2):240–244
- Nguelefack TB, Feumebo CB, Ateufack G, Watcho P, Tatsimo S, Atsamo AD, Tane P, Kamanyi A (2008a) Anti-ulcerogenic properties of the aqueous and methanol extracts from the leaves of *Solanum torvum* Swartz (Solanaceae) in rats. *J Ethnopharmacol* 119(1):135–140

- Nguelefack TB, Mekhfi H, Dimo T, Afkir S, Nguelefack-Mbuyo EP, Legssyer A, Ziyat A (2008b) Cardiovascular and anti-platelet aggregation activities of extracts from *Solanum torvum* (Solanaceae) fruits in rat. *J Complement Integr Med* 5(1):Article 7
- Nguelefack TB, Mekhfi H, Dongmo AB, Dimo T, Watcho P, Zoheir J, Legssyer A, Kamanyi A, Ziyat A (2009) Hypertensive effects of oral administration of the aqueous extract of *Solanum torvum* fruits in L-NAME treated rats: evidence from in vivo and in vitro studies. *J Ethnopharmacol* 124(3):592–599
- Ochse JJ, Bakhuizen van den Brink RC (1980) Vegetables of the Dutch Indies, 3rd edn. Ascher and Co, Amsterdam, 1016 pp
- PBI Solanum Project (2011) Solanaceae Source. May 2011. <http://www.nhm.ac.uk/solanaceaesource/>
- Perez-Amador MC, Munoz Ocotero V, Garcia Castaneda JM, Gonzalez Esquinca AR (2007) Alkaloids in *Solanum torvum* Sw (Solanaceae). *Phyton (B Aires)* 76:39–45
- Porcher MH et al (1995–2020) Searchable World Wide Web multilingual multiscript plant name database. Published by The University of Melbourne. Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Schreiber K, Ripperger H (1968) *Solanum* alkaloids. LXXXIV. Isolation of jurubine, neochlorogenin, and paniculogenin from *Solanum torvum*. *Kulturpflanze* 15:199–204
- Sivapriya M, Srinivas L (2007) Isolation and purification of a novel antioxidant protein from the water extract of Sundakai (*Solanum torvum*) seeds. *Food Chem* 104:510–517
- Sivapriya M, Dinesha R, Harsha R, Gowda SST, Srinivas L (2011) Antibacterial activity of different extracts of sundakai (*Solanum torvum*) fruit coat. *Int J Biol Chem* 5:61–67
- Sivarajan VV, Balachandran I (eds) (1994) Ayurvedic drugs and their plant sources, 1st edn. Oxford and IBH Publishing, New Delhi
- Smith SW, Giesbrecht E, Thompson M, Nelson LS, Hoffman RS (2008) Solanaceous steroidal glycoalkaloids and poisoning by *Solanum torvum*, the normally edible susumber berry. *Toxicon* 52(6):667–676
- Stuart GU (2010) Philippine alternative medicine. Manual of some Philippine medicinal plants. <http://www.stu-artschange.org/OtherHerbals.html>
- Takahashi K, Yoshioka Y, Kato E, Katsuki S, Iida O, Hosokawa K, Kawabata J (2010) Methyl caffeate as an alpha-glucosidase inhibitor from *Solanum torvum* fruits and the activity of related compounds. *Biosci Biotechnol Biochem* 74(4):741–745
- Waghulde H, Kamble S, Patankar P, Jaiswal B, Pattanayak S, Bhagat C, Mohan M (2011) Antioxidant activity, phenol and flavonoid contents of seeds of *Punica granatum* (Punicaceae) and *Solanum torvum* (Solanaceae). *Pharmacologyonline* 1:193–202
- Wetwitayaklung P, Phaechamud T (2011) Antioxidant activities and phenolic content of *Solanum* and *Capsicum* sp. *Res J Pharm Biol Chem Sci* 2(2):146–154
- Wiat C, Mogana S, Khalifah S, Mahan M, Ismail S, Buckle M, Narayana AK, Sulaiman M (2004) Antimicrobial screening of plants used for traditional medicine in the state of Perak, Peninsular Malaysia. *Fitoterapia* 75(1):68–73
- Yahara S, Yamashita T, Nozawa (nee Fujimura) N, Nohara T (1996) Steroidal glycosides from *Solanum torvum*. *Phytochemistry* 43(5):1069–1074
- Zhang ZY, Lu AM, D'Arcy WG (1994) Solanaceae A. L. Jussieu. In: Wu ZY, Raven PH, Hong DY (eds) *Flora of China*. vol. 17 (Verbenaceae through Solanaceae). Science Press/Missouri Botanical Garden Press, Beijing/St. Louis
- Zhou H, Wang F, Fang Z (2011) Study on triterpenes from *Solanum torvum*. *Zhongguo Zhong Yao Za Zhi* 36(15):2096–2098 (In Chinese)

Phaleria capitata

Scientific Name

Phaleria capitata Jack.

Synonyms

Dias dubiosa Blume, *Drymispermum blumei* Decne, *Drymispermum cauliflorum* Thwaites, *Drymispermum laurifolium* (non Decne) Hassk., *Drymispermum phaleria* Mesin., *Drymispermum urens* Reinw., *Leucosmia burnettiana* Benth., *Phaleria cauliflora* (Thwaites) Bedd., *Phaleria cumingii* (Meisn.) Fern.-Vill., *Phaleria disperma* (G. Forst.) Baill., *Phaleria dubiosa* (Blume) Zoll., *Phaleria urens* (Reinw.) Koord.

Family

Thymelaeaceae

Common/English Names

Ongaël, Phaleria Jack.

Vernacular Names

Indonesia: Godong-Laweh, Kakapassaii, Ki-Angkrieng, Ki Taiigkieh, Kojoian, Lawe, Lawean, Lawe, Lawe, Ulati (Java), Djariim Djariim (Kalimantan), La'awana (Maluku), Suka, Sunsiian, Susuati (Sulawesi), Lampong, Rimbo Siiloh, Siiwa Lansat, Simalur (Sumatra), Kakapasan (Sundanese);

Palauan: Ongaël;

Tongan: Huni.

Origin/Distribution

The species is found in Sri Lanka, Indonesia – Sumatra, Java, Kalimantan, Sulawesi, Maluku; New Guinea; Philippines and western edge of the Pacific – Palau, Tonga. It is cultivated in Peninsular Malaysia.

Agroecology

A shade tolerant, understorey tropical species, found in mixed forest or teak forest from 0 to 1,200 m altitude.

Edible Plant Parts and Uses

The ripe fruit is sweet and edible.

Botany

A shrub or small tree, 2–9 m high with branching near the base (Plate 1), branches smooth, glabrous. Leaves, opposite to sub-opposite, simple, elliptic-oblong, lanceolate-ovate, 8–23 cm by 3–10 cm, tapering acuminate, base obtuse to subacute, thinly coriaceous, glabrous, with entire margin and prominent mid-rib and 8–10 pairs of nerves (Plate 3). Petiole 0.5–1 cm long. Flowers usually terminal or axillary 6–10 flowered umbels and on old wood on branches and trunk. Flowers white, sessile, hermaphrodite, involucral bracts 4–6 oblong or obovate, semi-persistent, perianth tube glabrous, short,



Plate 1 Tree habit with low branching



Plate 2 White flowers



Plate 3 Red fruits and large lanceolate-ovate leaves

funnel shape to cylindric, perianth lobes 4 pubescent, white and obovate to elliptic; disk copular; stamens 8 exserted; ovary 2-celled, ellipsoid, glabrous; style filiform; stigma capitate (Plate 2). Fruit a bright red, succulent drupe broadly obovoid to pyriform to subglobose,



Plate 4 Cauliflorous fruits



Plate 5 Cluster of fruits arising from the trunk

shortly mucronulate, 2–3 cm across (Plates 3–5) with sweet white, soft, fleshy sarcocarp, endocarp of interwoven mesh network of fibres enclosing 2 seeds.

Nutritive/Medicinal Properties

No information has been published on the nutritive value of the fruit.

Anticancer Activity

Ethanol leaf extract of *P. cumingii* inhibited proliferation of mice mammary carcinoma cells (MM46) and human leukemia cells (HL60) at a concentration of 50–200 µg/mL (Matsuda et al. 2005a). Mangiferin a major component of the extract, showed antiproliferative activities on MM46 and HL60 cells at a concentration of 100 µg/mL. Oral administration of the extract (50 and 500 mg/kg) and mangiferin (10, 50 and 100 mg/kg) to MM46 cells transplanted C3H/HeN mice showed significant antitumour effects. In HL60 cells transplanted C. B-17/Icr SCID mice, the extract (50 and 500 mg/kg, p.o.) showed no significant antitumor effect. On cytokines production in the spleen isolated from MM46 carcinoma bearing mice, the extract (500 mg/kg, p.o.) and mangiferin (100 mg/kg, p.o.) significantly inhibited the reduction of tumour necrosis factor alpha (TNF-α) and interleukin (IL)-2 levels and the extract increased interferon-γ level compared to that of the vehicle control group. On in-vitro mitogen response of mice spleen T cells in the presence of sample-treated macrophage, the extract (25, 50 µg/m) and acylglucosylsterol (10 µg/m) (another active constituent) significantly increased both TNF-α and interferon-γ levels. The findings suggested that the in-vivo antitumour effect of the extract partly depended on immunostimulatory activity, and active constituents mangiferin and acylglucosylsterol.

Antidiabetic Activity

A 50% ethanolic leaf extract of *Phaleria cumingii* showed remarkable blood glucose level decreasing effects on male KK-Ay mice and on sucrose loading test in male ddY mice (Matsuda

et al. 2004). The extract did not show blood glucose level decreasing effect on glucose loading test in male ddY mice. The bioactive constituent, a known xanthone C-glycoside, mangiferin was isolated. Mangiferin contents in the 50% ethanolic, methanolic and aqueous leaf extracts were 23.6%, 42.2% and 19.9% respectively.

On the production of cytokine in the spleen ppfrom BKS Cg- + Leprdb/+Leprdb mice, an animal model of non-insulin-dependent diabetes mellitus, oral administration of the 50% ethanolic leaf extract (500 mg/kg) of Ongael significantly increased the production of interferon (IFN)- γ compared to that of vehicle control group (Tokunaga et al. 2006). Mangiferin (100 mg/kg, p.o.), a major constituent of the extract, significantly enhanced secretion of IFN- γ , tumour necrosis factor (TNF)- α and interleukin (IL)-2 compared to that of vehicle control group. The results suggested that Ongael acted as an immunopotentiator to immunoincompetence in diabetes mellitus.

Phagocytic Activity

Leaf extract of *P. cumingii* was found to enhance in-vitro phagocytic activity of mouse macrophages RAW 264.7 cells (Matsuda et al. 2005b). Fractionation of the extract yielded a mixture of acylglucosylsterols (1) as an active constituent along with other inactive constituents, tetracosanol and mangiferin. The mixture was identified as a mixture of the known 3-O-(6-O-acyl- β -D-glucosyl)- β -sitosterols, the acyl moiety being mainly palmitoyl (57%), oleoyl (12%) and α -linolenoyl (12%) with small amount of stearoyl (7%) and linoleoyl (4%).

Traditional Medicinal Uses

The plant is a well known medicinal plant in Palau and is used for various ailments including diabetes. The seed cotyledon is poisonous and has been reported to be applied against scurfy in children.

Other Uses

The tree is often planted as an ornamental tree. The bark is used for fibre. Fragrant flowers are used for making leis in Tonga.

Comments

The tree is propagated from seeds.

Selected References

- Backer CA, Bakhuizen van den Brink Jr RC (1963) Flora of Java (Spermatophytes only), vol 1. Noordhoff, Groningen, 648 pp
- Ding Hou (1960) Thymelaeaceae. Flora Malesiana. Series I: Spermatophyta 6:1–48, 982
- Matsuda H, Tokunaga M, Hirata N, Iwahashi H, Maruto S, Kubo M (2004) Studies on Palauan medicinal herbs. I. Antidiabetic effect of Ongael, *Leaves of Phaleria cumingii* (Meisn.) F. Vill. Nat Med 58(6):278–283
- Matsuda H, Tokunaga M, Hirata N, Iwahashi H, Naruto S, Yagi H, Masuko T, Kubo M (2005a) Studies on Palauan medicinal herbs. III. Antitumor and immunostimulatory activities of Ongael, leaves of *Phaleria cumingii* (Meisn.) F. Vill. J Tradit Med 22(6):314–320
- Matsuda H, Tokunaga M, Iwahashi H, Naruto S, Yagi H, Masuko T, Kubo M (2005b) Studies on Palauan medicinal herbs. II. Activation of mouse macrophages RAW 264.7 by Ongael, leaves of *Phaleria cumingii* (Meisn.) F. Vill. and its acylglucosylsterols. Biol Pharm Bull 28(5):929–933
- Merrill ED (1952) William Jack's genera and species of Malaysian plants. J Arnold Arbor 33(3):207
- Tawan CS (2004) Thymelaeaceae. In: Soepadmo E, Saw LG, Chung RCK (eds) Tree flora of Sabah and Sarawak, vol 5. Forest Research Institute Malaysia, Kuala Lumpur, pp 433–484
- Tokunaga M, Matsuda H, Iwahashi H, Naruto S, Tsuruoka T, Yagi H, Masuko T, Kubo M (2006) Studies on Palauan medicinal herbs. IV. Immunopotentiatory activities of Ongael, leaves of *Phaleria cumingii* (Meisn.) F. Vill. in diabetic mice. J Tradit Med 23(1):24–26
- Townsend CC (1981) Thymelaeaceae. Revised handbook to the flora of Ceylon. 2:501–511
- Whistler WA (1991) The ethnobotany of Tonga: the plants, their Tongan names and their uses. Bish Mus Bull 2:1–155
- Whitmore TC (1972) Thymelaeaceae. In: Whitmore TC (ed) Tree flora of Malaya, vol 2. Longman, Kuala Lumpur, pp 383–391

Pourouma cecropiifolia

Scientific Name

Pourouma cecropiifolia Mart.

Synonyms

Pourouma edulis Dufur., *Pourouma multifida* Trécul., *Pourouma sapida* Karsten, *Pourouma uvifera* Rusby.

Family

Urticaceae, also placed in Cecropiaceae.

Common/English Names

Amazon Grape, Amazon Tree Grape; Tree Grape, Uvilla.

Vernacular Names

Brazil: Tararanga Preta (Bahia), Mapati (Manaus), Amaitem, Ambaúva De Vinho, Ambaúva Mansa, Cucurca, Imbauba Mansa, Imbauba-De-Vinho, ImbaubaDeCheiro, Imbaubarana, Imbanapuruma, Inbauba, Puruma, Sucuuba, Uva Da Amazônia, Uva Da Mata, Umbaúba De Cheiro, Umbaúba De Vinho (General);

Columbia: Puruma, Caime, Caimaron, Caimaron Silvestre, Uva Caimarona, Camuirro, Cucura, Uva, Sirpe, Hiye, Joyahiye;

French: Caimaron;

French Guyana: Uvilla, Uva De Monte, Uva Caimarona, Caimarôn, Caimurro; Peru Uvilla, Uva De Monte, Sacha Uvillas;

Peru: Uva de Monte, uvilla;

Portuguese: Cucura, Imbauba De Vinho, Mapate, Puruma, Umbauba De Cheiro, Uva De Mata;

Spanish: Caima, Caimaren, Uva Caimarona, Uva De Monte, Uvilla;

Welsh: Ffa.

Origin/Distribution

The species is native to the tropical rainforests of Western Brazil, Ecuador, Bolivia and Peru.

Agroecology

The tree grows wild in the western part of Amazonas, Brazil, and adjacent areas of Ecuador and Peru. It is especially abundant in the vicinity of Iquitos. It has been cultivated since pre-Hispanic times by the Indians of south-western Colombia and is grown by Indians and non-Indians in Brazil.

The tree grows on high dry land at altitudes below 500 m within latitude 17°N and S of the equator. It is tolerant of poor soils but is intolerant

of prolonged drought and frost. It will stand short periods of flooding.

Edible Plant Parts and Uses

The fruit is sweet and juicy, eaten fresh and made into jams, jellies, other confections and wine. The fruit is very fragile and has poor post harvest shelf-life which limits marketing options. The sweet flower perianth is eaten raw or used for making drinks and wine.

The toasted seeds can be used as a substitute for coffee and the leaf ash is sometimes substituted as a coca additive.

Botany

A medium-sized, evergreen, dioecious, branched tree reaching 7–15 m high with grey bark marked by leaf scars with a rosette of branches high up the tree and leaves crowded toward the tips of the branches (Plate 1). Leaves are alternate, cordate-rotund and palmately compound, with 9–11 leaflets (Plate 2), 15–30 cm long and 10–20 cm broad, on a 20 cm long, glabrous petiole; segments are obovate-oblong-lanceolate, velvety, green on upper-side and ashy- or white-tomentose beneath, the largest middle ones, all more or less connate toward the base. Inflorescence erect, narrow, many-flowered axillary panicle. The unopened inflorescence is reddish-purple, densely coated

with fine white hairs. The white male and female flowers are borne in cluster of 20 or more in a 10 cm long inflorescence on separate trees. Male flowers with 4 free, strap-shaped sepals, with 4 or more stamens and basifixed anthers on short filaments, Female flowers with cup-shaped, fleshy perianth cup investing the one-celled, tomentose ovary with a short style and slightly lobed stigma. The fruit is ovoid to globose, drupaceous, 2–4 cm long, green turning reddish-purple to dark purple when ripe and borne in clusters like grapes; the skin is rough, inedible but easily peeled (Plates 2 and 3). The pulp is white, mucilaginous, juicy, subacid, very mild flavour; and encloses 1 conical seed with fibrous, grooved testa.



Plate 1 Leaves clustered at apices of branches



Plate 2 (a and b) Leaves and Amazon tree grape fruit clusters



Plate 3 Ripe and unripe Amazon tree grapes

Nutritive/Medicinal Properties

The fresh ripe fruit was reported to contain per 100 g edible portion: energy 70 cal, water 82.4 g, protein 0.3 g, fat 0.3 g, carbohydrates 15.5 g, ash 0.28 g; Ca 34 mg, P 10 mg, Fe 0.6 mg, K 127 mg, vitamin B2 0.22 mg, niacin 0.3 mg and vitamin C 0.6 mg (Lorenzi et al. 2006).

Total polyphenols content was higher in the peel than in the pulp of Amazon grape fruit (*Pourouma cecropiifolia*) (Lopes-Lutz et al. 2010). Anthocyanins, flavonols and chlorogenic acids were found mainly in the peel. Besides the main anthocyanins, i.e. delphinidin 3-glucoside, cyanidin 3-glucoside and cyanidin 3-(6"-malonyl)glucoside, several minor anthocyanins were identified in the peel. Among these, cyanidin 3,5-diglucoside, delphinidin 3-galactoside, cyanidin 3-rutinoside, cyanidin 3-(3"-malonyl)glucoside, malvidin 3-glucoside, pelargonidin 3-glucoside, peonidin 3-glucoside and petunidin 3-glucoside were characterized. The total anthocyanin content in the peel was 420.26 mg/kg fresh weight. The pulp contained mainly 5-O-caffeoylquinic acid (210.39 mg/kg fresh weight). Rutin was the predominant flavonol found in Amazon grape (peel 155.45 mg/kg fresh weight and pulp 2.64 mg/kg) fresh weight.

The anthocyanin-rich extract of *Pourouma cecropiifolia* fruit was found to show moderate cytotoxicity toward different cancer cell lines

when evaluated by MTT assays (Barrios et al. 2010). On fractionation the extract yielded 3 fractions (F1–F3). F1 was composed primarily of the monomeric anthocyanins delphinidin-3-O- β -glucopyranoside, cyanidin-3-O- β -glucopyranoside, and cyanidin-3-O-(6"-malonyl)glucopyranoside. F2 contained the isomeric flavonols quercetin 3-O- α -rhamnopyranosyl-(1 $\rightarrow$ 6)- β -galactopyranoside and quercetin 3-O- α -rhamnopyranosyl-(1 $\rightarrow$ 6)- β -glucopyranoside. F3 contained polymeric pigments, two proanthocyanidin and two flavanol-anthocyanin condensed pigments. After cell viability assays were performed, only fraction F3 showed a cell growth-inhibitory effect similar to the one found for ARE. F3 significantly reduced the viability of HEP-2 larynx, MKN-45 gastric carcinoma, and MCF-7 breast cancer cells. In contrast, the pure compounds did not show promising cytotoxicity toward the cancer cells evaluated.

Root scrapings had been reported to induce permanent sterility and had been used as a mastigatory intoxicant (Schultes and Raffauf 1990; Duke 1993).

Other Uses

The wood is light, coarse and non-durable and used for paper pulp and for making charcoal. The wood is unsuitable for furniture or general construction.

Comments

The fruit does not store well which hinders its commercial exploitation.

Selected References

- Barrios J, Cordero CP, Aristizabal F, Heredia FJ, Morales AL, Osorio C (2010) Chemical analysis and screening as anticancer agent of anthocyanin-rich extract from uva caimarona (*Pourouma cecropiifolia* Mart.) fruit. J Agric Food Chem 58(4):2100–2110
- Berg CC, Akkermans RWA, van Heusden ECH (1990) Cecropiaceae: *Coussapoa* and *Pourouma*, with an

- introduction to the family, Flora *Neotropica* monograph. 51. New York Bot. Garden, New York, 208 pp
- Duke JA (1993) CRC handbook of alternative cash crops. CRC Press, Boca Raton, 544 pp
- Huxley AJ, Griffiths M, Levy M (eds) (1992) The new RHS dictionary of gardening, 4 vols. MacMillan, London
- Instituto Nacional de Pesquisas da Amazonia (INPA) (1986) Food and fruit bearing forest species 3: examples from Latin America, Forestry paper 44–3. Food and Agriculture Organization of The United Nations, Rome, 332 pp
- Lopes-Lutz D, Dettmenn J, Nimalaratne C, Scheiber A (2010) Characterization and quantification of polyphenols in Amazon grape (*Pourouma cecropiifolia* Martius). *Molecules* 15(12):8543–8552
- Lorenzi H, Bacher L, Lacerda M, Sartori S (2006) Brazilian fruits & cultivated exotics (for Consuming in Natura). Instituto Plantarum de Etodos da Flora Ltda, Brazil, 740 pp
- Macbride JF, Dahlgren BE (1937) Flora of Peru, Fieldiana. Botany series, vol 13, part 2, no. 2. http://www.archive.org/stream/floraofperu22fimacb/floraofperu22fimacb_djvu.txt
- Morton J (1987) Amazon tree-grape. In: Fruits of warm climates. Julia F. Morton, Miami, p 64
- National Academy of Sciences (1975) Underexploited tropical plants with promising economic value. National Academy of Sciences, Washington, DC, 188 pp
- Schultes RE (1980) The Amazonia as a source of new economic plants. *Econ Bot* 33:259–266
- Schultes RE, Raffauf RF (1990) The healing forest. Dioscorides Press, Portland, 484 pp
- Uphof JCTh (1968) Dictionary of economic plants, 2nd edn (1st edn. 1959). Cramer, Lehre, 591 pp

Vitis vinifera

Scientific Name

Vitis vinifera L.

Synonyms

Cissus vinifera (L.) Kuntze, *Vitis sylvestris* C.C. Gmel., *Vitis vinifera* subsp. *sativa* Hegi, *Vitis vinifera* subsp. *sylvestris* (C.C. Gmel.) Hegi.

Family

Vitaceae

Common/English Names

Common Grapevine, Domestic Grape, European Grape, Grape, Grapes, Grapevine, Wine Grape.

Vernacular Names

Arabic: Aanab, Aenaeb, Ainab, Ainab, Anab, Enab Yabis, Kishmish, Mewiz, Zabeeb, Zabib;
Brazil: Parreira, Uva, Videira;
Bulgarian: Vino;
Burmese: Sa-Pyit;
Chinese: Ou Zhou Pu Tao, Pu Tao;

Czech: Réva Vinná;

Danish: Ægte Vinranke, Almindeligg Vin, Vin, Vinranke, Vinstok;

Dutch: Wijnstok, Wijnstok (Druiven);

Eastonian: Harilik Viinapuu;

French: Grappe, Vendange, Vigne, Vigne Cultivée, Vigne Vinifère;

German: Echter Weinstock, Echte Weintraube, Edler Weinstock, Europäische Weinrebe, Kultur-Weinrebe, Kulturrebe, Rebe, Rebstock, Traubenstock, Wein, Wein-Rebe, Weinlese, Weinrebe, Weinstock, Weintraube;

Greek: Ambeli, Ambelos, Klima, Stafylia, Stafyli;

Hungarian: Vinič Hroznorodý;

India: Angurphal (**Bengali**), Angoor, Angur, Dak, Dakh, Drakh (**Hindu**), Angoor, Angura, Dhrakshi, Draakshi, Draksa, Draksha, Drakshe, Drakshi, Drakshi Balli, Drakshi-Hannu, Dveepa Draakshi, Kisimis (**Kannada**), Dhrakshai, Gostani, Madhurasam, Mantirinnavalli, Mridvika, Mrydvika, Muntiri, Muntirika, Muntirinna, Muntirinnap-Pazham, Pach-Cha-Muntrinnap-Pazham, Saruphala, Svadvi (**Malayalam**), Angur (**Manipuri**), Dakshache-Jhad, Draaksha, Draksha, Kakanj (**Marathi**), Svadvi (**Oriya**), Amrtaphala, Amrutaphala, Caruphala, Charuphala, Dakha, Draksa, Draksha, Gostani, Guchhaphala, Harahura, Kakali, Kapisa, Kasmari, Krishna, La, Laghu-Draksha, Madhuras, Mrdvika, Mridirka, Mridvika, Phatotama, Priyala, Rasa, Rasala,

Soma, Svadi, Svadvi, Swaduphala, Tapasapriya, Yakshmaghni (**Sanskrit**), Aravam, Attica, Atticakkoti, Camparavalli, Carupalam, Cimutai, Cimutaikkoti, Cuvatavi, Dhrakshai, Diraksha-Pazham, Dividatsi-Pullum, Dividatsipalavuttil, Draksha, Gostanidraksha, Inippukkotimuntirikai, Inippumuntiri, Iratakirusta, Irattapittakkani, Kacamuntirikai, Kacumari, Karamarttikai, Karamarttikaikkoti, Kavin, Kirusnai, Kirusnap-piriyam, Kiruttinai, Kodi-Mundirip-Pazham, Kodimoondrie Pullum, Kodimundirigai, Kotimunti, Kotimuntiri, Kotimuntirikai, Kottai Tiratcai, Kottani, Kottanigai, Kottiram, Kottiramuntiri, Kottiri, Kottirikai, Kotumuntiri, Kuccapalam, Kulattiya, Maduram, Madurasam, Matucancai, Matucancam, Maturacam, Matura-cavalli, Maturam, Matuyoni, Miruntikam, Miruttikam, Mukkica, Mullutiratcai, Mundirigai, Muntiri, Muntirikai, Muntirikkoti, Murukki-patanatci, Nattukkotimuntirikai, Nemiyankani, Palottamai, Piriyalu, Rovini, Simudai, Tamama-tikam, Tapacappiriyai, Taracca, Taraccam, Taravakkoti, Taravam, Tatcam, Tatkam, Thiratchai, Thrakshi, Tirakkam, Tiraksai, Tirappakanam, Tiratcai, Tiratcam, Tiratci, Tirikai1, Tirkkapalai, Tittippukkotimuntiri, Tittippumuntiri, Tittippumuntirikkoti, Tivaratci, Tivatatci, Tivirtiratcai, Tivitatci, Tivitiratcam, Tivutiratcai, Uttarapati, Vakinimuntiri, Valli, Vanappiriyam (**Tamil**), Dhraksha, Draaksha, Draaksha Chettu, Draakshapandu, Dracha, Draksa, Draksha, Draksha-Pandu, Draksha-Pondu, Go Sthani Draaksha, Gostanidraksha, Gostini-Pandu, Kismisu, Kisumini, Kisumisu, Kisumisu Chettu (**Telugu**), Aab-E-Angur, Angoor, Angur, Angur-E-Khushk, Kishmish, Mawaiz Munaqa, Mawaiz Munaqqa, Maweez (Munaqqa), Monaqqa, Munaqqa, Rub Angur Tursh, Rub Ghura, Rub-I-Ghura (**Urdu**);

Indonesia: Buah Anggur;

Italian: Ambrusca, Lebrusca, Vite, Vite Comune, Vite Rossa, Uva, Vite Selvatica, Zampino;

Japanese: Budou, Yooroppu Budou;

Kampuchea: Tra Pèang Baay Chum, Tra Pèang Baay Chuu;

Korean: Podo;

Laos: 'Angunx;

Malaysia: Anggur;

Nepali: Dakh;

Norwegian: Vindrue;

Pakistan: Angur;

Persian: Ab-Josh, Angur, Maveez, Mavez;

Philippines: Ubas;

Polish: Winorośl, Winorośl Właściwa;

Portuguese: Videira-Europeia, Vinha, Vinho;

Russian: Obyknobennaia Vinogradnaia, Vinograd, Vinograd Kul'turnyi;

Serbian: Loza;

Slovenčina: Vinič Hroznorodý;

Spanish: Parra, Vid, Viña, Viñedo, Vino;

Swedish: Vindruva, Vinranka;

Thai: A Ngun;

Tibetan: Rgun Bru, Rgun Brum;

Turkish: Üzüml;

Vietnam: Nho.

Origin/Distribution

Vitis vinifera is native to the Mediterranean region, central Europe, and Asia minor, from Portugal north to southern Germany and east to northern Iran. It is cultivated on every continent except for Antarctica.

Agroecology

Being a Mediterranean species, *V. vinifera* has a requirement for a long, warm to hot dry summers and mild winters. It thrives in areas with annual temperature of 8.3–28.5°C and annual precipitation of 900–2,700 mm, falling mainly in the winter months. Frost kill young shoots and the plant is intolerant of high temperature and high humidity that promotes diseases. Grapes are predominantly grown between 20 and 50°N and from 20 to 40°S but can be grown in the tropics at cooler high altitudes. Grape culture is best where there is no rain between blooming and harvesting and several irrigations may be necessary. Grapes prefer sandy or gravelly soils where drainage is good. It grows best in deep, fertile, well-drained soil that has a pH of between 5.5 and 7.0. Presence of excess salts particularly sodium and free calcium is detrimental for grapes.

Edible Plant Parts and Uses

Fruits are eaten fresh or dried, processed into raisins, pressed for juice, fermented as wine, or made into jams and jellies. Grape seeds contained 6–20% oil which is edible and can be used for cooking. Young leaves are eaten as a vegetable. Grape leaves are a popular ingredient in many cuisines in the Middle East including Armenian, Turkish, Egyptian, Algerian, Syrian, Lebanese and Albanian and Greek. Grape leaves are filled with minced meat (such as lamb or beef), rice and onions in the making of Balkan traditional *dolma* and the Turkish, *Etli Yaprak Sarmasi*. Grapevine leaves are stuffed with rice, pine nuts and fresh herbs to make the Greek *dolmathakia*.



Plate 1 Fruiting table-grape vine

Botany

A vigorous, climbing woody, deciduous, perennial liana up to 15–20 m long (Plates 1, 9), but in cultivation drastically pruned to 1.5–3 m. Branchlets are terete, with longitudinal ridges, glabrous or sparsely pilose with branched tendrils. Leaves are simple, green, alternate; stipules caducous; petioles 4–9 cm and nearly glabrous; leaf blade circular to circular-ovate in outline, conspicuously 3–5-lobed or cleft, 7–18 cm by 6–16 cm, basal veins 5, lateral veins 4 or 5 pairs, base deeply cordate, margin irregularly serrate to dentate (Plates 1, 2, 9, 10). Panicle sparse or dense, opposite to leaves, basal branches well developed, 10–20 cm; peduncle 2–4 cm, glabrous or with



Plate 3 Red-globe tablegrapes



Plate 2 Leaf and fruit of Red-globe tablegrapes



Plate 4 Thompson seedless tablegrapes



Plate 5 Baskets of harvested tablegrapes



Plate 8 Black Diamond Seedless tablegrapes



Plate 6 Crimson seedless tablegrapes



Plate 9 Fruiting wine-grapes vine



Plate 7 Large cluster of Black Sable Seedless tablegrapes



Plate 10 Cluster of wine-grapes

sparse tomentum. Flower bisexual or functionally pistillate with shorter sterile stamens, greenish in colour. Calyx very shortly 5-lobed glabrous, undulate; petals 5, lanceolate, about 5 mm, pale green, sweet-scented; filaments filiform, 0.6–1 mm; anthers yellow, oval, 0.4–0.8 mm; pistil aborted in male flowers; ovary oval; style short; stigma expanded. Fruit a berry, ellipsoid to globose, 6–25 mm diameter, with soft skin adhering to the pulp, dark blue-purple, black, red, green or yellow, juicy, sweet or sour, seeded or seedless (Plates 1–10). Seeds 2–3, obovoid to pyriform, apex subrounded.

Nutritive/Medicinal Properties

Nutrient composition of fresh *Vitis vinifera* (red, green, seedless grapes) per 100 g edible portion was reported as: water 80.54 g, energy 69 kcal (288 kJ), protein 0.72 g, total lipid (fat) 0.16 g, ash 0.48 g, carbohydrate 18.10 g, total dietary fibre 0.9 g, total sugars 15.48 g, sucrose 0.15 g, glucose 7.20 g, fructose 8.13 g, Ca 10 mg, Fe 0.36 mg, Mg 7 mg, P 20 mg, K 191 mg, Na 2 mg, Zn 0.07 mg, Cu 0.127 mg, Mn 0.071 mg, F 7.8 µg, Se 0.1 µg, vitamin C 10.8 mg, thiamin 0.069 mg, riboflavin 0.070 mg, niacin 0.188 mg, pantothenic acid 0.050 mg, vitamin B-6 0.086 mg, total folate 2 µg, total choline 5.6 mg, betaine 0.1 mg, vitamin A 3 µgRAE, β-carotene 39 µg, α-carotene 1 µg, lutein+zeaxanthin 72 µg, vitamin E (α-tocopherol) 0.19 mg, γ-tocopherol 0.07 mg, vitamin K (phyloquinone) 14.6 µg, total saturated fatty acids 0.054 g, 14:0 (myristic) 0.001 g, 16:0 (palmitic) 0.046 g, 18:0 (stearic) 0.006 g, total monounsaturated fatty acids 0.007 g, 18:1 undifferentiated (oleic) 0.007 g, total polyunsaturated fatty acids 0.048 g, 18:2 undifferentiated (linoleic) 0.037 g, 18:3 undifferentiated (linolenic) 0.011 g, phytosterols 4 mg, tryptophan 0.011 g, threonine 0.022 g, isoleucine 0.011 g, leucine 0.022 g, lysine 0.027 g, methionine 0.009 g, cystine 0.010 g, phenylalanine 0.019 g, tyrosine 0.010 g, valine 0.022 g, arginine 0.130 g, histidine 0.022 g, alanine 0.022 g, aspartic acid 0.038 g, glutamic acid 0.081 g, glycine 0.016 g, proline 0.080 g and serine 0.022 g (USDA 2012).

Nutrient value of fresh grape leaves per 100 g was reported as: water 73.32 g, energy 93 kcal (390 kJ), protein 5.60 g, total lipid (fat) 2.12 g, ash 1.65 g, carbohydrate 17.31 g, total dietary fibre 11 g, total sugars 6.30 g, Ca 363 mg, Fe 2.63 mg, Mg 95 mg, P 91 mg, K 272 mg, Na 9 mg, Zn 0.067 mg, Cu 0.415 mg, Mn 2.855 mg, Se 0.9 µg, vitamin C 11.1 mg, thiamin 0.040 mg, riboflavin 0.354 mg, niacin 2.362 mg, pantothenic acid 0.231 mg, vitamin B-6 0.4006 mg, total folate 83 µg, total choline 12.8 mg, vitamin A 1376 µgRAE, vitamin A 27,251 IU, β-carotene 16,194 µg, α-carotene 629 µg, β-cryptoxanthin 9 µg, lutein+zeaxanthin 1,747 µg, vitamin E (α-tocopherol) 2 mg, vitamin K (phyloquinone) 108.6 µg, total saturated fatty acids 0.336 g, 14:0 (myristic) 0.005 g, 15:0 (pentadecanoic) 0.010 g, 16:0 (palmitic) 0.243 g, 17:0 (margaric) 0.002 g, 18:0 (stearic) 0.026 g, 20:0 (arachidic) 0.012 g, 22:0 (behenic) 0.008 g, 24:0 (lignoceric) 0.013 g, total monounsaturated fatty acids 0.081 g, 14:1 (myristoleic) 0.003 g, 16:1 (palmitoleic) 0.035 g, 18:1 undifferentiated (oleic) 0.039 g, total polyunsaturated fatty acids 1.065 g, 18:2 undifferentiated (linoleic) 0.148 g, 18:3 undifferentiated (linolenic) 0.856 g, phytosterols 21 mg, stigmasterol 2 mg and β-sitosterol 20 mg (USDA 2012).

Other Phytochemicals

The phytophenols in grapes could be arbitrarily categorised into single-ring phenolic acids, bisphenols including stilbenes, tricyclic phenols (flavonoids) and their subclasses, and oligomeric and polymeric species, the proanthocyanidins and anthocyanidins (Sovak 2001). Their precursors and the stilbenes, including resveratrol with its analogs and conjugates, had been reported to have preventative and possibly therapeutic value in atherosclerosis and certain neoplastic and inflammatory afflictions.

A stilbene glucoside (piceid) was isolated from grape cell suspension culture and determined as *trans*-resveratrol-3-O-β-glucoside (Teguo et al. 1996). Stilbenes (*cis*- and *trans*-piceid, *cis*- and *trans*-resveratrol) and anthocyanins (malvidin-3-O-β-glucoside and peonidin-3-O-β-glucoside)

were isolated from *Vitis vinifera* cell suspension obtained from Gamay Teinturier vine-plant (Mérillon et al. 1997). Other stilbenes, astringin and astringinin were also isolated. Grape suspension cell cultures were found to produce many hydroxylated stilbene glucosides found in red wine (Waffo Taegu et al. 1998). Glycosylated stilbenes isolated included: (Z)-piceatannol (3,5,3',4'-tetrahydroxystilbene)-3-O- β -D-glucopyranoside; (E)-resveratrol (3,5, 4'-trihydroxystilbene)-4'-O- β -D-glucopyranoside and (Z)-resveratrol (3,5,4'-trihydroxystilbene)-4'-O- β -D-glucopyranoside. Twelve phenols: the stilbenoids *trans*-astringin, *trans*-piceid, *trans*-resveratrol, *trans*-resveratrol, *trans*-piceatannol, *cis*-resveratrol, *cis*-piceid, and *cis*-resveratrol; the flavans (+)-catechin, (–)-epicatechin, and epicatechin 3-O-gallate; and the flavan dimer procyanidin B2 3'-O-gallate were extracted from grape cell cultures (Waffo-Tégou et al. 2001).

Amico et al. (2009) identified the following grape constituents: two triterpenoid acids, oleanolic and betulinic acids; daucosterol; a stilbenoid, E-resveratrol and its dimer E- ϵ -viniferin; the simple phenol gallic acid; the flavanols catechin and galocatechin and four 6'-O-acyldaucosterols (a-d) and five 1,2-di-O-acyl-3-O- β -D-galactopyranosyl glycerols (a-e).

Resveratrol (3,4',5-trihydroxystilbene) a natural phenolic compound occurs in *cis* and *trans* isomers in grapes. *Trans*-resveratrol is abundant in the skin of grapes (but not in the flesh) and in the leaf epidermis, and present in wines, especially red wines (Orallo 2006) and has been reported to have antiinflammatory and anticarcinogenic properties. *Cis*-resveratrol is also found in wines but little is known about this isomer's pharmacological activity. Eight natural stilbenes (*trans*-resveratrol, *trans*-piceid, *cis*-piceid, *trans*-astringin, *trans*-piceatannol, (+)-*trans*- ϵ -viniferin, pallidol, and hopeaphenol), were isolated and purified from *Vitis vinifera* (Boutegrabet et al. 2011). All stilbenes, except *trans*-astringin, *trans*-piceatannol, and pallidol were identified and quantified in Burgundy red wines at different concentrations after direct injection of the wines.

Mikulski and Molski (2010) reported *trans*-resveratrol oligomers, *trans*-resveratrol dimers,

pallidol, geometric stereoisomers of ϵ -viniferin, stereoisomers of *trans*- δ -viniferin and *trans*-resveratrol trimer-gnetin H; glucosides: *trans*-piceid, *cis*-piceid, *trans*-astringin; *trans*-resveratrol-4'-O- β -D-glucopyranoside, *trans*-resveratrol-3-O-glucuronide, dimer of *trans*-4,4'-dihydroxystilbene, *cis* stereoisomers of piceid and ϵ -viniferin.

Vilanova et al. (2012) found significant increase in volatile composition namely C(6)-compounds, alcohols, volatile fatty acids, monoterpenes, C(13)-norisoprenoids, volatile phenols and carbonyl compounds in free and glycosidically bound forms in white and red grape cultivars between the two ripening stages. Free C(6)-compounds ((E)-2-hexanal, 1-hexanol and (E)-2-hexen-1-ol) and bound alcohols (benzyl alcohol and 2-phenylethanol) showed the highest concentrations of volatile compounds for all grape cultivars in the two dates studied. A strong influence by the cultivar and the ripening stage on wine volatiles was observed. There was significant interaction of cultivar and ripening date for 93.8% of volatile compounds.

Melatonin was found to occur in grape berry tissues (skin, flesh, and seed) at two different phenological stages, pre-véraison and véraison (Vitalini et al. 2011). The highest melatonin level was found in skin, at pre-véraison, whereas, at véraison, the highest levels were reported in the seed. During ripening, melatonin decreased in skin, while increasing in both seed and flesh. The highest antiradical activity, determined by both DPPH (2,2-diphenyl-1-picryl hydrazyl) and ABTS [(2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid))] radical-scavenging assay, was reported at pre-véraison in the seed. Boccalandro et al. (2011) found that melatonin levels in grape berries fluctuated during the day/night cycle. They found that the diurnal decay of melatonin in berry skins was induced by sunlight, because covered bunches retained higher melatonin levels than exposed ones, thus partially explaining the basis of its daily fluctuation. Melatonin was detected in *Vitis vinifera* cv. Malbec grape extract within the range 120–160 ng/g while its isomer was found in musts and finished wines (Gomez et al. 2012). They found that *Saccharomyces cerevisiae* played a decisive role in contributing to the

content of melatonin and its isomer in wine. 2-methoxy-3-isobutylpyrazine (MIBP) imparts a bell pepper aroma to many grape cultivars and had a reported aroma threshold of ~2 ng/l in water (Koch et al. 2010). Its presence was found to be dependent on grape genotype. Quantifiable levels were found only in Cabernet franc, Cabernet Sauvignon, Merlot, Sauvignon blanc and Semillon wine grapes.

Under-ripe grape seeds were found to contain appreciable amounts of polyphenols (+)-catechin; (+)-(2R:3S)-5,7,3',4'-tetrahydroxyflavan-3-ol; (-)-epicatechin, (-)-(2R:3R)-5,7,3',4'-tetrahydroxyflavan-3-ol; and (-)-epicatechin-3-gallate (Su and Singleton 1969). All five fractions isolated from grape seeds consisted of catechin, epicatechin and epicatechin gallate units (Prieur et al. 1994). Epicatechin was the major component in the extended chain while catechin was more abundant in terminal units than in extension units. The proportion of galloylated units varied from 13 to 29%. Twenty-seven different flavan-3-ols of procyanidin type were detected in grape seeds of 17 varieties of grape cultivated in the main wine-producing areas of Castilla-Leon (Spain), but no prodelphinidins were found (Santos-Buelga et al. 1995). Minor amounts of four hydrolyzable tannins were detected in the seed extracts. All the varieties contained galloyled flavanols, the presence of which could be considered characteristic of the grape seed composition. Catechin, epicatechin, epicatechin gallate and epigallocatechin were the major constitutive units of grape skin tannins (Souquet et al. 1996). Gallocatechin and epigallocatechin gallate were also detected. Epicatechin represented 60% of the extension units, whereas 67% of the terminal units consisted of catechin. Six fractions were prepared from the skin tannin the mean degree of polymerization (mDP) calculated for each fraction ranged from three (in fraction I) to 80 (in fraction VI). All fractions contained prodelphinidins. The proportion of galloylated units was low (3 to 6%) and independent of mDP. The content of monomers ((+)-catechin and (-)-epicatechin), procyanidin dimers (B3, B1, B4, and B2), trimers (T2 and C1), and dimer gallates (B2-3-O-gallate, B2-3'-O-gallate, and B1-3-O-

gallate) ranged from 76.93 to 133.18 mg/l in wines, from 2.30 to 8.21 mg/g in grape seeds, and from 0.14 to 0.38 mg/g in grape skins of grape cvs. Graciano, Tempranillo, and Cabernet Sauvignon (Monagas et al. 2003). In wines, the polymeric fraction represented 77–84% of total flavan-3-ols and showed a mean degree of polymerization (mDP) value of 6.3–13.0. In grapes, the polymeric fraction represented 75–81% of total flavan-3-ols in seeds and 94–98% in skins and showed mDP values of 6.4–7.3 in seeds and 33.8–85.7 in skins. All the monomeric flavan-3-ols and oligomeric procyanidins found in wines were also present in seeds, although differences in their relative abundances were seen.

The phenolic profiles of grape skins of 21 different cultivars belonging to *Vitis vinifera*, East Asian and North American *Vitis* species and hybrids, as well as 2 varieties of muscadine grapes were investigated (Zhu et al. 2012). There were 45 anthocyanins, 28 flavonols, 8 flavan-3-ols, 9 cinnamic acids, 5 benzoic acids, 5 ellagic acids and 2 stilbenes detected in all the samples. Total contents of each phenolic type varied significantly among the different grape cultivars investigated. The differences in anthocyanin composition were obvious between *V. vinifera* and non-*V. vinifera* grapes and also between the grapes originating from Eurasia and North America. Quercetin-3-glucuronide and quercetin-3-glucoside were marker flavonol compounds for Euvitis grape skins. Flavan-3-ol monomers were dominant in the skins of muscadine and non-*V. amurensis* East Asian grapes, whereas polymers were more common in *V. vinifera* and North American grapes. The muscadine grapes were very rich in flavonols, flavan-3-ols and ellagic acids.

Grape seeds were found to contain tannins with a wide range of molecular weights 290–3,100 (decamers) (de Frietas et al. 1998). Catechins (Mw 290), procyanidin dimers (Mw 578), (-)-epicatechin gallate (Mw 442), procyanidin dimer gallates (Mw 730), procyanidin dimer digallates (Mw 882), procyanidin trimers (Mw 866) and procyanidin trimer gallates (Mw 1,018), were identified. Leucoselect™ (grape seed selected proanthocyanidins) were found to contain approxi-

mately 15% of (+)-catechin and (–)-epicatechin, 80% of (–)-epicatechin 3-O-gallate, dimers, trimers, tetramers and their gallates and 5% of pentamers, hexamers, heptamers and their gallates (Gabetta et al. 2000). The ethyl acetate extract of grape seeds was found to contain about 75% of flavanol monomers (catechin and epicatechin) corresponding to 18% of crude extract and another fraction B-type dimers (22% of crude extract) (Delaunay et al. 2002). From the stalk extracts, stilbenoid compounds (resveratrol and its oligomers; 12% of crude extract) which were extracted from flavanols. *trans*-resveratrol (7%; 90% purity) was also isolated. Fan et al. (2004) isolated viniferone, an oxidative derivative of catechin, together with viniferone B and C, presumably the oxidative derivatives of epicatechin from grape seeds. Dimeric to tetrameric procyanidins were isolated from grape seeds and their structure elucidated as: B1 [epicatechin-(4 β →8)-catechin], B2 [epicatechin-(4 β →8)-epicatechin], B3 [catechin-(4 α →8)-catechin], B4 [catechin-(4 α →8)-epicatechin], B5 [epicatechin-4 β →6-epicatechin], B7 [epicatechin-(4 β →8)-catechin], [epicatechin-3-O-gallate-(4 β →8)-catechin], trimeric procyanidin C1 [epicatechin-4 β →8-epicatechin-4 β →8-epicatechin], and the tetrameric procyanidin cinnamtannin A2 (Köhler et al. 2008). Two non-coloured anthocyanin derivatives were found in Pinot noir grape skin and identified as coupling products between both hydrated malvidin-3-glucoside and peonidin-3-glucoside, with 2-S-glutathionyl caffeoyl tartaric acid (GRP) (Kneknopoulos et al. 2011). Hollecker et al. (2009) identified 54 phenolic compounds in the freeze-dried grape skins or seeds including nonflavonoids (hydroxybenzoic and hydroxycinnamic acids and their derivatives, stilbenes) and flavonoids (flavanols, flavonols, dihydroxyflavonols). Iacopini et al. (2008) isolated catechin and epicatechin in grape seeds and quercetin, rutin and resveratrol in skin extracts.

The principal polyphenolic constituents of low molecular weight found in ethyl acetate grape seed extracts included gallic acid, catechin, epicatechin, epigallocatechin, epicatechin gallate, epigallocatechin gallate, and the procyanidins B1 and B2 (dimers) (Guendez et al. 2005). Grape

seeds were found to contain gallic acid, monomeric flavan-3-ols ((+)-catechin, (–)-epicatechin and epicatechin-3-O-gallate), procyanidins dimers (B3, B1, B4, B2, B3'-3-O-gallate), and trimers (T2 and C1) (Monagas et al. 2006a). These ingredients consisted of fractions enriched either in monomeric, oligomeric or polymeric flavan-3-ols, with a mean degree of polymerization (mDP) ranging from 2.1 to 11.2. Grape anthocyanins (delphinidin, cyanidin, petunidin, peonidin and malvidin-3-glucosides, -3-(6-acetyl)-glucosides and -3-(6-*p*-coumaroyl)-glucosides, and peonidin and malvidin-3-(6-caffeoyl)-glucosides) were detected in non-processed grape skins and in grape pomace anthocyanin-derived pigments (the pyruvate, vinylcatechol, vinylepicatechin, vinylphenol and vinylguaiacol derivatives of malvidin-3-glucoside, and malvidin-3-(6-acetyl)-glucoside-vinylepicatechin) were identified. Anthocyanins (delphinidin, cyanidin, petunidin, peonidin and malvidin-3-glucosides and -3-(6-*p*-coumaroyl)-glucosides, and cyanidin and peonidin-3-(6-acetyl)-glucosides), and non-anthocyanin compounds (*trans*-caftaric acid, and the -3-O-galactoside, -glucuronide and -glucoside derivatives of quercetin and kaempferol, and quercetin aglycone) were found in grape leaves (Monagas et al. 2006b). Grape seed extracts were found to contain high levels of flavan-3-ols and their derivatives, whereas pomace and stem extracts consisted of significant amounts of flavonoids, stilbenes, and phenolic acids (Anastasiadi et al. 2009). Ferrer-Gallego et al. (2010) found that grape seeds undergo important decreases in the content of catechins and procyanidin oligomers during ripening. Epicatechin-(4→8)-epicatechin-3-O-gallate (B2G) and (–)-epicatechin-3-O-gallate (ECG) were the flavanolic compounds whose contents decreased most. The changes in the phenolic composition accompanied changes in tannic intensity, astringency and hardness of seeds. Astringency and seed hardness were more affected by the presence of galloylated dimeric procyanidins in the molecule than tannic intensity.

Grapevine (*Vitis vinifera*) products, grapes and grape juice, represent a valuable source of bioactive phytochemicals, synthesized by three secondary metabolic pathways (phenylpropanoid,

isoprenoid and alkaloid biosynthetic routes) and stored in different plant tissues (Iriti and Faoro 2009). The scientists reiterated that the health benefits resulting from consumption of grapes products could be ascribed to the mixture of these bioactive chemicals in grapes such as the newly discovered melatonin and its possible synergistic action with the great variety of polyphenols.

Grape seeds were found to contain 5–8% polyphenols comprised mainly of flavonoids, including gallic acid, the monomeric flavan-3-ols catechin, epicatechin, gallocatechin, epigallocatechin, and epicatechin 3-O-gallate, and procyanidin dimers, trimers, more highly polymerized procyanidins and proanthocyanidins (oligomeric proanthocyanidins) (Shi et al. 2003). They reported scientific studies had shown the antioxidant power of proanthocyanidins to be 20 times greater than vitamin E and 50 times greater than vitamin C and that extensive research suggests grape seed extract to be beneficial in many areas of health because of its antioxidant effect to bond with collagen, promoting youthful skin, cell health, elasticity, and flexibility. They added that studies had shown proanthocyanidins to help protect the body from sun damage, to improve vision, to improve flexibility in joints, arteries, and body tissues such as the heart, and to improve blood circulation by strengthening capillaries, arteries, and veins.

Antioxidant flavanol derivatives, aminoethylthio-flavan-3-ol conjugates were extracted from a polymeric waste fraction of grapes (Torres and Bobet 2001). The new compounds described resulted from the breakdown of polymeric flavanols in the presence of cysteamine.

Grape and Grape Wine Volatiles

Of the volatile monoterpene and norisoprenoid compounds found in *Vitis vinifera* cv. Melon (a muscadet wine grape), the most odorous compounds detected were *p*-cymene, terpinen-4-ol, *cis*- and *trans*-vitispiranes, 1,6,6-trimethyl-1,2-dihydronaphthalene (TDN), β -damascenone and riesling acetal (Schneider et al. 2001).

Elevating the CO₂ level in grapevine did not significantly change the total antioxidant capa-

city of the red wines (Gonçalves et al. 2009). Thirty-five volatile compounds belonging to seven chemical groups were identified: C6 alcohols, higher alcohols, esters, terpenols, carbonyl compounds, acids, volatile phenols, and C13 norisoprenoids. The effect of elevated [CO₂] on volatile composition and levels was significant because it was detected as an increase in ethyl 2-methylbutyrate, isoamyl acetate, ethyl hexanoate, ethyl octanoate, butyric acid, and isovaleric acid concentrations and a decrease in ethyl acetate concentration when compared to wines produced in ambient [CO₂] in 2005. In elevated [CO₂], wines from 2006 had lower methionol, 1-octanol, and 4-ethylguaiacol and higher ethyl lactate and linalool concentrations. The increase in [CO₂] did not significantly affect C6 alcohols, citronellol, carbonyl compounds, and β -damascenone concentrations. Their study showed that the predicted rise in [CO₂] did not produce negative effects on the quality of grapes and red wine. The volatile compounds contributing to the aroma profile of the two grape varieties, Carménère and Cabernet Sauvignon, were identified as terpenes (linalool, etc.), sesquiterpenes (farnesol), norisoprenoids (vitispirane, etc.), C(6) alcohols (1-hexanol, etc.), etc., and their amount decreased significantly with the oven-drying method (60°C), in contrast to the freeze-drying method (De Torres et al. 2010). Also phenolic compounds, anthocyanins and flavonols, were identified in fresh and dehydrated samples, thus resulting in the freeze-drying method being less aggressive than oven-drying methods.

Aroma compounds, 4-terpineol, geraniol, nerol, and linalool oxide (furan) were found in Chardonnay wines from all of the regions of California (Arrhenius et al. 1996). Frequency of use of individual grape-based aroma terms (citrus, oaky, honey, caramel, fruity, muscat, buttery, vegetal, apple, neutral) were found to be significantly correlated with linalool, 1,1,6-trimethyldihydronaphthalene, 3-methylbutyl acetate, ethyl 2-hydroxypropanoate, and 2-phenylethanol. Linalool concentrations were also correlated with R-terpineol. A total of 45, 44 and 42 volatile compounds were identified and quantified in Cabernet Sauvignon, Cabernet Gernischet and Chardonnay wines grown in Loess

Plateau region of China, respectively (Jiang and Zhang 2010). Alcohols formed the most abundant group in the aroma compounds of the three wines, followed by esters and fatty acids. According to their odor active values (OAVs), 18 volatile compounds were always present in the three wines at concentrations higher than their threshold values, but ethyl octanoate, ethyl hexanoate, and isoamyl acetate were found to jointly contribute to 92.9, 93.3, and 98.7%, of the global aroma of Cabernet Sauvignon, Cabernet Gernischet and Chardonnay wines, respectively. These odorants are associated with “fruity” and “ripe fruit” odor descriptors. The aroma composition of the Uruguay grape cv Tannat was characterised by a prevalence of *cis*-3-hexen-1-ol on the *trans* form and sometimes a appreciable level of *trans*-2-hexen-1-ol and a low content of C(6) alcohols (Boido et al. 2003). C(13)-norisoprenoidic and monoterpenic volatiles comprised about 42% of the total level of the volatiles, C(6) alcohols (6%) and benzenoid compounds (51%). The dominating monoterpene alcohols were the *cis* and *trans* isomers of 3,7-dimethyl-1,6-octadiene-3,8-diol (8-hydroxylinalool). The C(13)-norisoprenoid pattern was composed by 3-hydroxy- β -damascone; 3-oxo- α -ionol; vomifoliol; 4-oxo- β -ionol; 3-oxo-7,8-dihydro- α -ionol; 4-oxo-7,8-dihydro- β -ionol; grasshopper ketone; and 7,8-dihydrovomifoliol.

Deficit irrigation had no effect on the concentrations of other measured volatiles such as esters and terpenes. Fifty-eight aroma compounds were identified in the grapes of Cabernet gernischt, Cabernet sauvignon, Cabernet franc, and Merlot (Fan et al. 2010). The most significant odour active volatiles were β -damascenone, hexanal, (Z)-3-hexen-1-ol, (E,Z)-2,6-nonadienal, β -ionone, and an unknown. According to the odour activity values (OAVs), (E,Z)-2,6-nonadienal (OAV from 334 to 777), β -damascenone (OAV 245–790), β -ionone (OAV 97–193), and acetic acid (OAV 7–165) had comparatively high OVA values. One-hundred and seventy-nine compounds were identified in Brazilian Merlot wines comprising 94 esters, 80 alcohols, 29 ketones, 29 acids, 23 aldehydes, 23 terpenes, 16 lactones, 14 furans, 9 sulphur compounds, 7 phenols, 5 pyrroles, 3 C13-norisoprenoids and 2 pyrans (Welke et al.

2012). Differentiation among Merlot wines and wines of other grape varieties were mainly perceived through the following components: ethyl dodecanoate, 1-hexanol, ethyl nonanoate, ethyl hexanoate, ethyl decanoate, dehydro-2-methyl-3(2 H)thiophenone, 3-methyl butanoic acid, ethyl tetradecanoate, methyl octanoate, 1,4 butanediol, and 6-methyloctan-1-ol.

Wine produced from deficit-irrigated Merlot vines had increased amounts of vitispiranes, β -damascenone, guaiacol, 4-methylguaiacol, 4-ethylguaiacol, and 4-vinylguaiacol volatiles relative to wine produced from well-watered vines (Qian et al. 2009). From all the aroma compounds identified in free-run and pressed grape juices of cv. Emir, hexan-1-ol, (E)-hex-2-en-1-ol, isobutanol, isoamyl alcohol, and 2-phenylethanol were the most abundant volatile compounds (Selli et al. 2011). According to their results, pressing uniformly increased the levels of the aromatic constituents but reduced grape juice quality for winemaking by increasing the total phenolic compounds, browning index, and C(6)-alcohol levels (green-herbaceous odor) as compared to the free-run juice.

Manfra et al. (2011) found that levels of single anthocyanins in wine were not always correlated with those detected in grapes, as they were affected by winemaking. Peonidin-O-acetyl-glucoside was transferred from skin more slowly than petunidin-O-acetyl-glucoside and malvidin-O-acetyl-glucoside. The anthocyanin composition of the resulting wine showed that the total anthocyanin content was about one-tenth of the corresponding berry skin content. The ratio acetyl/coumaroyl anthocyanins in the wine was sharply higher than the value in berry skin (0.85 and 0.10, respectively), indicating an enrichment of acetyl derivatives in the wine. The high values of some anthocyanins in Aglianico wine could ameliorate its quality, increasing the chromatic properties, aging stability and product acceptance.

Up to 13 anthocyanins, 11 hydroxybenzoic and hydroxycinnamic acids, and 13 catechins and flavonols as well as 2 stilbenes were identified and quantified in the skins and seeds in pomace samples originating from red and white winemaking (Kammerer et al. 2004). Large

variabilities comprising all individual phenolic compounds were observed, depending on cultivar and vintage. Grape skins proved to be rich sources of anthocyanins, hydroxycinnamic acids, flavanols, and flavonol glycosides, whereas flavanols were mainly present in the seeds.

Phytochemicals in Other Plant Parts

Grape stems were found to contain significant amounts of polyphenolic compounds, especially phenolic acids, flavonols, and flavanonols such as astilbin (Souquet et al. 2000). Tannins comprised polymeric proanthocyanidins (up to 27 units) mainly consisting of (–)-epicatechin units along with smaller amounts of (+)-catechin, (–)-epicatechin gallate, and (–)-epigallocatechin. Of the phenolic compounds in grape stems, quercetin 3-glucuronide was the most important, followed by catechin, caffeoyltartaric acid, and dihydroquercetin 3-rhamnoside (astilbin). Stem-condensed tannins were qualitatively intermediate between grape seed and skin but could not be differentiated between red and white varieties. Grape stems were also characterized by high *trans*-resveratrol and ϵ -viniferin content. The main group of methanol-extractable polyphenols of grape stems comprised *trans*-resveratrol and its derivatives including oligomers and glucosides (Püssa et al. 2006). As, stilbenoid piceatannol as well as a number of nonstilbenoid polyphenols, mostly flavan-3-ols and phenolic acids glucosides, were determined as minor components of the extract. Ampelopsin A, ϵ -viniferin, vitisin A and vitisin B were isolated from the methanol extract of grape bark (Koo et al. 2008). Choi et al. (2009) isolated a new resveratrol dimer, (+)-vitisinol E and four known resveratrol oligomers, (+)-epsilon-viniferin, (+)-ampelopsin A, (+)-vitisin A and (–)-vitisin B from grape stem bark.

Antioxidant Activity

In-Vitro Studies

Grape juice made from blue grapes (Autumn Royal, Ribier) exhibited higher phenolic content and antioxidant capacity than juice from red grapes

(Red Globe, Crimson Seedless) (Lutz et al. 2011). The most abundant phenolic compound observed was catechin. The skin was found to be a rich source of phenolics and to have a high antioxidant capacity. Among the grape phenolic compounds flavonoids (anthocyanins, catechins) and non-flavonoids (stilbenes), also found in red wine, the stilbene astringin was found to have an important antioxidant effect similar to that of *trans*-resveratrol, and a higher radical scavenger activity than the latter as assessed by their capacity to prevent Fe²⁺–induced lipid peroxidation in microsomes and their action on Cu²⁺–induced lipid peroxidation in low-density lipoproteins and 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity (Fauconneau et al. 1997). Astringinin appeared to be more active. The authors asserted that the results may account in part for the so-called “French paradox,” i.e. that moderate drinking of red wine over a long period of time can protect against coronary heart disease.

Extracts of Greek currants and sultanas exhibited DPPH scavenging activity and inhibited tert-butylhydroperoxide (tBHP)-induced cytotoxicity, glutathione decrease, and low-density lipoprotein LDL oxidation (Kaliora et al. 2009). Fluorescence microscopy revealed the characteristic apoptotic patterns with tBHP and inhibition with the extracts. Elevated levels of total glutathione and unaltered levels of oxidized glutathione with extract treatment demonstrated the induction of gamma-glutamylcysteine synthetase. The antioxidant activity was correlated to the polyphenolic content.

Red grape marc (crushed grapes) was found to be rich in polyphenol compounds with a marked antioxidant activity (Negro et al. 2003). Grape seed appeared to contribute significantly to the antioxidant activity as they possessed high contents of proanthocyanidins a type of flavonoid known for its high antioxidant properties. Total polyphenolic content in ethyl acetate grape seed extract varied from 55.1 to 964 mg per 100 g of seeds, the average being 380 mg per 100 g (Guendez et al. 2005). The most abundant polyphenol was catechin, accounting for 49.8% of the total content, followed by epicatechin (26.0%), epicatechin gallate (9.3%), procyanidin B1 (5.8%), and procyanidin B2 (5.1%), whereas

epigallocatechin and gallic acid were minor components. There was a significant correlation between in-vitro antiradical activity (DPPH) and total polyphenol content ($R^2=0.6499$). The correlations with the individual compounds, however, revealed that procyanidin B1 may be one of the most important radical scavengers in grape seed extracts ($R^2=0.7934$), despite its low contribution to the overall polyphenol content.

Ingredients from grape skins and pomace showed antioxidant activity with oxygen radical absorbance capacity (ORAC) values from 1.38 to 21.4 μmol Trolox equivalents/mg whereas ingredients from leaves showed ORAC values from 1.52 to 2.55 μmol Trolox equivalents/mg (Monagas et al. 2006b). All the grape skin and seed extracts of 10 native Tuscan and international grape varieties showed significant antiradical (DPPH and peroxynitrite) capacity and Merlot skin was most active towards both radicals (Iacopini et al. 2008). All the five phenols namely catechin and epicatechin in seeds and quercetin, rutin and resveratrol in skin extracts investigated possessed strong antiradical activity. Quercetin, catechin and epicatechin exhibited maximum activity (respectively, IC_{50} (DPPH) 5.5, 6.7 and 6.8 μM , IC_{50} (ONOO-) 48.8, 55.7 and 56.7 μM). Potential antiradical interactive effects indicated possible synergy between quercetin, rutin and resveratrol towards peroxynitrite. The effect was additive for catechin and epicatechin. A significant positive correlation between total polymeric proanthocyanidin content from grape skin and seeds and antiradical activity was found ($R^2=0.6410$); in contrast, the mean degree of polymerisation (mDP) appeared to be negatively correlated to the antiradical activity ($R^2=-0.6238$) (Bordiga et al. 2011). Acetone, ethyl acetate, methanol and mixtures of different solvents, such as ethyl acetate (EtOAc) and water in 9:1, 17:3 and 4:1 ratios of grape seeds at 100 ppm concentration exhibited showed 65–90% antioxidant activity. Mixtures of EtOAc and water at different concentrations exhibited more antioxidant activity than other extracts (Jayaprakasha et al. 2001). These extracts also showed good reducing power, at 500 $\mu\text{g/mL}$ concentration, by the potassium ferri-cyanide reduction method. Grape seed extracts showed stronger antioxidant activity compared

to bagasse extract as measured by their capacity to scavenge DPPH and hydrogen peroxide; to reduce Mo(VI) to Mo(V) and to decrease in the rate of peroxide formation (Baydar et al. 2007). Antioxidant activities of the extracts increased as the extract concentration increased.

The 17 identified compounds in grape seed extract (GSE) comprised gallic and protocatechuic acid, catechin and epicatechin monomers, procyanidin oligomers, and procyanidin gallates (Stanković et al. 2008). Treatment of human lymphocytes with GSE at a concentration of 2.5 $\mu\text{g/mL}$ induced a significant decrease in the frequency of micronuclei by 40%, reduction of malonyldialdehyde production by 30%, while a concentration of 5 $\mu\text{g/mL}$ increased catalase and glutathione S-transferase activity by 10% and 15%, respectively. The results demonstrated that GSE may be effective in the prevention of oxidative lymphocyte damage by ROS. There was a greater concentration of phenolic compounds in the seeds (2,128 to 16,518 mg of catechin equivalents (CE)/100 g) than in the skins (660 to 1,839 mg CE/100 g) of Brazilian grape wine varieties (Rockenbach et al. 2011). The grape seed extracts were rich in oligomeric and polymeric flavanols. The highest antioxidant activity values determined as DPPH radical-scavenging ability and ferric reducing-antioxidant power (FRAP) were found for var Pinot Noir seeds (16,925 μmol Trolox equivalents (TE)/100 g and 21,492 μmol Fe^{2+} /100 g, respectively) and in the skin extracts of the Isabel variety (3,640 μmol TE/100 g and 4,362 μmol Fe^{2+} /100 g, respectively). The skin of Cabernet Sauvignon and Primitivo varieties had the highest contents of anthocyanins (935 and 832 mg/100 g, respectively). In the powdered grape seeds extracts the content of total phenolic compounds was found to be 627.98 mg gallic acid equivalent (GAE)/g with acetone:water:acetic acid (90:9.5:0.5) and 667.87 mg GAE/g with ethyl acetate: methanol:water (60:30:10) (Baydar et al. 2004). The bagasse extracts contained 45.44 mg GAE/g and 29.55 mg GAE/g with ethyl acetate: methanol:water (60:30:10) and ethanol:water (95:5), respectively.

Procyanidines (polyphenol oligomers) from *Vitis vinifera* seeds were found to have high free

radicals scavenging activities (Facino et al. 1994). In the iron-promoted (Fenton-driven) model, procyanidines had a remarkable, dose-dependent antilipoperoxidant activity ($IC_{50}=2.5 \mu\text{mol/l}$) which was due partly to their metal-chelating properties. In the ultrasound-induced lipid peroxidation model, procyanidines were highly effective in preventing conjugated diene formation in both the induction ($IC_{50}=0.1 \mu\text{mol/l}$) and propagation ($IC_{50}=0.05 \mu\text{mol/l}$) phases (the scavenging effect of α -tocopherol was weaker, with IC_{50} of 1.5 and 1.25 $\mu\text{mol/l}$). Further procyanidines at 0.5 $\mu\text{mol/l}$ markedly delayed the onset of the breakdown phase (48 h), totally inhibiting during this time the formation of degradation products (the lag-time induced by α -tocopherol was only of 24 h at 10 $\mu\text{mol/l}$ concentration). procyanidines also markedly reduced, in a dose-dependent manner, the signal intensity of the DMPO-OH (5,5 -dimethyl-L-pyrroline N-oxide – hydroxyl) radical spin adduct (100% inhibition at 40 $\mu\text{mol/l}$).

Chardonnay grape seed flour was found to have excellent peroxyl radical scavenging activity with ORAC value of 1076.4 Trolox equivalent $\mu\text{mol/g}$ flour, and its total phenolic content was 186.3 mg gallic acid equivalents/g flour (Parry et al. 2006). These values were 3–12 times higher than the other tested fruit seed flours (black raspberry, red raspberry, blueberry, cranberry, pinot noir grape). These fruit seed flours also differed in their total anthocyanin content values and Fe^{2+} -chelating capacities. Heating grape seeds was found to increase total phenol content and antioxidant activity (Kim et al. 2006). The maximum TPC and radical scavenging activity of whole grape seed extract (WGSE) were achieved when the seeds were heat-treated at 150°C for 40 min, while that of powdered grape seed extract (PGSE) were at 100°C for 10 min, and were greater than that of the non-treated control. Heating also increased slightly the reducing power of both WGSE and PGSE. The contents of gallic acid, gallocatechin gallate and caffeine in GSE significantly increased by heat treatment. Several low-molecular-weight phenolic compounds such as azelaic acid, 3,4-dihydroxy benzoic acid, and *o*-cinnamic acid were newly formed in the WGSE heated at 150°C for 40 min. Chedea

et al. (2010) reported that polyphenolic grape seed extract may have prooxidant activity as well as antioxidant activity. The antioxidant activity of the extract might be mediated by prooxidant quinones and oxidation products of the polyphenols from grape seeds.

The tocotrienol-rich fraction, a mixture of γ -tocopherol and α - and γ -tocotrienol, obtained from grape seed oil showed 3.5-, 40.0-, and 39.0-fold higher ABTS radical scavenging activity, inhibition of lipid peroxidation, and reducing power, respectively, compared to α -tocopherol fraction (5% diethyl ether fraction) (Choi and Lee 2009).

In-vitro-studies by Ivanov et al. (2001) indicated that red wine components bound to human low-density lipoprotein (LDL) and HDL and protected these lipoproteins from metal ion-dependent and -independent protein and lipid oxidation. Under oxidative stress induced by copper and aqueous peroxyl radicals (2,2'-azobis-[2-amidinopropane] dihydrochloride, AAPH), LDL-associated and free red wine components significantly decreased oxidation of the lipoprotein's protein moiety and lipid moiety. Similar protective effects of red wine components were observed against HDL oxidation. In contrast, red wine exerted a pro-oxidant effect on copper-induced oxidation of bovine serum albumin tryptophan residues, while protecting them from AAPH-induced oxidation. Ascorbate strongly enhanced the protective effect of red wine against copper-induced LDL oxidation, and had an additive effect against AAPH-induced oxidation. The highest concentrations of gallic, syringic and ferulic acids were found in organic Cabernet Sauvignon; 2,3-dihydroxybenzoic acid in organic Carignan and *p*-coumaric and vanillic acids in non-organic Merlot wine (Yildirim et al. 2004). High levels of antioxidant activity (AOA), inhibition of LDL oxidation and total phenol levels were found in non-organic Merlot and non-organic Cabernet Sauvignon grape varieties. Concentrations of some individual phenolic constituents (ferulic, *p*-coumaric, vanillic) were correlated with high antioxidant activity and inhibition of LDL oxidation. The best correlation value for all examined characteristics was determined for gallic acid, followed by 2,3-dihydroxy-

benzoic, syringic, ferulic and *p*-coumaric acids. Negative correlation of vanillic with MDA and *p*-hydroxybenzoic acid with LDL were confirmed by principal component analysis (PCA) analyses. Red wines displayed a higher antioxidant activity (81.110% AOA) than white ones (19.512% AOA). The average level of LDL inhibition capacity in red wine was determined as 87.072% and for the white as 54.867%.

Antioxidant potential of silbenes and anthocyanins isolated from *Vitis vinifera* cell suspension obtained from Gamay Teinturier vine-plant assessed by of lipid peroxidation induced by Cu²⁺ revealed that *cis*-resveratrol (IC₅₀ 19 µmol/l) was seven times weaker than *trans*-resveratrol (IC₅₀ 2.6 µmol/l) (Mérillon et al. 1997). The silbenes, astringin (IC₅₀ 3.3 µmol/l) and astringinin (IC₅₀ 1.9 µmol/l) were more potent than *cis*-piceid (IC₅₀ 16.6 µmol/l) and *trans*-piceid (IC₅₀ 19.3 µmol/l). Both anthocyanins malvidin-3-O-β-glucoside (IC₅₀ 3.8 µmol/l) and peonidin-3-O-β-glucoside (IC₅₀ 3.8 µmol/l) had stronger antioxidant potential. Studies by Mikulski and Molski (2010) showed that all *trans*-resveratrol oligomers: *trans*-resveratrol dimers: pallidol, geometric stereoisomers of ε-viniferin, stereoisomers of *trans*-δ-viniferin and *trans*-resveratrol trimer-gnetin H, glucosides: *trans*-piceid, *cis*-piceid, *trans*-astringin, and *trans*-resveratrol-4'-O-β-D-glucopyranoside and *trans*-resveratrol-3-O-glucuronide exhibited stronger antioxidant activity than *trans*-resveratrol. The dimer of *trans*-4,4'-dihydroxystilbene was a stronger antioxidant than its monomer and the *cis* stereoisomers of piceid and ε-viniferin were weaker antioxidant than their *trans* stereoisomers.

Ugartondo et al. (2007) found that the polyphenolic rich fractions of grape pomace and pine bark exhibited high antioxidant capacity in a concentration range that was not harmful to normal human cells. Pine fractions presented slightly lower antioxidant activity than grape fractions but were less cytotoxic to human keratinocyte cell line HaCaT and the mouse fibroblast cell line 3 T3. These fractions contained similar polymerised flavonoids but different percentages of pyrogallol groups that conferred on them different biological properties.

Antioxidant activity of grape cane extracts, determined by the TEAC assay, varied from 85.6 to 238.6 µmol Trolox equivalents/g of dry sample (Karacabey and Mazza 2010). ORACFL (oxygen radical absorbance capacity using fluorescein) values ranged from 308.4 to 1302.7 µmol Trolox equivalents/g of dry sample. Ethanol concentrations of 40.4% and 55.4% were optimal for the highest antioxidant activities measured by the TEAC assay and the ORACFL method, respectively. Antioxidant activity correlated with total phenolic content of extracts.

In-Vivo Studies

The ethyl acetate, methanol, and water extracts of grape pomace showed 76, 87.1, and 21.7% antioxidant activities at 100 ppm, respectively, using the DPPH model system (Chidambara Murthy et al. 2002). The methanol extract showed 71.7, 73.6, and 91.2% inhibition using the thiobarbituric acid method, hydroxyl radical scavenging activity, and LDL oxidation, respectively, at 200 ppm. Treatment of albino rats of the Wistar strain with a single dose of CCl₄ at 1.25 mL/kg of body weight decreased the activities of catalase, superoxide dismutase (SOD), and peroxidase by 81, 49, and 89%, respectively, whereas the lipid peroxidation value increased nearly 3-fold. Pretreatment of the rats with the methanolic extract of grape pomace at 50 mg/kg (in terms of catechin equivalents) followed by CCl₄ treatment causes restoration of catalase, SOD, and peroxidase by 43.6, 73.2, and 54%, respectively, as compared with control, whereas lipid peroxidation was restored to values comparable with the control. Histopathological studies of the liver of different groups also supported the protective effects exhibited by the methanol extract of grape pomace by restoring the normal hepatic architecture. Ahn et al. (2002) found that grape seed extract had potent radical scavenging activity in-vitro, and inhibited lipid peroxidation in rats. Catalase and superoxide dismutase (SOD) activities were increased by its administration. The liver thiobarbituric acid reactive substances (TBARS) and phosphatidylcholine hydroperoxides (PCOOH) levels were decreased compared to control group. Results of in-vivo studies suggested

that grape leaf extract (GLEt) exhibited protective effect against alcohol induced oxidative damage in rats (Pari and Suresh 2008). Administration of ethanol along with GLEt significantly decreased the activities of liver markers enzyme in serum towards near normal level. GLEt also significantly reduced the levels of lipid peroxidation and restored the enzymic and non-enzymatic antioxidants levels in liver and kidney of alcohol administration rats. In-vitro studies with DPPH* and ABTS*(+) (cation radical) assays, grape leaf extract was found to possess antioxidant activity.

The amount of total phenolics and flavonoids were found to be 1208.00 µg/mL as the gallic acid equivalent and 5.2 µg/mL as the quercetin equivalent in Öküzgözü grape juice, respectively (Pirinçioğlu et al. 2012). In-vivo administration of CCl₄ caused a significant increase of various biochemical parameters such as alanine amino transferase (ALT), aspartate amino transferase (AST), total bilirubin (TB) and a decrease in albumin (ALB) levels in serum or an increase in malondialdehyde (MDA) levels in the tissues when compared to a control. Administration of CCl₄ along with Öküzgözü grape juice or ursodeoxycolic acid (UDCA) significantly reduces these changes. Histopathological studies also supported the protective effect of grape juice extract.

In a month- long study of ten healthy volunteers, dietary supplementation of grapes procyanidins was found to exert an antioxidant protective effect by reducing DNA oxidative damage and sparing liposoluble vitamin E (Simonetti et al. 2002). The levels of α-tocopherol in red blood cell membranes was increased significantly and the red blood cell membrane fatty acid composition shifted to a higher level of polyunsaturated fatty acids. Vigna et al. (2003) conducted a randomized, double-blind, crossover study in 24 healthy male heavy smokers, aged ≥50 years, wherein 2 capsules of a standardized formulation of a polyphenolic extract of grapes (Leucoselect-Phytosome [LP]), were administered twice daily for 4 weeks (phase 1) with a wash out period of 3 weeks was then followed by 4 weeks of the opposite treatment (phase 2). Subjects did not show significant modification of total cholesterol

(TC), triglycerides (TG), high-density lipoprotein-cholesterol (HDL-C) and LDL-C during LP treatment. Among oxidative indices, thiobarbituric acid reactive substances (TBARS) concentration was significantly reduced in subjects taking LP, and the lag phase prolonged compared with placebo and basal values.

Cardioprotective Activity

The cardioprotective effect of grape extracts (seed, skin, juice) and red wine had been attributed to antioxidants present in the polyphenol fraction (Lugasi et al. 1997; Das et al. 1999; Leifert and Abeywardena 2008). Grapes had been reported to contain a variety of antioxidants, including resveratrol, catechin, epicatechin, phenolic acids, anthocyanins, proanthocyanidins, and flavonoids. Resveratrol in grape skin and proanthocyanidin in seeds had been scientifically reported to be effective in reducing myocardial ischemic reperfusion injury suggesting that these red wine polyphenolic antioxidants may play a crucial role in cardioprotection (Das et al. 1999). Polyphenolic compounds present in red wine in concentration of 1,800–3,000 mg/l had been reported to act as antioxidants, free radical scavengers and inhibitors of lipid peroxidation processes in-vitro and in-vivo (Lugasi et al. 1997). Beside dietary antioxidants such as tocopherols, ascorbic acid and carotenoids, the polyphenolic compounds of plant origin were also reported to exert favourable effects on cardioprotective mechanisms. These phenolic compounds had been reported to possess potent antioxidant properties and had been shown to decrease low-density lipoprotein-cholesterol oxidation and platelet aggregation (Leifert and Abeywardena 2008). These compounds had also been reported to possess a range of additional cardioprotective and vasoprotective properties including antiatherosclerotic, antiarrhythmic, and vasorelaxation actions. Lugasi et al. (1997) in their review reaffirmed the notion that moderate consumption of red wine - 2–3 unit/day for healthy men, and 1–2 unit/day for healthy women (1 unit=12 g alcohol) may have a beneficial effect on reducing coronary heart diseases.

Facino et al. (1996) found that infusion of rabbit heart with 100 or 200 $\mu\text{g/mL}$ grape seed procyanidines dose-dependently reduced ventricular contracture during ischemia, decreased coronary perfusion pressure, improved cardiac mechanical performance upon reperfusion, increased the release of 6-keto-PGF $_{1\alpha}$ into the perfusate in both the pre-ischemic and the reperfusion periods, and suppressed rhythm irregularity. Further, procyanidines were found to be potent scavengers of several reactive oxygen species involved in the ischemia/reperfusion damage: the superoxide anion ($\text{IC}_{50}=5.64\text{ }\mu\text{M}$ determined by the phenazine methosulfate/NADH method); the hydroxyl radical ($\text{IC}_{50}=28\text{ }\mu\text{M}$, determined by the electron spin resonance spectroscopy); peroxy radicals ($\text{IC}_{50}=0.025\text{ }\mu\text{M}$ and $0.35\text{ }\mu\text{M}$, determined using two different lipid substrates, phosphatidylcholine liposomes and methyl linoleate micelles by UV spectroscopy at 233 nm). Additionally, procyanidines interact with Fe^{2+} and Cu^{2+} ions (the catalysts of HO $^{\cdot}$ radicals production) giving rise to strong complexes. In another subsequent study by Facino et al. (1999) demonstrated that grape seed procyanidin supplementation in the rat (young and aged) made the heart less susceptible to ischemia/reperfusion damage. The cardioprotective effect was positively associated with an increase in plasma antioxidant activity. The results of a separate study showed that grape seed-proanthocyanidins possessed a cardioprotective effect against ischemia reperfusion injury in rats (Sato et al. 1999). The cardioprotective property may be partly attributed to its ability to directly scavenge peroxy and hydroxyl radicals and to reduce oxidative stress developed during ischemia and reperfusion. proanthocyanidin-fed animals were resistant to myocardial ischemia reperfusion injury as evidenced by improved recovery of post-ischemic contractile functions. The proanthocyanidin-fed group revealed reduced extent of myocardial infarction compared to the control group.

Further study indicated that grape seed proanthocyanidin extract functioned as an in-vivo antioxidant, and its cardioprotective properties may partially be attributed to its ability to block antideath signal through the inhibition of proapop-

totic transcription factor and inhibition of JNK-1 and c-Jun genes in the ischemic/reperfused myocardium (Sato et al. 2001). Similarly, Pataki et al. (2002) treatment of rats with grape seed proanthocyanidins had cardioprotective effects against reperfusion-induced injury via their ability to reduce or remove, directly or indirectly, free radicals in myocardium that was reperfused after ischemia. In rats treated with 100 mg proanthocyanidins/kg, free radical intensity was reduced by 75% compared with the control rats. GSPE supplementation improved cardiac functional assessment including post-ischemic left ventricular function, reduced myocardial infarct size, reduced ventricular fibrillation (VF) and tachycardia, decreased the amount of reactive oxygen species (ROS) as detected by ESR spectroscopy and reduced malondialdehyde (MDA) formation in the heart perfusate. Studies showed that grape procyanidins exhibited cardioprotective effect in an experimental model of ischemia-reperfusion damage (Berti et al. 2003). The procyanidins infusion dose-dependently reduced left ventricular end-diastolic pressure during ischemia, decreased coronary perfusion pressure, improved cardiac mechanical performance upon reperfusion, increased the release of 6-keto-prostaglandin $\text{F}_{1\alpha}$ into the perfusate in both the preischemic and the reperfusion periods and suppressed rhythm irregularity. Procyanidins also dose-dependently relaxed human internal mammary aortic (IMA) rings (with intact endothelium) precontracted with norepinephrine. In another study, Aldini et al. (2003) found that in homogeneous phase, grape seed procyanidins dose-dependently inhibited 2',7'-dichloro-dihydrofluorescein (DCFH) oxidation induced by 3-morpholinodisulfonimine (SIN-1), a peroxy nitrite generator, with an IC_{50} value of $0.28\text{ }\mu\text{M}$. In endothelial cells, procyanidins suppressed cellular damage induced by SIN-1 with a MIC of $1\text{ }\mu\text{M}$. Also, procyanidins dose-dependently relaxed human internal mammary aortic (IMA) rings (with intact endothelium) pre-contracted with norepinephrine (NE), showing a maximal vasorelaxant effect (85%) at $50\text{ }\mu\text{M}$ (catechin: 18% relaxation at $50\text{ }\mu\text{M}$). Further, pre-incubation of IMA-rings with procyanidins (from 6.25 to $25\text{ }\mu\text{M}$) resulted in a

dose-dependent prevention of the endothelin-1 (ET-1) vasoconstriction. The ability of procyanidins to prevent peroxynitrite attack to vascular cells, by layering on the surface of coronary EC, and to enhance endothelial NO-synthase-mediated relaxation in IMA rings provided further insight into the molecular mechanisms through which they exerted cardioprotective activity in ischemia/reperfusion injury in-vivo.

The cardioprotective ability grape seed proanthocyanidin extract (GSPE) was demonstrated in a series of animal and human studies (Bagchi et al. 2003). GSPE supplementation improved cardiac functional assessment including post-ischemic left ventricular function, reduced myocardial infarct size, reduced ventricular fibrillation and tachycardia, decreased the amount of reactive oxygen species (ROS) and reduced malondialdehyde (MDA) formation in the heart perfusate. GSPE pretreatment significantly inhibited doxorubicin-induced cardiotoxicity, DNA damage and histopathological changes in the cardiac tissue of mice. A human clinical trial conducted on hypercholesterolemic subjects, GSPE supplementation significantly reduced oxidized LDL, a biomarker of cardiovascular diseases. In cDNA microarray study GSPE significantly inhibited inducible endothelial CD36 expression, a novel cardioregulatory gene. Concentration-dependent efficacy of GSPE was also assessed in a hamster atherosclerosis model where animals were fed a hypercholesterolemic diet of 0.2% cholesterol and 10% coconut oil (Vinson et al. 2002). Approximately 49 and 63% reduction in foam cells, a biomarker of early stage atherosclerosis, were observed following supplementation of 50 and 100 mg GSPE/kg body weight, respectively.

In-vitro studies in chick cardiomyocytes indicated that GSPE confers cardioprotection against exogenous H₂O₂- or antimycin A-induced oxidant injury (Shao et al. 2003a). GSPE dose-dependently attenuated oxidant formation and significantly improved cell survival and contractile function. GSPE scavenged hydrogen peroxide, hydroxyl radical and superoxide, and chelated iron directly. Studies in chick cardiomyocytes showed that high doses of GSPE could potentially have harmful pro-oxidant effects (Shao

et al. 2003b). Exposure to increasing concentrations of GSPE (100 or 500 µg/mL) resulted in an increase in ROS generation and cell death. Caspase-3 activity was significantly increased fourfold in cells exposed to GSPE 500 µg/mL compared to controls. The authors concluded that higher doses of GSPE could cause apoptotic cell injury via effector caspase-3 activation and subsequent induction of ROS generation. Further studies found that GSPE administration at reperfusion exerted a cardioprotective effect against GSPE administration at reperfusion injury in cardiomyocytes and may improve vascular health by enhancing nitric oxide production and Akt-eNOS signalling (Shao et al. 2009).

Studies in cultured primary cardiomyocytes showed that GSPE in combination with doxorubicin had protective effect against doxorubicin-induced toxicity in cardiomyocytes, which may be in part attributed to its antioxidative activity (Li et al. 2010). GSPE treatment did not decrease the proliferation-inhibitory effect of doxorubicin in MCF-7 human breast carcinoma cells. Thus, GSPE may be a promising adjuvant to prevent cardiotoxicity without interfering with antineoplastic activity during chemotherapeutic treatment with doxorubicin.

Grape seed proanthocyanidins exerted cardioprotective effects against cholesterol cholic diet-induced hypercholesterolemia in rats via their ability to reduce, directly or indirectly, free radicals in the myocardium (Thiruchenduran et al. 2011). Grape seed proanthocyanidin partially restored the altered activity of cardiac and serum creatine kinase, that was accompanied by a decreased cardiac enzymatic and non-enzymatic antioxidant defense system and an increase in the expression of cytochrome c and caspases-3 observed in cholesterol cholic diet-fed rats. It also restored the abnormal increase in lipid peroxidation, tissue cholesterol, triglyceride, serum low-density lipoprotein, and very low density lipoprotein, and decreased the high-density lipoprotein concentration induced by cholesterol cholic acid diet.

Grape seed extract administration by gavage to rats 14 days prior to gamma irradiation significantly attenuated the radiation-induced oxidative stress

in heart tissues which was substantiated by a significant amelioration of serum lactate dehydrogenase, creatine phosphokinase and aspartate transaminase activities (Saada et al. 2009). Grape seed treatment also attenuated the oxidative stress in pancreas tissues which was associated with a significant improvement in radiation-induced hyperglycemia and hyperinsulinemia. The data demonstrated that grape seed extract would protect the heart and pancreas tissues from oxidative damage induced by ionizing irradiation.

Antihypertensive Activity

Oral administration of alcohol-free hydroalcoholic grape skin extract significantly reduced systolic, mean and diastolic arterial pressure in Wistar rats with desoxycorticosterone acetate-salt and N(G)-nitro-L-arginine methyl ester (L-NAME) induced experimental hypertension (Soares De Moura et al. 2002). In the rat isolated mesenteric vascular bed pre-contracted with norepinephrine, bolus injections of the extract induced endothelium-dependent vasodilatation. Lipid peroxidation of hepatic microsomes estimated as malondialdehyde production was concentration-dependently inhibited by the extract. The data suggested that the antihypertensive effect of grape skin extract might be due to a combination of vasodilator and antioxidant actions. Chronic oral administration of myricetin isolated from *Vitis vinifera* at doses of 100 and 300 mg/kg, for 4 weeks, ameliorated hypertension and oxidative stress induced by deoxycorticosterone acetate (DOCA)-salt in rats (Borde et al. 2011). Myricetin treatment lowered systolic blood pressure, vascular reactivity changes and reversed the DOCA-induced elevation in heart rate. Urinary sodium excretion was significantly decreased in animals treated with myricetin compared to the DOCA group. Elevated levels of thiobarbituric acid reactive substances and decreased levels of superoxide dismutase, catalase and GSH (reduced glutathione) in the heart tissue of animals treated with DOCA, were reversed by myricetin. The cumulative concentration response curve of serotonin (5-HT) and angiotensin II (Ang II) were shifted towards the right

in rats treated with myricetin using the isolated rat fundus strip and ascending colon, respectively.

Grape skin extract was found to protect normally fed offspring of high fat-fed dams during lactation from phenotypic and metabolic characteristics of metabolic syndrome (Emiliano et al. 2011). The extract prevented hypertension and increased systolic blood pressure in adult offspring of high fat-fed dams. The extract decreased the elevated adiposity, plasma triglyceride, glucose levels and insulin resistance observed in offspring from both ages. The plasma oxidative damage assessed by malondialdehyde levels was increased and nitrite levels decreased in high fat group of both ages, which were reversed by the extract. Also the extract restored the decreased plasma and mesenteric arteries antioxidant activities of superoxide dismutase, catalase and glutathione peroxidase in high-fat group.

Feringa et al. (2011) conducted a meta-analysis of randomized, controlled trials and found that grape seed extract appeared to significantly lower systolic blood pressure and heart rate, with no effect on lipid or C-reactive protein (CRP) levels. No statistical heterogeneity was observed for any analysis ($I^2 < 39\%$ for all). Egger's weighted regression statistic suggested low likelihood of publication bias in all analysis, except for the effect on diastolic blood pressure.

Chemoprotective Activity (Anti-toxic Potential)

GSPE exhibited a dose-dependent inhibition of 12-O-tetradecanoylphorbol-13-acetate (TPA)-induced lipid peroxidation and DNA fragmentation in liver and brain, as well as a dose-dependent inhibition of TPA-induced reactive oxygen species production in peritoneal macrophages (Bagchi et al. 1998). GSPE and other antioxidants provided significant protection against TPA-induced oxidative damage, with GSPE providing better protection than did other antioxidants at the doses that were employed. Treatment of mice with GSPE (100 mg/kg), vitamin C (100 mg/kg), vitamin E succinate (VES) (100 mg/kg) and β -carotene (50 mg/kg) decreased TPA-induced

production of reactive oxygen species, as evidenced by decreases in the chemiluminescence response in peritoneal macrophages by approximately 70%, 18%, 47% and 16%, respectively, and cytochrome c reduction by approximately 65%, 15%, 37% and 19%, respectively, compared with controls. GSPE, vitamin C, VES and β -carotene decreased TPA-induced DNA fragmentation by approximately 47%, 10%, 30% and 11%, respectively, in the hepatic tissues, and 50%, 14%, 31% and 11%, respectively, in the brain tissues, at the doses that were used. Similar results were observed with respect to lipid peroxidation in hepatic mitochondria and microsomes and in brain homogenates. In-vitro studies showed that GSPE pretreatment protected primary glial cells against nitrosative/oxidative stress (Roychowdhury et al. 2001). In addition to its antioxidative property, GSPE enhanced low-level production of intracellular NO in primary rat astroglial cultures. Further, GSPE pretreatment protected the microglial glutathione pool during high output NO production and resulted in an elevation of the H₂O₂ tolerance in astroglial cells. Administration of leucocyanidines, procyanidolic oligomers, extracted from grape seeds markedly decreased the activities of NADPH-cytochrome P450 reductase, P4501A1, P4501A2, and P4503A4, but significantly increased the activities of glutathione S-transferase and phenolsulfotransferase in the rat liver (Seo et al. 2001). The activities of antioxidant enzymes however, were not affected by leucocyanidine administration. The inhibition of P450s and increases in phase II enzyme activities suggest a role for leucocyanidines as a chemopreventive agent against toxic or carcinogenic metabolites of P450 isozymes.

The results of studies by Stagos et al. (2006) suggested that the protection of DNA from mutations induced by reactive oxygen species (ROS) may be one of the mechanisms accounting for the chemopreventive activity of grape extracts. However, polyphenol-rich fractions as well as individual polyphenols (quercetin, (+)-catechin, (–)-epicatechin, *trans*-resveratrol, gallic acid and protocatechuic acid) at concentrations found in the extracts either did not diminish or did enhance the activity of the oxidant mutagens used were

bleomycin and hydrogen peroxide. The results also suggested that this protective activity may not be attributed to polyphenols but rather to a synergism of many compounds in the grapes.

In-vivo studies in mice demonstrated that GSPE preexposure may significantly attenuate acetaminophen (AAP)-induced hepatic DNA damage, apoptotic and necrotic cell death of liver cells, and significantly antagonized the influence of AAP-induced changes in cell death inhibitory gene bcl-XL expression (Ray et al. 1999). Animal studies demonstrated that GSPE scavenged ROS (reactive oxygen species) that was enhanced by acute stress and chronic stress and provided significant protection against gastrointestinal oxidative stress and mucosal injury (Bagchi et al. 1999). GSPE decreased lipid peroxidation, DNA fragmentation and membrane microviscosity in both gastric mucosa and intestinal mucosa induced by acute stress (water immersion restraint stress for 90 min) and chronic stress (water immersion restraint stress 15 min/day for 15 days) by scavenging reactive oxygen species.

IH636 grape seed proanthocyanidin extract (GSPE) was found to have multi-organ protective activity; studies demonstrated GSPE to be highly bioavailable and may serve as a potential therapeutic tool in protecting multiple target organs from structurally diverse drug- and chemical-induced toxicity (Bagchi et al. 2000, 2002b). Preexposure of mice to IH636 grape seed proanthocyanidin extract (GSPE) prior to acetaminophen-induced nephrotoxicity, amiodarone-induced lung toxicity, and doxorubicin-induced cardiotoxicity provided near complete protection in terms of serum chemistry changes (alanine aminotransferase, blood urea nitrogen and creatine phosphokinase), and significantly reduced DNA fragmentation (Ray et al. 2000). The protection by GSPE may be linked to both inhibition of metabolism and/or detoxification of cytotoxic radicals. In addition, its' presumed contribution to DNA repair may be another important attribute, which played a role in the chemoprevention process. These events undoubtedly established GSPE's abundant bioavailability, and the power to defend multiple target organs from toxic assaults induced by structurally diverse and functionally different entities in-vivo.

Studies on the effect of GSPE against acetaminophen-induced hepatotoxicity, amiodarone-induced pulmonary toxicity, doxorubicin-induced cardiotoxicity, cadmium chloride-induced nephrotoxicity, dimethylnitrosamine-induced splentotoxicity and O-ethyl-S,S-dipropyl phosphorodithioate (MOCAP)-induced neurotoxicity in mice indicated that GSPE preexposure prior to the drugs/chemicals such as acetaminophen, amiodarone, doxorubicin, cadmium chloride or dimethylnitrosamine assault, provided near complete protection in terms of serum chemistry changes (alanine amino-transferase, blood urea nitrogen and creatine kinase) and inhibition of both forms of cell death, e.g., apoptosis and necrosis (Bagchi et al. 2001). DNA damage in various tissues triggered by these agents was significantly reduced. GSPE afforded only partial protection against O-ethyl-S,S-dipropyl phosphorodithioate (MOCAP)-induced neurotoxicity in mice in the brain tissue. Histopathological examination of the organs liver, lungs, kidney and spleen reflected similar patterns to those of the serum chemistry and DNA results. These results suggested GSPE exposure to be bioavailable and provides significant multiorgan protection against drug- and chemical-induced toxic assaults. GSPE protected against tobacco-induced apoptotic cell death in human oral keratinocytes and provided protection against cancer chemotherapeutic drug-induced cytotoxicity in human liver cells by modulating cell cycle/apoptosis regulatory genes such as bcl2, p53 and c-myc (Bagchi et al. 2000, 2002a).

Comparative protective abilities of GSPE, and vitamins C and E, singly and in combination, were assessed against smokeless tobacco extract (STE)-induced oxidative stress, DNA fragmentation and apoptotic cell death in a primary culture of normal human oral keratinocytes. GSPE protected against smokeless tobacco extract induced oxidative stress, DNA damage and apoptotic cell death, and provided better protection as compared to vitamins C and E, singly and in combination (Bagchi et al. 2002a). Serum chemistry changes, histopathology and DNA damage were evaluated. Results of studies indicated that GSPE pre exposure prior to the drugs/chemicals such as acetaminophen (AP), amiodarone (AM), doxorubicin

(DoX) or dimethylnitrosamine (DM) treatment, provided near complete protection in terms of serum chemistry changes and inhibition of both forms of cell death, e.g., apoptosis and necrosis in acetaminophen (AP)-induced hepato- and nephrotoxicity, amiodarone (AM)-induced lung toxicity, doxorubicin (DX)-induced cardiotoxicity and dimethylnitrosamine (DM)-induced splentotoxicity in mice (Bagchi et al. 2002b). DNA damage in various tissues triggered by these agents was significantly reduced in GSPE-fed animals. Further, these studies exhibited a series of mechanistic information including free radical scavenging ability, anti-endonucleolytic activity, cytochrome P450 2E1 inhibitory activity, anti-necrotic, anti-apoptotic and anti-carcinogenic activities, modulatory effects on antioxidative and apoptotic regulatory genes such as Bcl2, c-myc and p53, which may be responsible for the novel chemoprotective properties exhibited by GSPE.

GSPE treatment protected against oxidative stress induced by cisplatin toxicity in rats (Saad et al. 2009; Yousef et al. 2009). Findings showed that GSPE may be used to prevent toxicity during chemotherapeutic treatment with cisplatin. Cisplatin induced damage in the kidney genomic DNA, lipid peroxidation, inhibition of antioxidant enzymes (GST, SOD, CAT and GSH-Px) (GST, SOD, CAT and GSH-Px) and alterations of biochemical parameters in plasma and kidney of rats (Saad et al. 2009). GSPE reduced cisplatin-induced elevated levels of thiobarbituric acid reactive substances (TBARS) in plasma, heart, kidney and liver, total lipids, cholesterol, urea and creatinine, and liver aspartate and alanine transaminases (Yousef et al. 2009). GSPE ameliorated cisplatin-induced decrease in the activities of antioxidant enzymes, and glutathione, total protein and albumin.

Administration of leucocyanidines, procyanidolic oligomers, extracted from grape seeds markedly decreased the activities of NADPH-cytochrome P450 reductase, P4501A1, P4501A2, and P4503A4, but significantly increased the activities of glutathione S-transferase and phenolsulfotransferase in the rat liver (Seo et al. 2001). The activities of antioxidant enzymes

however, were not affected by leucocyanidine administration. The inhibition of P450s and increases in phase II enzyme activities suggest a role for leucocyanidines as a chemopreventive agent against toxic or carcinogenic metabolites of P450 isozymes.

Anticancer Activity

IH636 grape seed proanthocyanidin extract (GSPE) was shown to have concentration- and time-dependent cytotoxicity towards MCF-7 human breast cancer cells, A-427 human lung cancer cells, and CRL-1739 human gastric adenocarcinoma cells while enhancing the growth and viability of normal human gastric mucosal cells (Ye et al. 1999). GSPE protected against tobacco-induced apoptotic cell death in human oral keratinocytes and provided protection against cancer chemotherapeutic drug-induced cytotoxicity in human liver cells by modulating cell cycle/apoptosis regulatory genes such as bcl2, p53 and c-myc (Bagchi et al. 2000, 2002a). In-vivo studies in mice revealed that long-term exposure of 9 months to proanthocyanidin-rich grape seed extract may serve as a potent barrier to all three stages of dimethylnitrosamine-induced liver carcinogenesis and tumorigenesis by selectively altering oxidative stress, genomic integrity and cell death processes involved during the multistage tumorigenic process (Ray et al. 2005). GSPE inactivated PI3-kinase/PKB pathway and induced apoptosis in colon cancer cells and inhibited its viability but did not alter viability in the normal colon cell line (NCM460) (Engelbrecht et al. 2007). The tocotrienol-rich fraction, a mixture of γ -tocopherol and α - and γ -tocotrienol, obtained from grape seed oil exhibited high antiproliferative activity against MCF7 breast cancer (81%) and NCI-H460 (human lung cancer) (76%) cells at a concentration of 1.0 mg/mL (Choi and Lee 2009).

Grape extract was found to have chemopreventive potential against 12-O-tetradecanoyl-13-phorbol acetate (TPA)-mediated tumour promotion in 7,12-dimethyl-benz[a]anthracene (DMBA) initiated mice skin (Alam et al. 2002). Pretreatment of grape extract resulted in

significant inhibition against TPA-caused induction of epidermal ornithine decarboxylase activity and DNA synthesis. Pretreatment of grape extract also resulted in partial significant inhibition of oxidative stress in dose-dependent manner. The concomitant increase in the microsomal lipid peroxidation and xanthine oxidase activities were significantly reduced; the depleted level of glutathione and inhibited activities of antioxidant enzymes were restored to the partial significant level.

Grape polyphenolic fractions were found to be potent antiradical agents and exerted an antiproliferative effect in mouse hepatoma Hepa-1c1c7 cells (Matito et al. 2003). The fraction with the highest degree of polymerization and galloylation (containing flavonols and procyanidin oligomers of higher molecular weight) had the most influence on the cell cycle and induction of apoptosis on Hepa-1c1c7. Grape seed procyanidins were found to protect against carcinogen-induced oxidative cellular and genotoxic damage (Lu et al. 2004). Procyanidins exhibited significant protective effects on carcinogen phorbol-12-myristate-13-acetate (PMA)-induced DNA damage. Procyanidins inhibited the PMA-induced release of hydrogen peroxide by polymorphonuclear leukocytes, and inhibited respiratory burst activity in NIH3T3 mouse fibroblasts. Further, procyanidins suppressed liver mitochondrial lipid peroxidation induced by PMA and protected the activity of superoxide dismutase and decreased the level of malondialdehyde (MDA) in liver mitochondria damaged by PMA.

Two grape stilbenoid *trans*-astringin and *trans*-piceatannol were found to have potential cancer-chemopreventive agents by a mechanism different from that of *trans*-resveratrol (Waffo-Tégou et al. 2001). At 10 μ g/mL, *trans*-astringin and *trans*-piceatannol inhibited development of DMBA-induced preneoplastic lesions in mouse mammary glands with 68.8% and 76.9% inhibition, respectively, compared with untreated glands. *Trans*-piceatannol was the most potent of the 12 compounds (stilbenoids: *trans*-astringin, *trans*-piceid, *trans*-resveratrol, *trans*-resveratrol, *trans*-piceatannol, *cis*-resveratrol, *cis*-piceid, and *cis*-resveratrol; the flavans (+)-catechin,

(-)-epicatechin, and epicatechin 3-O-gallate; and the flavan dimer procyanidin B2 3'-O-gallate) tested in this assay, with the exception of *trans*-resveratrol (87.5% inhibition). *Trans*-astringin and its aglycone *trans*-piceatannol were active in the mouse mammary gland organ culture assay but did not exhibit activity in COX-1 and COX-2 assays. In the cyclooxygenase (COX)-1 assay, *trans* isomers of the stilbenoids appeared to be more active than *cis* isomers: *trans*-resveratrol [50% inhibitory concentration (IC_{50}) = 14.9 μ M, 96%] vs. *cis*-resveratrol (IC_{50} = 55.4 μ M). In the COX-2 assay, among the compounds tested, only *trans*- and *cis*-resveratrol exhibited significant inhibitory activity (IC_{50} = 32.2 and 50.2 M, respectively).

Wine antioxidant polyphenols (catechin, epicatechin, quercetin, and resveratrol) were found inhibit the proliferation of human prostate cancer cell lines in a dose- and time-dependent at nanomolar concentrations (Kampa et al. 2000). The proliferation of LNCaP and PC3 cells was preferentially inhibited by flavonoids (catechin, epicatechin, and quercetin), whereas resveratrol was the most potent inhibitor of DU145 cell growth. The scientists proposed that the antiproliferative effect of polyphenols was mediated through the modulation of NO production. Studies by Damianaki et al. (2000) showed that grape polyphenols, catechin, epicatechin, quercetin, and resveratrol, which account for more than 70% of the total polyphenols in red wine, decreased cell proliferation of hormone sensitive (MCF7, T47D) and resistant (MDA-MB-231) breast cancer cell lines in a dose- and a time-dependant manner at the picomolar or the nanomolar range.

Stagos et al. (2005) found that whole grape extracts acted as chemopreventive agents by inhibiting topoiosomerase I and mitomycin C-induced DNA damage while polyphenol enriched fractions and grape polyphenolics (caffeic acid, ferulic acid, gallic acid, protocatechuic acid and rutin) exerted prooxidant activity leading to enhancement of DNA damage which may account for the cytotoxic and apoptosis-inducing properties of plant polyphenols against cancer cells. In-vitro studies demonstrated that GSPE could suppress repeated exposures to low doses of combined environmental carcinogens, 4-(methylnitrosamino)-

1-(3-pyridyl)-1-butanone (NNK) and benzo[a]pyrene-induced precancerous cellular carcinogenesis in human breast epithelial MCF10A cells (Song et al. 2010). It was identified that hydroxysteroid-11- β -dehydrogenase 2 (HSD11B2) may play a role in NNK- and B[a]P-induced precancerous cellular carcinogenesis, and its expression may act as a molecular target endpoint in GSPE's suppression of precancerous cellular carcinogenesis. Further, the ability of GSPE to reduce gene expression of cytochrome-P450 enzymes CYP1A1 and CYP1B1, which could bioactivate NNK and B[a]P, may have contributed to the preventive mechanism for GSPE in suppression of precancerous cellular carcinogenesis.

The majority of grape constituents comprising two triterpenoid acids, oleanolic (1) and betulinic acids (5); daucosterol (7); a stilbenoid, E-resveratrol (3) and its dimer E-epsilon-viniferin (4); the simple phenol gallic acid (8); the flavanols catechin (9) and galocatechin (10) and four 6'-O-acyldaucosterols (2a-d) and five 1,2-di-O-acyl-3-O- β -D-galactopyranosyl glycerols (6a-e) showed growth-inhibitory activity on MCF-7 human breast cancer cells, 5 being the most active (GI_{50} = 0.57 μ M) (Amico et al. 2009). Compounds 3–5 were also tested on colon cancer HT-29, human glioblastoma U87-MG and human glioma U373-MG cell lines.

Studies by Bomser et al. (1999) demonstrated that pretreatment of mouse skin with 5, 10, 20 and 30 mg of a polyphenolic fraction from grape seeds (GSP) resulted in a dose-dependent reduction in TPA-induced epidermal ornithine decarboxylase (ODC) activity of 27, 37, 48 and 70%, respectively, compared to controls. In addition, pretreatment of mouse skin with 1, 5, 10 and 20 mg of GSP resulted in a significant 43, 39, 54 and 73% inhibition of myeloperoxidase activity, respectively, compared to controls. In DMBA-initiated CD-1 mice, biweekly treatment of mouse skin with 5, 10, and 20 mg of GSP 20 min prior to TPA application resulted in a 30, 40, and 60% inhibition of final skin tumour incidence, respectively, compared to controls. In addition, the final number of tumours per mouse in the 5, 10 and 20 mg GSP-treated animals was decreased 63, 51, and 94%, respectively, compared to controls.

These studies indicated GSP to possess anti-tumour promoting activity when applied to CD-1 mouse skin prior to treatment with TPA and its potential as skin cancer chemopreventative agent. In a subsequent paper they (Bomser et al. 2000) showed that application of grape polyphenolics fraction (20 mg) at 60 and 30 min prior to treatment with TPA inhibited ornithine decarboxylase (ODC) activity by 62 and 68%, respectively, compared with controls. When applied to mouse skin prior to TPA, grape polyphenolics fraction elicited a decrease in subsequent protein kinase C (PKC) activity. The grape polyphenolics-associated decrease in PKC activity preceded the decrease in ODC activity. In addition, grape polyphenolics fraction was found to be a competitive inhibitor of ODC activity in-vitro. The data again suggested grape polyphenolics fraction to have potential as a skin cancer chemopreventative agent that interfered with cellular events associated with TPA promotion. Filip et al. (2011) reported that topical treatment of mice skin with red grape seed extract (*Vitis vinifera* Burgund Mare variety) prior to UVB-irradiation significantly decreased GSH (reduced glutathione) formation and glutathione peroxidase activity and inhibited UVB-induced lipid peroxidation and nitric oxide production. Additionally, the extract significantly reduced caspase 3 activity, indicating that the cells were protected against apoptosis. The results suggested that grape seed extract might be chemopreventive candidates for reducing UV-induced risk for skin cancer.

In another study, following tumour initiation with DMBA topical application of grape seed polyphenol fraction (GSP) at doses of 0.5 and 1.5 mg/mouse/application to the dorsal initiated mouse skin resulted in a highly significant inhibition of TPA tumour promotion (Zhao et al. 1999). The observed anti-tumour-promoting effects of GSP were dose dependent and were evident in terms of a reduction in tumour incidence (35 and 60% inhibition), tumour multiplicity (61 and 83% inhibition) and tumour volume (67 and 87% inhibition). Nine individual polyphenols in the fraction were identified as catechin, epicatechin, procyanidins B1-B5 and C1 and procyanidin B5-3'-gallate, catechin, procyanidin B2, procya-

nidin B5, procyanidin C1 and procyanidin B5-3'-gallate significantly inhibited epidermal lipid peroxidation, albeit to different levels. Procyanidin B5-3'-gallate showed the most potent antioxidant activity with an IC_{50} of 20 μ M in an epidermal lipid peroxidation assay. The results showed grape seed polyphenols to possess high anti-tumour-promoting activity due to the strong antioxidant effect of procyanidins.

Commercially prepared grape anthocyanin-rich extract was found to inhibit the growth of colon-cancer-derived HT-29 cells but not the growth of nontumorigenic NCM460 colon cells (Zhao et al. 2004). Grape anthocyanins were found to be the glucosylated derivatives of five different anthocyanidin molecules, with or without *p*-coumaric acid acylation. Black raspberry, cranberry, and chardonnay grape seed flour extracts were found to significantly inhibit HT-29 colon cancer cell proliferation (Parry et al. 2006). Lizaraga et al. (2007) found that the most efficient procyanidin-rich fractions in inhibiting cell proliferation of HT29 human colon cancer cells, arresting the cell cycle in G(2) phase and inducing apoptosis were the grape fractions with the highest percentage of galloylation and mean degree of polymerization. Furthermore, the anti-proliferative effects of grape fractions were consistent with their oxygen radical-scavenging capacity and their ability to trigger DNA condensation-fragmentation. Studies by Kaliora et al. (2008) showed that methanol extracts of dried raisin and currant grape products from different Greek regions, rich in phenolic compounds, exhibited cancer preventive efficacy by limiting cell proliferation, inducing cell death, and suppressing ICAM-1 levels in human gastric cancer AGS cells. Recent studies by Wang et al. (2011) showed that GSPE administered intragastrically to mice inhibited the TNBS (2,4,6-trinitrobenzene sulfonic acid)-induced inflammatory of recurrent colitis by modifying the inflammatory response and promoting damaged tissue repair to improve colonic oxidative stress through blocking NF- κ B signaling pathways.

Dietary supplementation with grape seed proanthocyanidins was found to be associated with a decrease of UVB-induced skin tumour

development in terms of tumour incidence, tumour multiplicity, and a reduction in the malignant transformation of papillomas to carcinomas in SKH-1 hairless mice (Katiyar 2008). It was suggested that its chemopreventive effects were mediated through the attenuation of UV-induced: (i) oxidative stress; (ii) activation of mitogen-activated protein kinases and nuclear factor-kappa B (NF-kappaB) signalling pathways; and (iii) immunosuppression through alterations in immunoregulatory cytokines.

Cold-pressed chardonnay, muscadine, ruby red, and concord grape seed oils and their defatted flours were characterised and their anti-oxidative and antiproliferative activities were investigated by Lutterodt et al. (2011). The most abundant fatty acid in the oils was linoleic acid, ranging from 66.0 g/100 g of total fatty acids in ruby red seed oil to 75.3 g/100 g of total fatty acids in concord seed oil. The oils were also high in oleic acid and low in saturated fat. Ruby red grape seed oil recorded the highest oxidative stability index of 40 h under the accelerated conditions. Total phenolic content (TPC) was up to 100 times lower in the oils than in the flours. DPPH radical-scavenging capacity ranged from 0.07 to 2.22 mmol trolox equivalents (TE)/g of oil and 11.8–15.0 mmol TE/g of flour. Oxidative stability of menhaden fish oil containing extracts of the seed flours was extended by up to 137%. All of the seed flours and muscadine seed oil exhibited significant antiproliferative activity against HT-29 colon cancer cells.

Grape juice was found to have antidotal effect against hepatorenal carcinogenesis caused by the mycotoxin, ochratoxin A (Jeswal 1998). Concurrent administration of grape berry and leaf juice to mice together with ochratoxin A significantly reduced the hepatic and renal damage caused by ingestion of this mycotoxin. None of the animals receiving grape berry/leaf juice showed the formation of hepatorenal carcinoma whereas 25% of animals receiving only ochratoxin A developed well differentiated renal carcinoma and hepatic lesions.

A double-blind placebo-controlled randomised phase II trial failed to show efficacy of orally-administered GSPE in patients with breast

induration following radiotherapy for breast cancer (Brooker et al. 2006). At 12 months post-randomisation, about 50% reduction in surface area of breast induration was recorded in 13/44 (29.5%) GSPE and 6/22 (27%) placebo group patients (NS). At 12 months post-randomisation, there was no significant difference between treatment and control groups in terms of external assessments of tissue hardness, breast appearance or patient self-assessments of breast hardness, pain or tenderness.

Antimutagenic Activities

Anter et al. (2011) found red table grapes (skin, pulp and seeds) to be potent anti-mutagens that protected DNA from oxidative damage as well as being cytotoxic toward the HL60 human leukemia tumour cell line. The skin, pulp and seeds were found not to be genotoxic in the *Drosophila melanogaster* somatic mutation and recombination test. In the antigenotoxicity assays, all three fruit parts exhibited a desmutagenic effect, with seeds and skin showing the most potent effect. In the cytotoxicity test, only skin and pulp fractions were able to inhibit the tumour growth, with skin having the lowest IC₅₀ (1.8 mg/mL versus 8 mg/mL of pulp).

Antihypercholesterolemic Activity

In a randomized, double-blind, placebo-controlled study of 40 hypercholesterolemic subjects, a combination of chromium polynicotinate and GSPE significantly decrease total cholesterol and LDL levels compared to the placebo (Preuss et al. 2000). Further, there was a trend to decrease the circulating autoantibodies to oxidized LDL in the two groups receiving GSPE. Concentration-dependent efficacy of GSPE was also assessed in a hamster atherosclerosis model where animals were fed a hypercholesterolemic diet of 0.2% cholesterol and 10% coconut oil (Vinson et al. 2002). Approximately 49 and 63% reduction in foam cells, a biomarker of early stage atherosclerosis, were observed following supplementation

of 50 and 100 mg GSPE/kg body weight, respectively. Vitisin A and vitisin B isolated from grape bark showed appreciable inhibitory activity against 3-hydroxy-3-methylglutaryl-Coenzyme A (HMG-CoA) reductase with IC_{50} value of 42.1 μ M and 23.9 μ M, respectively (Koo et al. 2008).

Red wines from grape cvs. Cabernet Franc, Merlot, Sangiovese, and Syrah, 2006 and 2007 vintages, from the São Joaquim region, southern Brazil, were found to have stilbene monomers, *cis*-resveratrol, *trans*-resveratrol, *cis*-piceid, *trans*-piceid, with appreciable levels of resveratrols (the predominant forms were glycoside and trans) and tyrosol (Gris et al. 2011). Biomonitoring of antioxidant and hypolipidemic activities in vivo revealed that consumption of these wines increased the antioxidant capacity and reduced the hypercholesterolemia and hypertriglyceridemia promoted by the hypercholesterolemic diet. Significant correlations were found between the increase of antioxidant capacity markers, the decrease of lipid levels promoted by wine consumption, and the contents of stilbenes and tyrosol, confirming the important biological activity of these compounds.

Antiobesity Activity

Grape seed extract rich in bioactive compounds inhibited activity of fat-metabolizing enzymes pancreatic lipase and lipoprotein lipase, thus suggesting that the extract might be useful as a treatment to suppress dietary fat absorption and the accumulation of fat in adipose tissue (Moreno et al. 2003). The observed reduction in intracellular lipolytic activity of cultured 3 T3-L1 adipocytes may reduce the levels of circulating free fatty acids linked to insulin resistance in obese patients. The results suggested that the extract may provide a safe, natural, and cost-effective weight control treatment. Findings from animal (mice) studies suggested that grape seed extract supplements in high fat diet might normalize body weight, epididymal and back fat weights, lipid concentrations, and carnitine levels through controlling lipid metabolism (Park et al. 2008). Grape seed extract supplementation increased mRNA levels

of lipolytic genes such as carnitine palmitoyltransferase-1 (CPT-1) and decreased mRNA levels of lipogenic genes such as acetyl CoA carboxylase (ACC).

Wound Healing Activity

Pretreatment of HaCaT keratinocytes with GSPE upregulated both hydrogen peroxide as well as TNF- α -induced vascular endothelial growth factor (VEGF) expression and release (Khanna et al. 2001). VEGF is believed to be the most prevalent, efficacious, and long-term signal that is known to stimulate angiogenesis in wounds. The results suggested that GSPE may have beneficial therapeutic effects in promoting dermal wound healing and other related skin disorders. In a further study, topical application of GSPE was found to accelerate wound contraction and closure (Khanna et al. 2002). GSPE treatment was associated with a more well-defined hyperproliferative epithelial region, higher cell density, enhanced deposition of connective tissue, and improved histological architecture. GSPE treatment also increased VEGF and tenascin expression in the wound edge tissue. Tissue glutathione oxidation and 4-hydroxynonenal immunostaining results supported that GSPE application enhanced the oxidizing environment at the wound site. The study provided firm evidence to support that topical application of GSPE represented a feasible and productive approach to support dermal wound healing.

Hemmati et al. (2011) reported that rabbits with skin excision wounds treated with 2% Grape seed extract cream in eucerin base applied twice daily gave the best results as evidenced by completed wound healing in 13 days, higher hydroxyproline content and higher tissue resistance. Animals treated with cranberry (*Vaccinium macrocarpon*) oil exhibited a (88.1%) reduction in the wound area compared with grape-oil treated (84.6%), controls (74.1%) and standard group animals (78.4%) on day 13 (Shivananda Nayak et al. 2011). The hydroxyproline content of the granulation tissue was significantly higher in the animals treated with cranberry and the grape-oil.

Anti-enzyme Activity

Procyanidins (polyphenol oligomers) from *Vitis vinifera* seeds were found to have anti-enzyme activities (Facino et al. 1994). It inhibited strongly and non-competitively, xanthine oxidase activity, the enzyme which triggers the oxy radical cascade ($IC_{50}=2.4\text{ }\mu\text{mol/l}$). In addition procyanidins inhibited non-competitively the activities of the proteolytic enzymes collagenase ($IC_{50}=38\text{ }\mu\text{mol/l}$) and elastase ($IC_{50}=4.24\text{ }\mu\text{mol/l}$) and of the glycosidases hyaluronidase and β -glucuronidase ($IC_{50}=80\text{ }\mu\text{mol/l}$ and $1.1\text{ }\mu\text{mol/l}$), involved in the turnover of the main structural components of the extracellular matrix collagen, elastin and hyaluronic acid. In another study, grape seed procyanidins, strongly inhibited superoxide generation with an IC_{50} of $7.2\text{ }\mu\text{M}$, through a direct scavenging of superoxide and prevented the respiratory release from calcium ionophore activated neutrophils of β -glucuronidase ($IC_{50}=13.9\text{ }\mu\text{M}$), myeloperoxidase ($IC_{50}=7.2\text{ }\mu\text{M}$) and elastase ($IC_{50}=5.4\text{ }\mu\text{M}$) (Carini et al. 2001). Further they dose-dependently inhibited the activity of myeloperoxidase released from calcium ionophore-stimulated cells with an IC_{50} value of $2\text{ }\mu\text{M}$. The results indicated that procyanidins efficiently restrained the inflammatory response of activated neutrophils in-vitro and whenever absorbed in-vivo could prevent their oxidative discharge at the site(s) of their adhesion.

Amelioration of Bone Debility

Studies with Wistar rats suggested that inclusion of GSPE in a diet mixture with calcium had a beneficial effect on bone formation and bone strength for the treatment of bone debility caused by a low level of calcium (Yahara et al. 2005). Data from a 6-week experimental period showed that tibial cortical parameters were increased by GSPE treatment, suggesting a potential therapeutic application of this compound for treatment of bone debility. The effects were greater toward periosteal perimeters than cortical bone thickness. Further, bone mass increases seemed to have had

a positive impact on diaphyseal stiffness and also strength. However, no conclusive statement could be established on any interaction of GSPE with calcium replacement in the diet.

Antiinflammatory Activity

Studies in murine peritoneal macrophages showed that *cis*-resveratrol at micromolar concentrations significantly attenuated several components of the macrophage response to proinflammatory stimuli (notably, production of superoxide radicals and of the proinflammatory mediators nitric oxide⁻ and prostaglandin E(2) (Leiro et al. 2004).

Studies showed that intraperitoneal injection of GSPE attenuated collagen-induced arthritis in mice in a dose-dependent manner and reduced the histology scores for synovial inflammation, cartilage erosion, bone erosion, and the number of TRAP+ osteoclasts (Cho et al. 2009). GSPE treatment significantly reduced the numbers of tumour necrosis factor alpha (TNF- α)- or interleukin 17 (IL-17)-producing cells in the synovial tissue and the spontaneous production of TNF- α and IL-17 by splenocytes compared with those in the control mice. The serum levels of type-II-collagen-specific IgG2a and plasma levels of 8-isoprostane in the GSPE-treated mice were significantly lower than those in the control mice. GSPE also dose-dependently suppressed osteoclastogenesis in-vitro. GSPE significantly reduced hydrogen peroxide production by anti-CD3-monoclonal-antibody-stimulated CD4+ splenocytes. The findings suggested that GSPE may be useful in the treatment of rheumatoid arthritis.

Further in-vitro studies in mouse and human CD4+ T cells suggested that GSPE possessed a reciprocal control over interleukin IL-17 and Foxp3 expression. The presence of GSPE decreased the levels of IL-21, IL-22, IL-26 and IL-17 production by human CD4+ T cells in a STAT3-dependent manner. In contrast, GSPE induced Foxp3+ Treg cells in humans (Park et al. 2011). By potentially regulating inflammatory T cell differentiation, GSPE may serve as a possible

novel therapeutic agent for inflammatory and autoimmune diseases, including rheumatoid arthritis.

In-vitro studies showed that GSPE at low concentrations (1–5 µg/mL), down-regulated TNF α -induced VCAM-1 expression but not ICAM-1 expression in primary human umbilical vein endothelial cells (HUVEC) (Sen and Bagchi 2001). The potent inhibitory effect of low concentrations of GSPE on agonist-induced VCAM-1 expression suggested therapeutic potential of this extract in inflammatory conditions and other pathologies involving altered expression of VCAM-1. In-vitro studies showed that pre-incubation of human umbilical vein endothelial cells (HUVEC) with GSPE significantly inhibited the expression of vascular cell adhesion molecule-1 (VCAM-1) cell inflammatory factor induced by advanced glycation end products (AGEs) (Ma et al. 2007). GSPE also protected the function of endothelial cell through activation of peroxisome proliferators-activated receptor gamma (PPAR gamma) expression and inhibition of receptor for AGEs (RAGE) expression.

Vitisin A, a resveratrol tetramer isolated from grape roots, exhibited antioxidative, anticancer, antiapoptotic, and anti-inflammatory effects and also inhibited nitric oxide (NO) production (Sung et al. 2009). Vitisin A dose dependently inhibited lipopolysaccharide (LPS)-induced NO production and inducible NO synthase (iNOS) expression via downregulation of ERK1/2 and p38 and the NF-kappaB signal pathway in RAW 264.7 cells.

Immunomodulatory Activity

Kaneko et al. (2010) demonstrated that fermented grape marc from *V. vinifera* cv. Negroamaro markedly suppressed the antigen-induced degranulation and phosphorylation of Syk in rat basophilic leukemia RBL-2 H3 cells did not reduce the expression of Fc ϵ RI on RBL-2 H3 cells. The fermented marc was found to contain high amounts of quercetin. Quercetin also suppressed the antigen-induced degranulation and phosphorylation of Syk but did not

reduce the expression of Fc ϵ RI on RBL-2 H3 cells. The results suggest that inhibition of antigen-induced degranulation and Syk phosphorylation by fermented grape marc might be due to the action of quercetin, as an active component.

Antidiabetic Activity

In-vitro studies demonstrated that GSPE could inhibit the enhanced VCAM-1 expression but not ICAM-1 in advanced glycation end products (AGE)-exposed human umbilical vein endothelial cells (HUVECs) by suppressing ROS generation (Zhang et al. 2006, 2007). GSPE inhibited enhanced cell-surface receptor for AGEs (RAGE) expression in advanced glycation end products (AGE)-exposed endothelial cells by suppressing ROS generation, thereby limiting the AGE-RAGE interaction. Hence, GSPE may have therapeutic potential in the prevention and treatment of vascular complications in patients with diabetes. Soares de Moura et al. (2012) found that grape skin extract exerted hypoglycaemic and antihyperglycaemic effects that were independent of an increase in insulin release but were probably dependent on an increase in insulin sensitivity resulting from an activation of the insulin-signalling cascade in skeletal muscle. Glycemia values in the alloxan-induced mice treated with the extract or in non-alloxan mice treated with extract were significantly lower than in the alloxan-treated and control groups. Insulin receptor content and Akt phosphorylation were significantly greater in the alloxan plus extract group compared with the alloxan-treated group. Grape seed extract treated mice showed a significant increase in glucose transporter (GLUT-4) content.

The ethyl acetate grape leaf fraction was found to be rich in polyphenolics and to exhibit significant antihyperglycemic and antioxidant activities equipotent with the reference hypoglycaemic agent (tolbutamide), when evaluated in streptozotocin-induced diabetic rats (Orhan et al. 2006).

Gastroprotective Activity

Grape seed proanthocyanidin extract was found to have a protective effect against ischaemia/reperfusion injury in a rat epigastric flap model (Karaaslan et al. 2010). Mean flap survival areas in the control group (non-purified rat diet) and extract treated group were calculated to be 58.3% and 81.0% respectively. Histopathological semi-quantitative analysis of the specimens revealed infiltration by polymorphonuclear leucocytes, oedema formation and necrosis in the control, whereas neo-vascularisation and fibrosis were the prominent findings in the extract treated group.

Neuroprotective Activity

Balu et al. (2005b) demonstrated that supplementation of aged rats with grape seed extract increased memory performance, reduced reactive oxygen species production, decreased protein carbonyl levels and improved thiol levels. Their findings showed that grape seed extract enhanced the antioxidant status and decreased the incidence of free radical induced protein oxidation in aged rats thereby protecting the central nervous system from the reactive oxygen species. The grape seed also decreased the incidence of free radical-induced lipid peroxidation in the central nervous system of aged rats (Balu et al. 2005b). Grape seed extract also had an inhibitory effect on the accumulation of age-related oxidative DNA damages in spinal cord and in various brain regions such as cerebral cortex, striatum and hippocampus (Balu et al. 2006).

Stilbenes isolated from grapes were found to have anti-amyloidogenic activity (Zga et al. 2009). E-resveratrol and (+)-ampelopsin A were found to be the most active compounds with 63 and 46% inhibition at 10 μ M, respectively. Their findings suggested that E-resveratrol and (+)-ampelopsin A may have potential as new candidates for protecting against brain cell dysfunction in-vivo in Alzheimer's disease by inhibiting the aggregation of A β .

Narita et al. (2011) found that the grape seed extract of a Koshu, a white, local variety alleviated the acute inactivation of Erk1/2 and dendrite retraction in cultured hippocampal neurons exposed to a toxic concentration of glutamate (1.0 ng/mL). In contrast, the grape seed extract of Muscat Bailey A, a red, hybrid variety exhibited no neuroprotective effect. Glutamate excitotoxicity is one of the major events that occurs during various neurotoxic injuries such as brain ischemia. They found that Koshu had higher amounts of low molecular weight polyphenols along with several Koshu-specific procyanidin oligomers. Their data suggested the presence of high affinity molecular targets for polyphenols in hippocampal neurons, which induced neuroprotective effects different from BDNF (Brain Derived Neurotrophic Factor) and the importance of low molecular weight polyphenols and/or procyanidin oligomers for neuroprotection.

Hepatoprotective Activity

Dulundu et al. (2007) found that grape seed extract (GSE) exhibited protective effect against oxidative liver injury and fibrosis induced by biliary obstruction in rats. Elevated serum aspartate aminotransferase, alanine aminotransferase, lactate dehydrogenase and plasma tumour necrosis factor- α induced by bile duct ligation were significantly reduced with GSE treatment. Bile duct ligation increases in tissue malondialdehyde level and myeloperoxidase activity were also attenuated by GSE treatment. The data suggested that the hepatoprotective effect may involve the inhibition of neutrophil infiltration and lipid peroxidation leading to restoration of oxidant and antioxidant status in the tissues.

Oral intake of grape seeds extract (GSE), black seed (*Nigella sativa*) extract (NSE), curcumin (CUR) or silymarin (SYL) to tamoxifen-intoxicated rats, attenuated histopathological changes and corrected all parameters namely declines in liver antioxidant enzymes levels (glutathione peroxidase, glutathione reductase, superoxide dismutase and catalase), reduced glutathione (GSH) and GSH/

GSSG ratio plus the hepatic elevations in lipid peroxides, oxidized glutathione (GSSG), tumour necrosis factor- α (TNF- α) and serum liver enzymes: alanine transaminase, aspartate transaminase, alkaline phosphatase, lactate dehydrogenase and gamma glutamyl transferase levels (El-Beshbishy et al. 2010). Improvements were prominent in case of NSE ($\equiv$ SYL) > CUR > GSE. Data indicated that NSE, GSE or CUR acted as free radicals scavengers and protected tamoxifen-induced liver injury in rats.

Diet supplementation of rats with grape skin or seeds (10% daily for 4 weeks) prevented elevations of serum alanine transaminase, aspartate transaminase, alkaline phosphatase, and bilirubin induced by dimethylnitrosamine (DMN) (Shin and Moon 2010). The grape skin and seeds also restored serum albumin and total protein levels, and reduced the hepatic level of hydroxyproline and malondialdehyde. Additionally, grape skin and seeds reduced DMN-induced collagen accumulation. Grape skin and seeds also reduced hepatic stellate cell activation. The authors concluded that grape skin and seeds exhibited in-vivo hepatoprotective and antifibrogenic effects against DMN-induced liver injury, suggesting that grape skin and seeds may be useful in preventing the development of hepatic fibrosis. Grape seed feed supplementation decreased the ethanol-induced elevated levels of liver damage serum marker enzymes, aspartate aminotransferase, alanine aminotransferase, γ -glutamyl transpeptidase and lactate dehydrogenase, antioxidant defence system such as GSH, glutathione reductase, superoxide dismutase, glutathione S-transferase and glutathione peroxidase and malondialdehyde (MDA) content in various tissues of the rats (Dogan and Celik 2012). Administration of grape seed-supplemented food restored the ethanol-induced MDA, which was increased near the control level. The results indicated that grape seeds could be as important as diet-derived antioxidants in preventing oxidative damage in the tissues by reducing the lipid oxidation or inhibiting the production of ethanol-induced free radicals in rats.

In a 3 month study involving 50 patients with nonalcoholic fatty liver disease, grape seed extract (GSE) significantly improved the grade of

fatty liver change; and resulted in significant decrease in alanine aminotransferase in patients receiving the concentrate compared to those receiving vitamin C independently, from the initial grade of steatosis (Khoshbaten et al. 2010).

Antithrombotic/Anticoagulant Activity

In-vitro studies showed that grape seed extract prolonged clotting time and decreased the maximal velocity of fibrin polymerization in human plasma (Bijak et al. 2011). Further, thrombin incubation with the extract resulted in the inhibition of amidolytic activity of this enzyme.. In-vitro studies showed that grape seed extract inhibited proteolytic activity of thrombin observed as inhibition of thrombin-induced fibrinogen polymerization, stabilized fibrin formation, and platelet aggregation. (Bijak et al. 2012). Further, thrombin amidolytic activity was inhibited by polyphenols belonging to the flavonoid class. The results suggested its potential in diet supplements which may be used to prevent thrombosis in pathological states.

Grape seed proanthocyanidins extract significantly inhibited the propagation of thrombus induced by inferior vena cava ligation in a rat model (Zhang et al. 2011). The antithrombotic properties of proanthocyanidins were found to be directly associated with endothelial protection and regeneration, platelet aggregation, and inhibition of inflammatory cell and thrombus adhesion. The extract significantly lowered the cytokines interleukin-6 and tumour necrosis factor- α . The results indicated that proanthocyanidins may have a clinical application in deep vein thrombosis treatment.

Antiatherosclerotic Activity

In the apo E deficient (E(0)) mice, red wine consumption for two months resulted in a 40% decrement in basal LDL oxidation, a similar decrement in LDL oxidizability and aggregation, a 35% reduction in lesion size, and a marked attenuation in the number and morphology of lesion's macrophage foam cells (Aviram and

Fuhrman 2002). Red wine consumption acted against the accumulation of oxidized LDL in lesions in mouse macrophages as a first line of defense (by a direct inhibition of LDL oxidation), and as a second line of defense (by paraoxonase elevation and removal of atherogenic lesion's and lipoprotein's oxidized lipids).

Anti-fibrosis Activity

Studies showed that silica induced pulmonary fibrosis in male Wistar rats as evidenced by a significant increase in hydroxyproline content of lungs and malondialdehyde levels in the plasma but not in silica instilled rats treated with grape seed extract (Hemmati et al. 2008). The results suggested that grape seed extract could reduce the fibrogenic effect of silica, however; no synergistic effect was observed after co-administration of the extract and Vitamin E.

Anticataract Activity

Studies demonstrated that oral administration of IH636 grape seed proanthocyanidin extract effectively suppressed cataract formation induced by sodium selenite injection in Sprague-Dawley rats (Durukan et al. 2006). Glutathione (GSH) level in the removed rat lenses were significantly lower in rats treated with GSPE while malondialdehyde level was significantly higher compared to control rats. The results suggested that routine consumption of grape seed proanthocyanidin extract in the form of food or dietary supplement may offer a prophylactic measure against onset and progression of cataract.

Adaptogenic/Nootropic Activities

Studies by Sreemantula et al. (2005) found that grape seed extract had antistress (adaptogenic), antioxidant and nootropic activities. Daily administration of the extract at doses of 100, 200 and 300 mg/kg body weight one hour prior to induction of stress inhibited the stress induced

urinary biochemical changes in a dose dependent manner. nootropic activity as determined by the acquisition, retention and recovery in rats was observed to be dose dependent. The extract also produced significant inhibition of hydroxyl radicals in comparison to ascorbic acid in a dose dependent manner. The results substantiated the traditional usage of grape fruits and seeds in stress induced disorders.

Antimicrobial Activity

Jayaprakasha et al. (2003) found that acetone: water:acetic acid (90:9.5:0.5) extract of defatted grape seed powder was a better radical scavenger than methanol:water:acetic acid (90:9.5:0.5) extract. Monomeric procyanidin was found to be the major compound being at 48 and 40% in acetone:water:acetic acid (90:9.5:0.5) and methanol:water:acetic acid (90:9.5:0.5) extracts, respectively. Gram-positive bacteria (*Bacillus cereus*, *Bacillus coagulans*, *Bacillus subtilis*, *Staphylococcus aureus*) were completely inhibited at 850–1,000 ppm, while Gram-negative bacteria (*Escherichia coli*, *Pseudomonas aeruginosa*) were inhibited at 1,250–1,500 ppm concentration. Grape seed extract at 20% concentration inhibited all the bacteria *Aeromonas hydrophila*, *Bacillus brevis*, *Bacillus cereus*, *Bacillus megaterium*, *Bacillus subtilis*, *Enterobacter aerogenes*, *Enterococcus faecalis*, *Escherichia coli*, *Klebsiella pneumoniae*, *Listeria monocytogenes*, *Mycobacterium smegmatis*, *Proteus vulgaris*, *Pseudomonas aeruginosa* and *Staphylococcus aureus* except *Bacillus amyloliquefaciens* (Baydar et al. 2004). The acetone:water:acetic acid (90:9.5:0.5) extract was found to be more effective than the ethyl acetate:methanol:water extract, which at 4% concentration were inactive against *A. hydrophila*, *B. amyloliquefaciens*, *B. megaterium* and *B. subtilis*, while the acetone:water:acetic acid (90:9.5:0.5) extract at 4% was effective against most of the test bacteria. The grape bagasse extracts and methanol (control) had no inhibitory effects on the fifteen bacteria tested. The grape seed extracts at 1% and 2% concentrations were also ineffective. In another study, grape seed

proanthocyanidin extract treatment of macrophages (RAW 264.7) strongly decreased NO and ROS production and iNOS expression stimulated by lipopolysaccharides (LPS) of periodontopathogens, *Actinobacillus actinomycetemcomitans* or *Fusobacterium nucleatum* (Houde et al. 2006). The findings demonstrated that proanthocyanidins had potent antioxidant properties and should be considered a potential agent in the prevention of periodontal diseases.

The seed and stem extracts of the red grapes variety Mandilaria exhibited potent antilisterial activities in-vitro against *Listeria monocytogenes* (Anastasiadi et al. 2009). Their minimum inhibitory concentrations (MICs) were 0.26 and 0.34 for seeds and stems. Grape seed extract exhibited a bacteriostatic effect on two oral anaerobes closely associated with periodontal diseases (Furiga et al. 2009). At a concentration of 2,000 µg/mL, it significantly decreased the formation of biofilm. The extract also registered high TEAC values and exhibited greater antioxidant capacity than vitamins C and E. All methicillin-resistant *Staphylococcus aureus* (MRSA) strains were found to be sensitive to grape seed extract (Al-Habib et al. 2010). Complete inhibition of all bacterial strains tested was observed at a concentration of 3 mg/mL crude grape seed proanthocyanidins extract (GPSE), equivalent of 20.7 µg/mL flavonoid content. Antibacterial activity was bactericidal as shown by a disruption of the bacterial cell wall in scanning and transmission electron microscopy.

Badet (2011) found that the acetone: acetic acid extract and methanol:water:acetic acid extract of grape seeds exhibited higher antibacterial activity against Gram-positive bacteria than Gram-negative bacteria. The acetone:water: acetic acid extract appeared to be more active than the ethyl acetate : methanol:water extract. Strong antibacterial effects were obtained against *Escherichia coli*, *Staphylococcus aureus* (methicillin-resistant *Staphylococcus aureus*), the oral bacteria(*Streptococcus mutans*, *Porphyromonas gingivalis*, and *Fusobacterium nucleatum*), and *Helicobacter pylori*. High antibacterial activity was found with a fraction that contains oligomeric units of catechins and epicatechins.

Antiviral Activity

A new resveratrol dimer, (+)-vitisinol E and four known resveratrol oligomers, (+)-epsilon-viniferin, (+)-ampelopsin A, (+)-vitisin A and (–)-vitisin B from grape stem bark, all demonstrated significant in-vitro inhibition on baculovirus-expressed BACE-1(beta-site APP-cleaving enzyme 1) in a dose-dependent manner (Choi et al. 2009). Berardi et al. (2009) demonstrated that resveratrol exhibited dose-dependent cytotoxic effect on stabilized cell-line (3 T6) as well as a tumour-line (HL60) and antiviral effect on the synthesis of polyomavirus DNA in the infected cell. Their data suggested that cytotoxicity may be attributed to the membrane damage caused by the drug and that the transfer of polyomavirus from the endoplasmic reticulum to the cytoplasm may be hindered. They concluded that the cytotoxic and antiviral properties of resveratrol make it a potential candidate for the clinical control of proliferative as well as viral pathologies.

Skin-Protective Activity

Vitis vinifera shoot extract appeared to have significantly stronger in-vitro antioxidant capacity than vitamin C or vitamin E in cultured normal human keratinocytes (Cornacchione et al. 2007). In the same vehicle (placebo emulsion), ascorbic acid (0.5%), Sarmentine (1%, grape shoot extract in hydroglycolic solution), and the Sarmentine (1%) plus Ronacare Hydroine (1%) combination had a significant in-vivo antioxidant effect versus a nontreated area. The combination Sarmentine (1%) plus Ronacare Hydroine (1%) showed a higher efficacy than Sarmentine alone. The dermatologic evaluation showed that a 4-week twice-daily application of a serum containing the combination improved the main clinical signs of photoaged skin. The addition of the cream with the serum appeared to enhance the serum-induced improvement of most of the skin characteristics.

Neuroprotective Activity

Three months oral supplementation of grape seed proanthocyanidin extract lowered blood glucose, lipid peroxidation, hydrogen peroxide level, and increased protein sulphhydryl (P-SH) content in the hippocampus of female Wistar rats (Devi et al. 2011). Further the extract significantly improved cognitive performance in the young and old age groups. The results demonstrated that the extent of oxidative stress-related lipofuscin accumulation was reducible by the extract and also suggest a potential role for grape seed proanthocyanidin extract as a neuroprotectant in the hippocampus and in preventing cognitive loss with aging.

Radioprotective Activity

The most effective antioxidant activity compounds to scavenge the ABTS(*)+(+) radical cation (TEAC) were, in order: GSE (grape seed extract) > rutin > (+)-catechin > diosmin > ascorbic acid (Castillo et al. 2000). The most effective radioprotective compounds determined by using the micronucleus test for anticlastogenic activity were, in order: GSE > rutin > dimethyl sulfoxide (DMSO) > ascorbic acid > 6-n-propyl-2-thiouracil-6c (PTU) > diosmin. The higher ABTS(*)+(+) scavenging capacity and anticlastogenic activity of GSE was elucidated structurally, by the high number of conjugated structures between the catechol groups in the B-rings and the 3-OH free groups of the polymeric polyphenolic skeleton and, in addition, by the stability of the aroxyl flavonoid radical generated in the above processes.

Clastogenic Activity

Grape extracts were found to have clastogenic effects in human peripheral blood lymphocytes (Stagos et al. 2007). The grape extracts and two of the three polyphenol-rich fractions promoted mitomycin C-induced induced sister chromatid

exchanges at concentrations from 75 to 300 µg/mL. Among the polyphenols tested, caffeic acid, gallic acid, and rutin hydrate enhanced mitomycin C -induced clastogenicity, whereas ferulic acid, protocatechuic acid, (+)-catechin, (–)-epicatechin, and *trans*-resveratrol had no effect at concentrations between 5 and 100 µM.

Toxicity Studies

Meganatural™ brand grape seed extract (GSE) and grape skin extract (GSKE), containing proanthocyanidin polyphenolic compounds were found to be safe when tested in a GLP (good laboratory practice)-compliant subchronic 3-month oral toxicity study in rats (Bentivegna and Whitney 2002). There were no treatment-related changes that were considered to be of toxicologic significance. The dietary concentration of 2.5% GSE or 2.5% GSKE was considered to be a no-observed-adverse effect level (NOAEL).

Traditional Medicinal Uses

Sap of young branches used as remedy for skin diseases. Leaves astringent, used in diarrhea. Juice of unripe fruit astringent, used in throat affections. Dried fruit demulcent, cooling, sweet, laxative, stomachic, used in thirst, heat of body, coughs, hoarseness, consumption and in wasting diseases. A malagma made from the seed is said to be a folk remedy for condylomata of the joints. The fruit, prepared in various manners, is said to remedy mola, uterine tumours, hardness of the liver, tumours, and cancer. The juice, prepared in various manners, is said to remedy tumors of the tonsils, excrescences of the seat, tumors of the fauces, indurations, tumors of the neck, chronic tumors, and hard cancers.

Using the sap of grapevines, European folk healers sought to cure skin and eye diseases. Other historical uses include the leaves being used to stop bleeding, pain and inflammation of hemorrhoids. Unripe grapes were used for treating sore throats, and raisins were given as

treatments for consumption (tuberculosis), constipation and thirst. Ripe grapes were used for the treatment of cancer, cholera, smallpox, nausea, skin and eye infections as well as kidney and liver diseases.

Other Uses

Residue from pressed grapes is used as livestock feed or used to make tannin and cream of tartar. Grape seeds yield a drying that is used for lighting, paints and cooking.

Comments

Important Australian wine grape cultivars grown commercially include:

Red Grapes: Barbera, Cabernet France, Cabernet Sauvignon, Durif, Grenache, Malbec, Mataro, Merlot, Muscat a Petit Grains, Petit Verdot, Pinot Noir, Ruby Cabernet, Sanglovese, Shiraz, Tarrango;

White Grapes: Chardonnay, Chenin Blance, Colombard, Doradillo, Marsanne, Muscadelle, Muscat a Petit Grains Blance, Muscat Gordo Blanco, Palomino, Pedro Ximenes, Pinot Gris, Pinot Grigio, Reisling, Sauvignon, Semillon, Sultana, Traminer, Trebbiano, Verdelho, Viognier.

Selected References

- Ahn HS, Jeon TI, Lee JY, Hwang SG, Lim YH, Park DK (2002) Antioxidative activity of persimmon and grape seed extract: in vitro and in vivo. *Nutr Res* 22(11):1265–1273
- Alam A, Khan N, Sharma S, Saleem M, Sultana S (2002) Chemopreventive effect of *Vitis vinifera* extract on 12-*O*-tetradecanoyl-13-phorbol acetate-induced cutaneous oxidative stress and tumor promotion in murine skin. *Pharmacol Res* 46(6):557–64
- Aldini G, Carini M, Piccoli A, Rossoni G, Facino RM (2003) Procyanidins from grape seeds protect endothelial cells from peroxynitrite damage and enhance endothelium-dependent relaxation in human artery: new evidences for cardio-protection. *Life Sci* 73(22):2883–2898
- Al-Habib A, Al-Saleh E, Safer AM, Afzal M (2010) Bactericidal effect of grape seed extract on methicillin-resistant *Staphylococcus aureus* (MRSA). *J Toxicol Sci* 35(3):357–364
- Amico V, Barresi V, Chillemi R, Condorelli DF, Sciuto S, Spatafora C, Tringali C (2009) Bioassay-guided isolation of antiproliferative compounds from grape (*Vitis vinifera*) stems. *Nat Prod Commun* 4(1):27–34
- Anastasiadi M, Chorianopoulos NG, Nychas G-JE, Haroutounian SA (2009) Antilisterial activities of polyphenol-rich extracts of grapes and vinification byproducts. *J Agric Food Chem* 57(2):457–463
- Anter J, de Abreu-Abreu N, Fernández-Bedmar Z, Villatoro-Pulido M, Alonso-Moraga A, Muñoz-Serrano A (2011) Targets of red grapes: oxidative damage of DNA and leukaemia cells. *Nat Prod Commun* 6(1):59–64
- Arrhenius SP, McCloskey LP, Sylvan M (1996) Chemical markers for aroma of *Vitis vinifera* var. Chardonnay regional wines. *J Agric Food Chem* 44(4):1085–1090
- Aviram M, Fuhrman B (2002) Wine flavonoids protect against LDL oxidation and atherosclerosis. *Ann N Y Acad Sci* 957:146–161
- Badet C (2011) Antibacterial activity of grape (*Vitis vinifera*, *Vitis rotundifolia*) seeds. In: Preedy VR, Watson RR, Patel VB (eds) *Nuts and seeds in health and disease prevention*. Academic, London, pp 545–552
- Bagchi D, Garg A, Krohn RL, Bagchi M, Bagchi DJ, Balmoori J, Stohs SJ (1998) Protective effects of grape seed proanthocyanidins and selected antioxidants against TPA-induced hepatic and brain lipid peroxidation and dna fragmentation, and peritoneal macrophage activation in mice. *Gen Pharmacol* 30(5):771–776
- Bagchi M, Milnes M, Williams C, Balmoori J, Ye X, Stohs S, Bagchi D (1999) Acute and chronic stress-induced oxidative gastrointestinal injury in rats, and the protective ability of a novel grape seed proanthocyanidin extract. *Nutr Res* 19(8):1189–1199
- Bagchi D, Bagchi M, Stohs SJ, Das DK, Ray SD, Kuszynski CA, Joshi SS, Pruess HG (2000) Free radicals and grape seed proanthocyanidin extract: importance in human health and disease prevention. *Toxicology* 148(2–3):187–197
- Bagchi D, Ray SD, Patel D, Bagchi M (2001) Protection against drug- and chemical-induced multiorgan toxicity by a novel IH636 grape seed proanthocyanidin extract. *Drugs Exp Clin Res* 27(1):3–15
- Bagchi D, Bagchi M, Stohs S, Ray SD, Sen CK, Preuss HG (2002a) Cellular protection with proanthocyanidins derived from grape seeds. *Ann N Y Acad Sci* 957:260–270
- Bagchi D, Ray SD, Bagchi M, Preuss HG, Stohs SJ (2002b) Mechanistic pathways of antioxidant cytoprotection by a novel IH636 grape seed proanthocyanidin extract. *Indian J Exp Biol* 40(6):717–726
- Bagchi D, Sen CK, Ray SD, Das DK, Bagchi M, Preuss HG, Vinson JA (2003) Molecular mechanisms of cardioprotection by a novel grape seed proanthocyanidin extract. *Mutat Res* 523–524:87–97
- Balu M, Sangeetha P, Haripriya D, Panneerselvam C (2005a) Rejuvenation of antioxidant system in central

- nervous system of aged rats by grape seed extract. *Neurosci Lett* 383(3):295–300
- Balu M, Sangeetha P, Murali G, Panneerselvam C (2005b) Age-related oxidative protein damages in central nervous system of rats: modulatory role of grape seed extract. *Int J Dev Neurosci* 23(6):501–507
- Balu M, Sangeetha P, Murali G, Panneerselvam C (2006) Modulatory role of grape seed extract on age-related oxidative DNA damage in central nervous system of rats. *Brian Res Bull* 86(6):469–473
- Baydar NG, Özkan G, Sağdıç O (2004) Total phenolic contents and antibacterial activities of grape (*Vitis vinifera* L.) extracts. *Food Control* 15(5):335–339
- Baydar NG, Özkan G, Yaşar S (2007) Evaluation of the antiradical and antioxidant potential of grape extracts. *Food Control* 18(9):1131–1136
- Bentivegna SS, Whitney KM (2002) Subchronic 3-month oral toxicity study of grape seed and grape skin extracts. *Food Chem Toxicol* 40(12):1731–1743
- Berardi V, Ricci F, Castelli M, Galati G, Risuleo G (2009) Resveratrol exhibits a strong cytotoxic activity in cultured cells and has an antiviral action against polyomavirus: potential clinical use. *J Exp Clin Cancer Res* 28:96
- Berti F, Manfredi B, Mantegazza P, Rossoni G (2003) Procyanidins from *Vitis vinifera* seeds display cardioprotection in an experimental model of ischemia-reperfusion damage. *Drugs Exp Clin Res* 29(5–6):207–216
- Bijak M, Bobrowski K, Borowiecka M, Podsekdek A, Golański J, Nowak P (2011) Anticoagulant effect of polyphenols-rich extracts from black chokeberry and grape seeds. *Fitoterapia* 82(6):811–817
- Bijak M, Saluk J, Ponczek MB, Nowak P (2012) Antithrombin effect of polyphenol-rich extracts from black chokeberry and grape seeds. *Phytother Res* doi:10.1002.pt.4682
- Boccalandro HE, González CV, Wunderlin DA, Silva MF (2011) Melatonin levels, determined by LC-ESI-MS/MS, fluctuate during the day/night cycle in *Vitis vinifera* cv Malbec: evidence of its antioxidant role in fruits. *J Pineal Res* 51(2):226–232
- Boido E, Lloret A, Medina K, Fariña L, Carrau F, Versini G, Dellacassa E (2003) Aroma composition of *Vitis vinifera* Cv. tannat: the typical red wine from Uruguay. *J Agric Food Chem* 51(18):5408–5413
- Bomser JA, Singletary KW, Wallig MA, Smith MA (1999) Inhibition of TPA-induced tumor promotion in CD-1 mouse epidermis by a polyphenolic fraction from grape seeds. *Cancer Lett* 135(2):151–157
- Bomser JA, Singletary KW, Meline B (2000) Inhibition of 12-*O*-tetradecanoylphorbol-13-acetate (TPA)-induced mouse skin ornithine decarboxylase and protein kinase C by polyphenolics from grapes. *Chem Biol Interact* 127(1):45–59
- Borde P, Mohan M, Kasture S (2011) Effect of myricetin on deoxycorticosterone acetate (DOCA)-salt-hypertensive rats. *Nat Prod Res* 25(16):1549–1559
- Bordiga M, Travaglia F, Locatelli M, Coisson JD, Arlorio M (2011) Characterisation of polymeric skin and seed proanthocyanidins during ripening in six *Vitis vinifera* L. cv. *Food Chem* 127(1):180–187
- Boutegrabet L, Fekete A, Hertkorn N, Papastamoulis Y, Waffo-Tégou P, Mérellon JM, Jeandet P, Gougeon RD, Schmitt-Kopplin P (2011) Determination of stilbene derivatives in Burgundy red wines by ultra-high-pressure liquid chromatography. *Anal Bioanal Chem* 401(5):1513–1521
- Brooker S, Martin S, Pearson A, Bagchi D, Earl J, Gothard L, Hall E, Porter L, Yarnold J (2006) Double-blind, placebo-controlled, randomised phase II trial of IH636 grape seed proanthocyanidin extract (GSPE) in patients with radiation-induced breast induration. *Radiother Oncol* 79(1):45–51
- Burkill IH (1966) A dictionary of the economic products of the Malay Peninsula. Revised reprint, 2 vols, vol 1 (A–H), 2 (I–Z). Ministry of Agriculture and Co-operatives, Kuala Lumpur, pp 1–1240, pp 1241–2444
- Carini M, Stefani R, Aldini G, Ozioli M, Facino RM (2001) Procyanidins from *Vitis vinifera* seeds inhibit the respiratory burst of activated human neutrophils and lysosomal enzyme release. *Planta Med* 67(8):714–717
- Castillo J, Benavente-García O, Lorente J, Alcaraz M, Redondo A, Ortuño A, Del Río JA (2000) Antioxidant activity and radioprotective effects against chromosomal damage induced in vivo by X-rays of flavan-3-ols (Procyanidins) from grape seeds (*Vitis vinifera*): comparative study versus other phenolic and organic compounds. *J Agric Food Chem* 48(5):1738–1745
- Chedea VS, Braicu C, Socaciu C (2010) Antioxidant/prooxidant activity of a polyphenolic grape seed extract. *Food Chem* 121(1):132–139
- Chen ZD, Ren H, Wen J (2007) Vitaceae. In: Wu ZY, Raven PH, Hong DY (eds) *Flora of China*, vol 12 (Hippocastanaceae through Theaceae). Science Press/Missouri Botanical Garden Press, Beijing/StLouis
- Chidambaram Murthy KN, Singh RP, Jayaprakasha GK (2002) Antioxidant activities of grape (*Vitis vinifera*) pomace extracts. *J Agric Food Chem* 50(21):5909–5914
- Cho ML, Heo YJ, Park MK, Oh HJ, Park JS, Woo YJ, Ju JH, Park SH, Kim HY, Min JK (2009) Grape seed proanthocyanidin extract (GSPE) attenuates collagen-induced arthritis. *Immunol Lett* 124(2):102–110
- Choi YM, Lee JS (2009) Antioxidant and antiproliferative properties of a tocotrienol-rich fraction from grape seeds. *Food Chem* 114(4):1386–1390
- Choi YH, Yoo MY, Choi CW, Cha MR, Yon GH, Kwon DY, Kim YS, Park WK, Ryu SY (2009) A new specific BACE-1 inhibitor from the stem bark extract of *Vitis vinifera*. *Planta Med* 75(5):537–540
- Cornacchione S, Sadick NS, Neveu M, Talbourdet S, Lazou K, Viron C, Renimel I, de Quétel D, Kurfurst R, Schnebert S, Heusèle C, André P, Perrier E (2007) In vivo skin antioxidant effect of a new combination based on a specific *Vitis vinifera* shoot extract and a biotechnological extract. *J Drugs Dermatol* 6(6 Suppl):s8–s13
- Damianaki A, Bakogeorgou E, Kampa M, Notas G, Hatzoglou A, Panagiotou S, Gemetzi C, Kouroumalis E, Martin PM, Castanas E (2000) Potent inhibitory action of red wine polyphenols on human breast cancer cells. *J Cell Biochem* 78(3):429–441

- Das DK, Sato M, Ray PS, Maulik G, Engelman RM, Bertelli AA, Bertelli A (1999) Cardioprotection of red wine: role of polyphenolic antioxidants. *Drugs Exp Clin Res* 25(2–3):115–120
- de Freitas VAP, Glories Y, Guy Bourgeois G, Christiane Vitry C (1998) Characterisation of oligomeric and polymeric procyanidins from grape seeds by liquid secondary ion mass spectrometry. *Phytochemistry* 49(5):1435–1441
- de Torres C, Díaz-Maroto MC, Hermosín-Gutiérrez I, Pérez-Coello MS (2010) Effect of freeze-drying and oven-drying on volatiles and phenolics composition of grape skin. *Anal Chim Acta* 660(1–2):177–182
- Delaunay J-C, Castagnino C, Chèze C, Vercauteren J (2002) Preparative isolation of polyphenolic compounds from *Vitis vinifera* by centrifugal partition chromatography. *J Chromatogr A* 964(1–2):123–128
- Devi SA, Chandrasekar BKS, Manjula KR, Ishii N (2011) Grape seed proanthocyanidin lowers brain oxidative stress in adult and middle-aged rats. *Exp Gerontol* 46(11):958–964
- Dogan A, Celik I (2012) Hepatoprotective and antioxidant activities of grape seeds against ethanol-induced oxidative stress in rats. *Br J Nutr* 107(1):45–51
- Dulundu E, Ozel Y, Topaloglu U, Toklu H, Ercan F, Gedik N, Sener G (2007) Grape seed extract reduces oxidative stress and fibrosis in experimental biliary obstruction. *J Gastroenterol Hepatol* 22(6):885–892
- Durukan AH, Evereklioglu C, Hurmeric V, Kerimoglu H, Erdurman C, Bayraktar MZ, Mumcuoglu T (2006) Ingestion of IH636 grape seed proanthocyanidin extract to prevent selenite-induced oxidative stress in experimental cataract. *J Cataract Refract Surg* 32(6):1041–1045
- El-Beshbishy HA, Mohamadine AM, Nagy AA, Abdel-Naim AB (2010) Amelioration of tamoxifen-induced liver injury in rats by grape seed extract, black seed extract and curcumin. *Indian J Exp Biol* 48(3):280–288
- Emiliano AF, de Cavalho LC, da Silva Cristino Cordeiro V, da Costa CA, de Oliveira PR, Queiroz EF, Moreira DD, Boaventura GT, de Moura RS, Resende AC (2011) Metabolic disorders and oxidative stress programming in offspring of rats fed a high-fat diet during lactation: effects of a *Vinifera* grape skin (ACH 09) extract. *J Cardiovasc Pharmacol* 58(3):319–328
- Engelbrecht AM, Mattheyse M, Ellis B, Loos B, Thomas M, Smith R, Peters S, Smith C, Myburgh K (2007) Proanthocyanidin from grape seeds inactivates the PI3-kinase/PKB pathway and induces apoptosis in a colon cancer cell line. *Cancer Lett* 258(1):144–153
- Facino RM, Carini M, Aldini G, Bombardelli E, Morazzoni P, Morelli R (1994) Free radicals scavenging action and anti-enzyme activities of procyanidins from *Vitis vinifera*. A mechanism for their capillary protective action. *Arzneimittelforschung* 44(5):592–601
- Facinó RM, Carini M, Aldini G, Berti F, Rossoni G, Bombardelli E, Morazzoni P (1996) Procyanidins from *Vitis vinifera* seeds protect rabbit heart from ischemia/reperfusion injury: antioxidant intervention and/or iron and copper sequestering ability. *Planta Med* 62(6):495–502
- Facino RM, Carini M, Aldini G, Berti F, Rossoni G, Bombardelli E, Morazzoni P (1999) Diet enriched with procyanidins enhances antioxidant activity and reduces myocardial post-ischaemic damage in rats. *Life Sci* 64(8):627–642
- Fan PH, Lou HX, Yu WT, Ren DM, Ma B, Ji M (2004) Novel flavanol derivatives from grape seeds. *Tetrahedron Lett* 45(15):3163–3166
- Fan W, Xu Y, Jiang W, Li J (2010) Identification and quantification of impact aroma compounds in 4 nonfloral *Vitis vinifera* varieties grapes. *J Food Sci* 75(1):S81–S88
- Fauconneau B, Waffo-Teguo P, Huguet F, Barrier L, Decendit A, Merillon JM (1997) Comparative study of radical scavenger and antioxidant properties of phenolic compounds from *Vitis vinifera* cell cultures using in vitro tests. *Life Sci* 61(21):2103–2110
- Feringa HHH, Laskey DA, Dickson JE, Coleman CI (2011) The effect of grape seed extract on cardiovascular risk markers: a meta-analysis of randomized controlled trials. *J Am Diet Assoc* 111(8):1173–1181
- Ferrer-Gallego R, García-Marino M, Hernández-Hierro JM, Rivas-Gonzalo JC, Escribano-Bailón MT (2010) Statistical correlation between flavanolic composition, colour and sensorial parameters in grape seed during ripening. *Anal Chim Acta* 660(1–2):22–28
- Filip A, Daicovicu D, Clichici S, Mocan T, Muresan A, Postescu ID (2011) Photoprotective effects of two natural products on ultraviolet B-induced oxidative stress and apoptosis in SKH-1 mouse skin. *J Med Food* 14(7–8):761–766
- Furiga A, Lonvaud-Funel A, Badet C (2009) In vitro study of antioxidant capacity and antibacterial activity on oral anaerobes of a grape seed extract. *Food Chem* 113(4):1037–1040
- Gabetta B, Fuzzati N, Griffini A, Lolla E, Pace R, Ruffilli T, Peterlongo F (2000) Characterization of proanthocyanidins from grape seeds. *Fitoterapia* 71(2):162–175
- Gomez FJ, Raba J, Cerutti S, Silva MF (2012) Monitoring melatonin and its isomer in *Vitis vinifera* cv. Malbec by UHPLC-MS/MS from grape to bottle. *J Pineal Res* 52(3):349–355
- Gonçalves B, Falco V, Moutinho-Pereira J, Bacelar E, Peixoto F, Correia C (2009) Effects of elevated CO₂ on grapevine (*Vitis vinifera* L.): volatile composition, phenolic content, and in vitro antioxidant activity of red wine. *J Agric Food Chem* 57(1):265–273
- Gris EF, Mattivi F, Ferreira EA, Vrhovsek U, Filho DW, Pedrosa RC, Bordignon-Luiz MT (2011) Stilbenes and tyrosol as target compounds in the assessment of antioxidant and hypolipidemic activity of *Vitis vinifera* red wines from southern Brazil. *J Agric Food Chem* 59(14):7954–7961
- Guendez R, Kallithraka S, Makris DP, Kefalas P (2005) Determination of low molecular weight polyphenolic constituents in grape (*Vitis vinifera* sp.) seed extracts: correlation with antiradical activity. *Food Chem* 89(1):1–9
- Hanelt P (ed) (2001) *Mansfeld's encyclopedia of agricultural and horticultural crops*, vol 1–6. Springer, London, 3700 pp

- Hemmati AA, Nazari Z, Samei M (2008) A comparative study of grape seed extract and vitamin E effects on silica-induced pulmonary fibrosis in rats. *Pulm Pharmacol Ther* 21(4):668–674
- Hemmati AA, Aghel N, Rashidi I, Gholampur-Aghdani A (2011) Topical grape (*Vitis vinifera*) seed extract promotes repair of full thickness wound in rabbit. *Int Wound J*. doi:10.1111/j.1742-481X.2011.00833.x
- Hollecker L, Pinna M, Filippino G, Scrugli S, Pinna B, Argiolas F, Murru M (2009) Simultaneous determination of polyphenolic compounds in red and white grapes grown in Sardinia by high performance liquid chromatography-electron spray ionisation-mass spectrometry. *J Chromatogr A* 1216(15):3402–3408
- Houde V, Grenier D, Chandad F (2006) Protective effects of grape seed proanthocyanidins against oxidative stress induced by lipopolysaccharides of periodontopathogens. *J Periodontol* 77(8):1371–1379
- Hui R, Jun W (2007) *Vitis* Linnaeus. In: Wu ZY, Raven PH, Hong DY (eds) *Flora of China*, vol 12 (Hippocastanaceae through Theaceae). Science Press/Missouri Botanical Garden Press, Beijing/St. Louis
- Huxley AJ, Griffiths M, Levy M (eds) (1992) *The new RHS dictionary of gardening*, 4 vols. MacMillan, London
- Iacopini P, Baldi M, Storch P, Sebastiani L (2008) Catechin, epicatechin, quercetin, rutin and resveratrol in red grape: content, in vitro antioxidant activity and interactions. *J Food Compos Anal* 21(8):589–598
- Iriti M, Faoro F (2009) Bioactivity of grape chemicals for human health. *Nat Prod Commun* 4(5):611–634
- Ivanov V, Carr AC, Frei B (2001) Red wine antioxidants bind to human lipoproteins and protect them from metal ion-dependent and -independent oxidation. *J Agric Food Chem* 49(9):4442–4449
- Jayaprakasha GK, Singh RP, Sakariah KK (2001) Antioxidant activity of grape seed (*Vitis vinifera*) extracts on peroxidation models in vitro. *Food Chem* 73(3):285–290
- Jayaprakasha GK, Selvi T, Sakariah KK (2003) Antibacterial and antioxidant activities of grape (*Vitis vinifera*) seed extracts. *Food Res Int* 36(2):117–122
- Jeswal P (1998) Antidotal effect of grape juice (*Vitis vinifera*) on ochratoxin A caused hepatorenal carcinogenesis in mice (*Mus musculus*). *Cytobios* 93(373):123–128
- Jiang B, Zhang Z (2010) Volatile compounds of young wines from cabernet sauvignon, cabernet gernerischet and chardonnay varieties grown in the loess plateau region of China. *Molecules* 15(12):9184–9196
- Kaliora AC, Kountouri AM, Karathanos VT, Koumbi L, Papadopoulos NG, Andrikopoulos NK (2008) Effect of Greek raisins (*Vitis vinifera* L.) from different origins on gastric cancer cell growth. *Nutr Cancer* 60(6):792–799
- Kaliora AC, Kountouri AM, Karathanos VT (2009) Antioxidant properties of raisins (*Vitis vinifera* L.). *J Med Food* 12(6):1302–1309
- Kammerer D, Claus A, Carle R, Schieber A (2004) Polyphenol screening of pomace from red and white grape varieties (*Vitis vinifera* L.) by HPLC-DAD-MS/MS. *J Agric Food Chem* 52(14):4360–4367
- Kampa M, Hatzoglou A, Notas G, Damianaki A, Bakogeorgou E, Gemetzi C, Kouroumalis E, Martin PM, Castanas E (2000) Wine antioxidant polyphenols inhibit the proliferation of human prostate cancer cell lines. *Nutr Cancer* 37(2):223–233
- Kaneko M, Kanesaka M, Yoneyama M, Tominaga T, Jirillo E, Kumazawa Y (2010) Inhibitory effects of fermented grape marc from *Vitis vinifera* Negroamaro on antigen-induced degranulation. *Immunopharmacol Immunotoxicol* 32(3):454–461
- Karaaslan O, Ulusoy MG, Kankaya Y, Tiftikcioglu YO, Kocer U, Kankaya D, Karaaslan GM, Tuncer S, Berktaş M (2010) Protective effect of grape seed extract against ischaemia/reperfusion injury in a rat epigastric flap model. *J Plast Reconstr Aesthet Surg* 63(4):705–710
- Karacabey E, Mazza G (2010) Optimisation of antioxidant activity of grape cane extracts using response surface methodology. *Food Chem* 119(1):343–348
- Katiyar SK (2008) Grape seed proanthocyanidines and skin cancer prevention: inhibition of oxidative stress and protection of immune system. *Mol Nutr Food Res* 52(Suppl 1):S71–S76
- Ketsa S, Verheij EWM (1992) *Vitis vinifera* L. In: Verheij EWM, Coronel RE (eds) *Plant resources of south-east Asia*, no. 2, Edible fruits and nuts. Prosea Foundation, Bogor, pp 304–310
- Khanna S, Roy S, Bagchi D, Bagchi M, Sen CK (2001) Upregulation of oxidant-induced VEGF expression in cultured keratinocytes by a grape seed proanthocyanidin extract. *Free Radic Biol Med* 31(1):38–42
- Khanna S, Venojarvi M, Roy S, Sharma N, Tripathi P, Bagchi D, Bagchi M, Sen CK (2002) Dermal wound healing properties of redox-active grape seed proanthocyanidins. *Free Radic Biol Med* 33(8):1089–1096
- Khoshbaten M, Aliasgarzadeh A, Masnadi K, Farhang S, Tarzamani MK, Babaei H, Kiani J, Zaare M, Najafipour F (2010) Grape seed extract to improve liver function in patients with nonalcoholic fatty liver change. *Saudi J Gastroenterol* 16(3):194–197
- Kim SY, Jeong SM, Park WP, Nam KC, Ahn DU, Lee SC (2006) Effect of heating conditions of grape seeds on the antioxidant activity of grape seed extracts. *Food Chem* 97(3):472–479
- Kneknopoulou P, Skouroumounis GK, Hayasaka Y, Taylor DK (2011) New phenolic grape skin products from *Vitis vinifera* cv. Pinot Noir. *J Agric Food Chem* 59(3):1005–1011
- Koch A, Doyle CL, Matthews MA, Williams LE, Ebeler SE (2010) Methoxy-3-isobutylpyrazine in grape berries and its dependence on genotype. *Phytochemistry* 71(17–18):2190–2198
- Köhler N, Wray V, Winterhalter P (2008) Preparative isolation of procyanidins from grape seed extracts by high-speed counter-current chromatography. *J Chromatogr A* 1177(1):114–125
- Koo M, Kim SH, Lee N, Yoo MY, Ryu SY, Kwon DY, Kim YS (2008) 3-Hydroxy-3-methylglutaryl-CoA (HMG-CoA) reductase inhibitory effect of *Vitis vinifera*. *Fitoterapia* 79(3):204–206

- Kunkel G (1984) Plants for human consumption. An annotated checklist of the edible phanerogams and ferns. Koeltz Scientific Books, Koenigstein
- Leifert WR, Abeywardena MY (2008) Cardioprotective actions of grape polyphenols. *Nutr Res* 28(11):729–737
- Leiro J, Alvarez E, Arranz JA, Laguna R, Uriarte E, Orallo F (2004) Effects of *cis*-resveratrol on inflammatory murine macrophages: antioxidant activity and down-regulation of inflammatory genes. *J Leukoc Biol* 75(6):1156–1165
- Li J, Liu H, Ramachandran S, Waypa GB, Yin JJ, Li CQ, Han M, Huang HH, Sillard WW, Vanden Hoek TL, Shao ZH (2010) Grape seed proanthocyanidins ameliorate Doxorubicin-induced cardiotoxicity. *Am J Chin Med* 38(3):569–584
- Lizarraga D, Lozano C, Briedé JJ, van Delft JH, Touriño S, Centelles JJ, Torres JL, Cascante M (2007) The importance of polymerization and galloylation for the antiproliferative properties of procyanidin-rich natural extracts. *FEBS J* 274(18):4802–4811
- Lu Y, Zhao WZ, Chang Z, Chen WX, Li L (2004) Procyanidins from grape seeds protect against phorbol ester-induced oxidative cellular and genotoxic damage. *Acta Pharmacol Sin* 25(8):1083–1089
- Lugasi A, Blázovics A, Dworschk E, Fehér J (1997) Cardio-protective effect of red wine as reflected in the literature. *Orv Hetil* 138(11):673–678 (In Hungarian)
- Lutterodt H, Slavin M, Whent M, Turner E, Yu L (2011) Fatty acid composition, oxidative stability, antioxidant and antiproliferative properties of selected cold-pressed grape seed oils and flours. *Food Chem* 128(2):391–399
- Lutz M, Jorquera K, Cancino B, Ruby R, Henriquez C (2011) Phenolics and antioxidant capacity of table grape (*Vitis vinifera* L.) cultivars grown in Chile. *J Food Sci* 76:C1088–C1093
- Ma L, Gao HQ, Li BY, Ma YB, You BA, Zhang FL (2007) Grape seed proanthocyanidin extracts inhibit vascular cell adhesion molecule expression induced by advanced glycation end products through activation of peroxisome proliferators-activated receptor gamma. *J Cardiovasc Pharmacol* 49(5):293–298
- Manfra M, Nisco MD, Bolognese A, Nuzzo V, Sofo A, Scopa A, Santi L, Tenore GC, Novellino E (2011) Anthocyanin composition and extractability in berry skin and wine of *Vitis vinifera* L. cv. Aglianico. *J Sci Food Agric* 91:2749–2755
- Matito C, Mastorakou F, Centelles JJ, Torres JL, Cascante M (2003) Antiproliferative effect of antioxidant polyphenols from grape in murine Hepa-1c1c7. *Eur J Nutr* 42(1):43–49
- Mérillon JM, Fauconneau B, Teguo PW, Barrier L, Vercauteren J, Huguet F (1997) Antioxidant activity of the stilbene astringin, newly extracted from *Vitis vinifera* cell cultures. *Clin Chem* 43(6 Pt 1):1092–1093
- Mikulski D, Molski M (2010) Quantitative structure–antioxidant activity relationship of *trans*-resveratrol oligomers, *trans*-4,4'-dihydroxystilbene dimer, *trans*-resveratrol-3-*O*-glucuronide, glucosides: *trans*-piceid, *cis*-piceid, *trans*-astringin and *trans*-resveratrol-4'-*O*- β -D-glucopyranoside. *Eur J Med Chem* 45(6):2366–2380
- Monagas M, Gómez-Cordovés C, Bartolomé B, Laureano O, Ricardo da Silva JM (2003) Monomeric, oligomeric, and polymeric flavan-3-ol composition of wines and grapes from *Vitis vinifera* L. Cv. Graciano, Tempranillo, and Cabernet Sauvignon. *J Agric Food Chem* 51(22):6475–6481
- Monagas M, Garrido I, Bartolomé B, Gómez-Cordovés C (2006a) Chemical characterization of commercial dietary ingredients from *Vitis vinifera* L. *Anal Chim Acta* 563(1–2):401–410
- Monagas M, Hernández-Ledesma B, Gómez-Cordovés C, Bartolomé B (2006b) Commercial dietary ingredients from *Vitis vinifera* L. leaves and grape skins: antioxidant and chemical characterization. *J Agric Food Chem* 54(2):319–327
- Moreno DA, Ilıc N, Poulev A, Brasaemle DL, Fried SK, Raskin I (2003) Inhibitory effects of grape seed extract on lipases. *Nutrition* 19(10):876–879
- Narita K, Hisamoto M, Okuda T, Takeda S (2011) Differential neuroprotective activity of two different grape seed extracts. *PLoS One* 6(1):e14575
- Negro C, Tommasi L, Miceli A (2003) Phenolic compounds and antioxidant activity from red grape marc extracts. *Bioresour Technol* 87(1):41–44
- Oliver J (2010) The Australian Wine Annual 2010. Macmillan Publishing Services, Melbourne, 352 pp
- Orallo F (2006) Comparative studies of the antioxidant effects of *cis*- and *trans*-resveratrol. *Curr Med Chem* 13(1):87–98
- Orhan N, Aslan M, Orhan DD, Ergun F, Yeşilada E (2006) In-vivo assessment of antidiabetic and antioxidant activities of grapevine leaves (*Vitis vinifera*) in diabetic rats. *J Ethnopharmacol* 108(2):280–286
- Pari L, Suresh A (2008) Effect of grape (*Vitis vinifera* L.) leaf extract on alcohol induced oxidative stress in rats. *Food Chem Toxicol* 46(5):1627–1634
- Park SH, Park TS, Cha YS (2008) Grape seed extract (*Vitis vinifera*) partially reverses high fat diet-induced obesity in C57BL/6 J mice. *Nutr Res Pract* 2(4):227–233
- Park MK, Park JS, Cho ML, Oh HJ, Heo YJ, Woo YJ, Heo YM, Park MJ, Park HS, Park SH, Kim HY, Min JK (2011) Grape seed proanthocyanidin extract (GSPE) differentially regulates Foxp3+ regulatory and IL-17+ pathogenic T cell in autoimmune arthritis. *Immunol Lett* 135(1–2):50–58
- Parry J, Su L, Moore J, Cheng Z, Luther M, Rao JN, Wang JY, Yu LL (2006) Chemical compositions, antioxidant capacities, and antiproliferative activities of selected fruit seed flours. *J Agric Food Chem* 54(11):3773–3778
- Pataki T, Bak I, Kovacs P, Bagchi D, Das DK, Tosaki A (2002) Grape seed proanthocyanidins improved cardiac recovery during reperfusion after ischemia in isolated rat hearts. *Am J Clin Nutr* 75(5):894–899
- Pirinçcioğlu M, Kızıl G, Kızıl M, Özdemir G, Kanay Z, Aydın Ketani M (2012) Protective effect of Öküzgözü (*Vitis vinifera* L. cv.) grape juice against carbon tetrachloride induced oxidative stress in rats. *Food Funct* 3:668–673

- Porcher MH et al (1995–2020) Searchable World Wide Web multilingual multiscript plant name database. Published by The University of Melbourne, Australia. <http://www.plantnames.unimelb.edu.au/Sorting/Frontpage.html>
- Preuss HG, Wallerstedt D, Talpur N, Tutuncuoglu SO, Echard B, Myers A, Bui M, Bagchi D (2000) Effects of niacin bound chromium and grape seed proanthocyanidin extract on the lipid profile of hypercholesterolemic subjects: a pilot study. *J Med* 31:227–246
- Prieur C, Rigaud J, Moutounet M, Cheynier V (1994) Oligomeric and polymeric procyanidins from grape seeds. *Phytochemistry* 36(3):781–784
- Püssa T, Floren J, Kuldkepp P, Raal A (2006) Survey of grapevine *Vitis vinifera* stem polyphenols by liquid chromatography-diode array detection-tandem mass spectrometry. *J Agric Food Chem* 54(20):7488–7494
- Qian MC, Fang Y, Shellie K (2009) Volatile composition of Merlot wine from different vine water status. *J Agric Food Chem* 57(16):7459–7463
- Ray SD, Kumar MA, Bagchi D (1999) A novel proanthocyanidin ih636 grape seed extract increases in vivo Bcl-XL expression and prevents acetaminophen-induced programmed and unprogrammed cell death in mouse liver. *Arch Biochem Biophys* 369(1):42–58
- Ray SD, Patel D, Wong V, Bagchi D (2000) In vivo protection of DNA damage associated apoptotic and necrotic cell deaths during acetaminophen-induced nephrotoxicity, amiodarone-induced lung toxicity and doxorubicin-induced cardiotoxicity by a novel IH636 grape seed proanthocyanidin extract. *Res Commun Mol Pathol Pharmacol* 107(1–2):137–166
- Ray SD, Parikh H, Bagchi D (2005) Proanthocyanidin exposure to B6C3F1 mice significantly attenuates dimethylnitrosamine-induced liver tumor induction and mortality by differentially modulating programmed and unprogrammed cell deaths. *Mutat Res Fundam Mol Mech Mutagenesis* 579(1–2):81–106
- Rockenbach II, Gonzaga LV, Rizelio VM, Gonçalves AESS, Genovese MI, Fett R (2011) Phenolic compounds and antioxidant activity of seed and skin extracts of red grape (*Vitis vinifera* and *Vitis labrusca*) pomace from Brazilian winemaking. *Food Res Int* 44(4):897–901
- Roychowdhury S, Wolf G, Keilhoff G, Bagchi D, Horn T (2001) Protection of primary glial cells by grape seed proanthocyanidin extract against nitrosative/oxidative stress. *Nitric Oxide* 5(2):137–149
- Saad AA, Youssef MI, El-Shennawy LK (2009) Cisplatin induced damage in kidney genomic DNA and nephrotoxicity in male rats: the protective effect of grape seed proanthocyanidin extract. *Food Chem Toxicol* 47(7):1499–1506
- Saada HN, Said UZ, Meky NH, Abd El Azime AS (2009) Grape seed extract *Vitis vinifera* protects against radiation-induced oxidative damage and metabolic disorders in rats. *Phytother Res* 23(3):434–438
- Santos-Buelga C, Francia-Aricha EM, Escribano-Bailón MT (1995) Comparative flavan-3-ol composition of seeds from different grape varieties. *Food Chem* 53(2):197–201
- Sato M, Maulik G, Ray PS, Bagchi D, Das DK (1999) Cardioprotective effects of grape seed proanthocyanidin against ischemic reperfusion injury. *J Mol Cell Cardiol* 31(6):1289–1297
- Sato M, Bagchi D, Tosaki A, Das DK (2001) Grape seed proanthocyanidin reduces cardiomyocyte apoptosis by inhibiting ischemia/reperfusion-induced activation of JNK-1 and C-JUN. *Free Radic Biol Med* 31(6):729–737
- Schneider R, Razungles A, Augier C, Baumes R (2001) Monoterpenic and norisoprenoid glycoconjugates of *Vitis vinifera* L. cv. Melon B. as precursors of odorants in Muscadet wines. *J Chromatogr A* 936(1–2):145–157
- Selli S, Bagatar B, Sen K, Kelebek H (2011) Evaluation of differences in the aroma composition of free-run and pressed neutral grape juices obtained from Emir (*Vitis vinifera* L.). *Chem Biodivers* 8(9):1776–1782. doi:10.1002/cbdv.201100053
- Sen CK, Bagchi D (2001) Regulation of inducible adhesion molecule expression in human endothelial cells by grape seed proanthocyanidin extract. *Mol Cell Biochem* 216(1–2):1–7
- Seo K, Jung S, Park M, Song Y, Choung S (2001) Effects of leucocyanidins on activities of metabolizing enzymes and antioxidant enzymes. *Biol Pharm Bull* 24(5):592–593
- Shao ZH, Becker LB, Vanden Hoek TL, Schumacker PT, Li CQ, Zhao D, Wojcik K, Anderson T, Qin Y, Dey L, Yuan CS (2003a) Grape seed proanthocyanidin extract attenuates oxidant injury in cardiomyocytes. *Pharmacol Res* 47(6):463–469
- Shao ZH, Vanden Hoek TL, Xie J, Wojcik K, Chan KC, Li CQ, Hamann K, Qin Y, Schumacker PT, Becker LB, Yuan CS (2003b) Grape seed proanthocyanidins induce pro-oxidant toxicity in cardiomyocytes. *Cardiovasc Toxicol* 3(4):331–339
- Shao ZH, Wojcik KR, Dossumentkova A, Hsu C, Mehendale SR, Li CQ, Qin Y, Sharp WW, Chang WT, Hamann KJ, Yuan CS, Hoek TL (2009) Grape seed proanthocyanidins protect cardiomyocytes from ischemia and reperfusion injury via Akt-NOS signaling. *J Cell Biochem* 107(4):697–705
- Shi J, Yu J, Pohorly JE, Kakuda Y (2003) Polyphenolics in grape seeds-biochemistry and functionality. *J Med Food* 6(4):291–299
- Shin MO, Moon JO (2010) Effect of dietary supplementation of grape skin and seeds on liver fibrosis induced by dimethylnitrosamine in rats. *Nutr Res Pract* 4(5):369–374
- Shivananda Nayak B, Dan Ramdath D, Marshall JR, Isitor G, Xue S, Shi J (2011) Wound-healing properties of the oils of *Vitis vinifera* and *Vaccinium macrocarpon*. *Phytother Res* 25(8):1201–1208. doi:10.1002/ptr.3363
- Simonetti P, Ciappellano S, Gardana C, Bramati L, Pietta P (2002) Procyanidins from *Vitis vinifera* seeds: in vivo effects on oxidative stress. *J Agric Food Chem* 50(21):6217–6221
- Soares De Moura R, Costa Viana FS, Souza MA, Kovary K, Guedes DC, Oliveira EP, Rubenich LM, Carvalho LC, Oliveira RM, Tano T, Gusmão Correia ML (2002) Antihypertensive, vasodilator and antioxidant effects of a *vinifera* grape skin extract. *J Pharm Pharmacol* 54(11):1515–1520

- Soares de Moura R, da Costa GF, Moreira AS, Queiroz EF, Moreira DD, Garcia-Souza EP, Resende AC, Moura AS, Teixeira MT (2012) *Vitis vinifera* L. grape skin extract activates the insulin-signalling cascade and reduces hyperglycaemia in alloxan-induced diabetic mice. *J Pharm Pharmacol* 64(2):268–276
- Song X, Siriwardhana N, Rathore K, Lin D, Wang HC (2010) Grape seed proanthocyanidin suppression of breast cell carcinogenesis induced by chronic exposure to combined 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone and benzo[a]pyrene. *Mol Carcinog* 49(5):450–463
- Souquet J-M, Cheynier V, Brossaud F, Moutounet M (1996) Polymeric proanthocyanidins from grape skins. *Phytochemistry* 43(2):509–512
- Souquet J-M, Labarbe B, Le Guernevé C, Cheynier V, Moutounet M (2000) Phenolic composition of grape stems. *J Agric Food Chem* 48(4):1076–1080
- Sovak M (2001) Grape extract, resveratrol, and its analogs: a review. *J Med Food* 4(2):93–105
- Sreemantula S, Nammi S, Kolanukonda R, Koppula S, Boini KM (2005) Adaptogenic and nootropic activities of aqueous extract of *Vitis vinifera* (grape seed): an experimental study in rat model. *BMC Complement Altern Med* 5:1
- Stagos D, Kazantzoglou G, Magiatis P, Mitaku S, Anagnostopoulos K, Kouretas D (2005) Effects of plant phenolics and grape extracts from Greek varieties of *Vitis vinifera* on mitomycin C and topoisomerase I-induced nicking of DNA. *Int J Mol Med* 15(6):1013–1022
- Stagos D, Kazantzoglou G, Theofanidou D, Kakalopoulou G, Magiatis P, Mitaku S, Kouretas D (2006) Activity of grape extracts from Greek varieties of *Vitis vinifera* against mutagenicity induced by bleomycin and hydrogen peroxide in *Salmonella typhimurium* strain TA102. *Mutat Res* 609(2):165–175
- Stagos D, Spanou C, Margariti M, Stathopoulos C, Mamuris Z, Kazantzoglou G, Magiatis P, Kouretas D (2007) Cytogenetic effects of grape extracts (*Vitis vinifera*) and polyphenols on mitomycin C-induced sister chromatid exchanges (SCEs) in human blood lymphocytes. *J Agric Food Chem* 55(13):5246–5252
- Stanković M, Tesević V, Vajs V, Todorović N, Milosavljević S, Godevac D (2008) Antioxidant properties of grape seed extract on human lymphocyte oxidative defence. *Planta Med* 74(7):730–735
- Su CT, Singleton VL (1969) Identification of three flavan-3-ols from grapes. *Phytochemistry* 8(8):1553–1558
- Sung MJ, Davaatseren M, Kim W, Park SK, Kim SH, Hur HJ, Kim MS, Kim YS, Kwon DY (2009) Vitisin A suppresses LPS-induced NO production by inhibiting ERK, p38, and NF-kappaB activation in RAW 264.7 cells. *Int Immunopharmacol* 9(3):319–323
- Teguo PW, Decendit A, Vercauteren J, Deffieux G, Mérillon JM (1996) *trans*-Resveratrol-3-O- β -glucoside (piceid) in cell suspension cultures of *Vitis vinifera*. *Phytochemistry* 42:1591–1593
- Thiruchenduran M, Vijayan NA, Sawaminathan JK, Devaraj SN (2011) Protective effect of grape seed proanthocyanidins against cholesterol cholic acid diet-induced hypercholesterolemia in rats. *Cardiovasc Pathol* 20(6):361–368
- Torres JL, Bobet R (2001) New flavanol derivatives from grape (*Vitis vinifera*) byproducts. Antioxidant aminoethylthio-flavan-3-ol conjugates from a polymeric waste fraction used as a source of flavanols. *J Agric Food Chem* 49(10):4627–4634
- U.S. Department of Agriculture, Agricultural Research Service (USDA) (2012) USDA national nutrient database for standard reference, Release 25. Nutrient data laboratory home page. <http://www.ars.usda.gov/ba/bhnrc/ndl>
- Ugartondo V, Mitjans M, Touriño S, Torres JL, Vinardell MP (2007) Comparative antioxidant and cytotoxic effect of procyanidin fractions from grape and pine. *Chem Res Toxicol* 20(10):1543–1548
- Vigna GB, Costantini F, Aldini G, Carini M, Catapano A, Schena F, Tangerini A, Zanca R, Bombardelli E, Morazzoni P, Mezzetti A, Fellin R, Facino RM (2003) Effect of a standardized grape seed extract on low-density lipoprotein susceptibility to oxidation in heavy smokers. *Metabolism* 52(10):1250–1257
- Vilanova M, Genisheva Z, Bescansa L, Masa A, Oliveira JM (2012) Changes in free and bound fractions of aroma compounds of four *Vitis vinifera* cultivars at the last ripening stages. *Phytochemistry* 74:196–205
- Vinson JA, Mandarano MA, Shuta DL, Bagchi M, Bagchi D (2002) Beneficial effects of a novel IH636 grape seed proanthocyanidin extract and a niacin-bound chromium in a hamster atherosclerosis model. *Mol Cell Biochem* 240(1–2):99–103
- Vitalini S, Gardana C, Zanzotto A, Simonetti P, Faoro F, Fico G, Iriti M (2011) The presence of melatonin in grapevine (*Vitis vinifera* L.) berry tissues. *J Pineal Res* 51(3):331–337
- Waffo Taegu P, Fauconneau B, Deffieux G, Huguet F, Vercauteren J, Merillon JM (1998) Isolation, identification, and antioxidant activity of three stilbene glucosides newly extracted from *vitis vinifera* cell cultures. *J Nat Prod* 61(5):655–657
- Waffo-Tégou P, Hawthorne ME, Cuendet M, Mérillon JM, Kinghorn AD, Pezzuto JM, Mehta RG (2001) Potential cancer-chemopreventive activities of wine stilbenoids and flavans extracted from grape (*Vitis vinifera*) cell cultures. *Nutr Cancer* 40(2):173–179
- Wang YH, Ge B, Yang XL, Zhai J, Yang LN, Wang XX, Liu X, Shi JC, Wu YJ (2011) Proanthocyanidins from grape seeds modulates the nuclear factor-kappa B signal transduction pathways in rats with TNBS-induced recurrent ulcerative colitis. *Int Immunopharmacol* 11(10):1620–1627
- Welke JE, Manfroi V, Zanús M, Lazarotto M, Alcaraz Zini C (2012) Characterization of the volatile profile of Brazilian Merlot wines through comprehensive two dimensional gas chromatography time-of-flight mass spectrometric detection. *J Chromatogr A* 1226: 124–139
- Yahara N, Tofani I, Maki K, Kojima K, Kojima Y, Kimura M (2005) Mechanical assessment of effects of grape

- seed proanthocyanidins extract on tibial bone diaphysis in rats. *J Musculoskelet Neuronal Interact* 5(2):162–169
- Ye X, Krohn RL, Liu W, Joshi SS, Kuszynski CA, McGinn TR, Bagchi M, Preuss HG, Stohs SJ, Bagchi D (1999) The cytotoxic effects of a novel IH636 grape seed proanthocyanidin extract on cultured human cancer cells. *Mol Cell Biochem* 196(1–2):99–108
- Yildirim HK, Akçay YD, Güvenç U, Sözmen EY (2004) Protection capacity against low-density lipoprotein oxidation and antioxidant potential of some organic and non-organic wines. *Int J Food Sci Nutr* 55(5):351–362
- Yousef MI, Saad AA, El-Shennawy LK (2009) Protective effect of grape seed proanthocyanidin extract against oxidative stress induced by cisplatin in rats. *Food Chem Toxicol* 47(6):1176–1183
- Zga Z, Papastamoulis Y, Toribio A, Richard T, Delaunay JC, Jeandet P, Renault JH, Monti JP, Mérillon JM, Waffo-Tégou P (2009) Preparative purification of anti-amyloidogenic stilbenoids from *Vitis vinifera* (Chardonnay) stems by centrifugal partition chromatography. *J Chromatogr* 877(10):1000–1004
- Zhang FL, Gao HQ, Wu JM, Ma YB, You BA, Li BY, Xuan JH (2006) Selective inhibition by grape seed proanthocyanidin extracts of cell adhesion molecule expression induced by advanced glycation end products in endothelial cells. *J Cardiovasc Pharmacol* 48(2):47–53
- Zhang FL, Gao HQ, Shen L (2007) Inhibitory effect of GSPE on RAGE expression induced by advanced glycation end products in endothelial cells. *J Cardiovasc Pharmacol* 50(4):434–440
- Zhang YJ, Shi HP, Wang WJ, Ke ZF, Xu P, Zhong ZQ, Li XX, Wang SM (2011) Antithrombotic effect of grape seed proanthocyanidins extract in a rat model of deep vein thrombosis. *J Vasc Surg* 53(3):743–753
- Zhao J, Wang J, Chen Y, Agarwal R (1999) Anti-tumor-promoting activity of a polyphenolic fraction isolated from grape seeds in the mouse skin two-stage initiation-promotion protocol and identification of procyanidin B5-3'-gallate as the most effective antioxidant constituent. *Carcinogenesis* 20(9):1737–1745
- Zhao C, Giusti MM, Malik M, Moyer MP, Magnuson BA (2004) Effects of commercial anthocyanin-rich extracts on colonic cancer and nontumorigenic colonic cell growth. *J Agric Food Chem* 52(20):6122–6128
- Zhu L, Zhang Y, Lu J (2012) Phenolic contents and compositions in skins of red wine grape cultivars among various genetic backgrounds and originations. *Int J Mol Sci* 13(3):3492–3510

Tasmannia insipida

Scientific Name

Tasmannia insipida R.Br. ex DC.

Synonyms

Drimys insipida (DC.) Pilg., *Drimys dipetala* F. Muell. nom. illeg.

Family

Winteraceae

Common/English Names

Brush Pepperbush, Faint Pepper Bush, Dorrigo Pepper, Pepper Bush, Pepper Tree.

Vernacular Names

None

Origin/Distribution

The species is indigenous to Australia and is found in southeast New South Wales to southeast Queensland and in the highlands of northeast Queensland.

Agroecology

Tasmannia insipida is an understorey plant, usually found in or near the cool wet subtropical, warm temperate, cool temperate and littoral rainforests on the coast and ranges from southeast New South Wales to southeast Queensland and also in highlands of north-east Queensland. It is shade tolerant, growing well in the open, partial-shade and complete shade. It has been reported to be slow growing and to benefit from mulching and additional watering during dry periods until established (Webb 2009–10).

Edible Plant Parts and Uses

The fruit is edible but rather tasteless and insipid. The seeds are hot and peppery and can be used as a bush-food condiment/spice but are not sold commercially for culinary purposes. Leaves may also be used to render a peppery flavour to cooking, and can be used as whole fresh leaves (like bay leaves) or dried and ground as a spice.

Botany

A semi-woody shrub, 1–3 m (occasionally to 5 m) high. New growth and juvenile stems are reddish especially when grown in exposed situation. Leaves occur in whorls on short 2–5 mm



Plate 1 Fruiting twigs



Plate 3 Close-up of fruit cluster



Plate 2 Whorled leaves and fruits



Plate 4 Whole and halved fruit with seeds

petioles (Plates 1 and 2) at the end of twigs. Lamina is lanceolate, 11–21 cm by 2–5 cm, with acute apex and truncate or auriculate base, entire margin, glabrous, and glossy green on both surfaces, lateral veins forming loops. Each flower arises from the axil of a bud scale, forming bunches of 8–15 flowers that look like a small terminal umbel. Male and female flowers occur on the same plant. Perianth in two whorls of two, two outer lobes enclosing two inner lobes, white to creamy-white, 5–10 mm long. Female flowers with staminodes and sessile, solitary ovary and sessile stigma. Male flower with numerous stamens (50–70) arising spirally around the base of the rudimentary ovary. Fruit ovoid berry, 12–20 mm long 8–11 mm, with a suture on one side, borne on 12–20 mm long peduncle, pale green turning to purplish or white speckled with purple or red (Plates 2–4) and containing about

20–40 tiny, 2–3 mm long by 2 mm wide, black, comma-shaped seeds (Plate 4).

Nutritive/Medicinal Properties

Tasmannia oils including from *Tasmannia insipida* were found to contain the following volatiles: monoterpenoids α -pinene, β -pinene, limonene, sabinene, α -phellandrene, 1,8-cineole and linalool; sesquiterpenoids caryophyllene, bicyclogermacrene, germacrene D, cadina-1,4-diene, calamenene, α -copaene, α -cubebene, elemol, α -eudesmol, β -eudesmol and γ -eudesmol and viridiflorol and phenylpropanoids eugenol, saffrole and myristicin (Southwell and Brophy 1992). The characteristic hot spice flavour of *Tasmannia* species was not attributed to the volatile constituents.

Other Uses

Pepper Bush is an attractive small shrub for a shaded or semi-shaded garden. It is well suited to enrichment planting as rainforest revegetation plots mature.

Comments

Pepper bush can be propagated from seeds or cuttings. Germination from seeds has been reported to be slow and unreliable and cuttings taken from current season growth have been found to strike readily.

Selected References

- Pellow BJ, Pellow B, Henwood M, Carolin R (2009) Flora of the Sydney region. University Press, Sydney
- Southwell IA, Brophy JJ (1992) Differentiation within the Australian *Tasmannia* by essential oil comparison. *Phytochemistry* 31(9):3073–3081
- Vink W (1970) The Winteraceae of the old world. I. Pseudowintera and Drimys – morphology and taxonomy. *Blumea* 18:225–354
- Vink W (1988) Taxonomy in Winteraceae. *Taxonomy* 37(3):691–698
- Webb W (2009–10) *Tasmania insipida* pepper bush. Barung Landcare News. Dec 2009–Jan 2010. P 7. http://www.barunglandcare.org.au/newsletters/news-letter_dec09jan10.pdf

Tasmannia lanceolata

Scientific Name

Tasmannia lanceolata (Poir.) A.C. Smith.

Synonyms

Drimys aromatica (R.Br.) F.Muell., *Drimys lanceolata* (Poir.) Baill., *Tasmannia aromatica* R.Br., *Winterana lanceolata* Poir., *Winterania lanceolata* orth. var. Poir.

Family

Winteraceae

Common/English Names

Cornish Pepper Leaf, Mountain Pepper, Mountain Pepperbush, Tasmanian Pepperberry, Tasmanian Pepper Bush.

Vernacular Names

French: Poivre indigène;

German: Australischer Pfeffer, Bergpfeffer, Tasmanischer Pfeffer.

Origin/Distribution

The species is endemic to southeastern Australia and Tasmania. It is found from New South Wales, from Barrington Tops southwards through to Victoria and Tasmania.

Agroecology

It grows naturally in moist woodlands, moist eucalypt forest, gullies and cool temperate mountain rainforest up to the alpine zones to 1,500 m altitude.

Edible Plant Parts and Uses

The peppery-flavored fruits, seeds and leaves when dried are increasingly used as a condiment in local cookery in Australia. The berries are sweet at first with a peppery, hot and aromatic aftertaste. It has been used by the aboriginals and early white-settlers as a pepper substitute (Plate 3). The peppery flavour can be attributed to a compound called polygodial. Mountain pepper is used for typical Australian cuisines, e.g. emu hamburger or kangaroo steaks; it is common to marinate meat with a mixture of crushed Tasmanian pepper berries and vegetable oil



Plate 1 Young Mountain pepper plant



Plate 3 Mountain pepper plant label with usage information



Plate 2 Reddish stems and glossy lanceolate leaves



Plate 4 Packet of dried mountain pepper berries

before grilling or frying. Stews with longer cooking period, are seasoned with the ground grains before serving, as long simmering destroys the taste of this spice. Mountain pepper is used to flavour curries, cheeses, alcoholic beverages, wines and salad dressings or ground as a substitute for black pepper. It is exported to Japan to flavour wasabi.

Botany

Mountain pepper is a shrub to a small, evergreen dioecious tree 2–5 m (–10 m) high with a straight stem and many acute branches. Young stem and branches are reddish (Plates 1 and 2). Leaves are alternate and borne on 2–4 mm thick, red petioles. Lamina is lanceolate to narrow-elliptic, 4–12 cm long by 0.8–2 cm wide, with acuminate apex, tapering base and entire margin, thick, glabrous, glossy green above and paler green below (Plates 1 and 2). Leaves are aromatic when

crushed. Flowers are small, white to creamy white, 1–2 cm across and borne on short 5–15 mm pedicel; each flower arises from the axil of a bud scale, forming bunches of eight to ten flowers that look like a small terminal umbel. Flower perianth in 2 whorls, outer 2–3 sepal-like lobes which are shed after anthesis and inner 4–8 strap-shaped petal lobes. Male flower has 20–25 stamens and female flower has a solitary carpel. Fruit globose to subglobose berry, 5–8 mm across, green becoming dark purplish-red to black (Plate 4) when ripe and containing numerous, 10–18, small seeds.

Nutritive/Medicinal Properties

Tasmannia oils including from *Tasmannia lanceolata* were found to contain monoterpenoids α -pinene, β -pinene, limonene, sabinene, α -phel-

landrene, 1,8-cineole and linalool; sesquiterpenoids caryophyllene, bicyclogermacrene, germacrene D, cadina-1,4-diene, calamenene, α -copaene, α -cubebene, elemol, α -eudesmol, β -eudesmol and γ -eudesmol and viridiflorol and phenylpropanoids eugenol, safrole and myristicin (Southwell and Brophy 1992). The characteristic hot spice flavour of *Tasmannia* species was not attributed to these volatile constituents.

The leaves were found to contain the sesquiterpenes polygodial (drim-7-en-11,12-dial), the pungent, peppery principle and guaiol (0.035%) and no alkaloids (Loder 1962). The simple, robust oil cells found in leaves of *Tasmannia lanceolata* were shown to contain a preponderance of the bioactive compound polygodial (Read and Menary 2000). Two distinct groups of *Tasmannia lanceolata* were identified, the low-polygodial group, where the polygodial levels tend to remain constant over time, and the high-polygodial group where concentrations varied (Dragar et al. 1988).

Polygodial had been reported to exhibit antihyperalgesic/analgesic (Mendes et al. 1998, 2000; Malheiros et al. 2001), antiinflammatory and antiallergic (Tratsk et al. 1997; Cunha et al. 2001; Martin et al. 2009), gastroprotective (Matsuda et al. 2002), antimicrobial (Lee et al. 1999; Kubo et al. 2001, 2011; Kubo and Fujita 2001; Malheiros et al. 2005; Fujita and Kubo 2005a, b), potent attachment-inhibitory (Ban et al. 2000), vasorelaxation (André et al. 1999; El Sayah et al. 2000), insect antifeedant (Caprioli et al. 1987; Moreno-Osorio et al. 2008), anti-leishmanial and anti-trypansomal activities (Corrêa et al. 2011).

Antioxidant Activity

Tasmannia pepper leaf, followed by anise myrtle and lemon myrtle contained the highest levels of total phenolics (102.1; 55.9 and 31.4 mg gallic acid equivalents (GAE)/g dry weight (DW), respectively) (Konczak et al. 2010). Tasmannia pepper leaf exhibited the highest oxygen radical absorbance capacity (ORAC assay) followed by lemon myrtle and anise myrtle. Anise myrtle

exhibited the highest total reducing capacity [ferric reducing antioxidant power (FRAP) assay], followed by Tasmannia pepper leaf and lemon myrtle. The total phenolics content of Tasmannia pepper berry (16.86 mg GAE/gDW) was similar to that of black pepper, but its total reducing capacity was 25% lower. Cinnamic acids and flavonoids, were identified as the main sources of antioxidant activities.

Gastroprotective Activity

The methanolic leaf extract of *Tasmannia lanceolata* was found to potently inhibit ethanol-induced gastric lesions in rats (Matsuda et al. 2002). Three known sesquiterpenes, polygodial, polygodial 12 α -acetal, and polygodial 12 β -acetal, and a new sesquiterpene, methyl isodrimeninol, were isolated as the bioactive constituents. Among them, polygodial showed very potent gastroprotective effects (ED_{50} =0.028 mg/kg, po). Pretreatment with indomethacin, N-ethylmaleimide, NG-nitro-L-arginine methyl ester and ruthenium red attenuated the gastroprotection of polygodial indicating that endogenous prostaglandins, sulfhydryl compounds, nitric oxide and vanilloid receptors may be involved in the protective activity. Polygodial isolated from *T. lanceolata* leaves, distinctly inhibited the gastric mucosal lesions induced by several necrotizing agents, such as ethanol (ED_{50} =0.029 mg/kg, p.o.), 0.6 M HCl (ED_{50} =0.26 mg/kg, p.o.), and aspirin (ED_{50} =0.38 mg/kg, p.o.), and partly inhibited the gastric mucosal lesions induced by indomethacin, but exerted no significant effect on acid output in pylorus-ligated rats at doses of 0.05–0.5 mg/kg (Pongpiriyadacha et al. 2003). The gastroprotection of polygodial was attenuated by pretreatment with indomethacin, NG-nitro-L-arginine methyl ester, N-ethylmaleimide and ruthenium red. Polygodial (0.2 mg/kg, p.o.) increased the amount of reduced glutathione in gastric mucosa of ethanol-treated group. These results suggested that endogenous prostaglandins, nitric oxide, sulfhydryl compounds and vanilloid receptor-mediated effects were involved in the protective activity of polygodial.

Vasorelaxant Activity

Polygodial was found to elicit graded vasorelaxation in rings of rabbit pulmonary artery or thoracic aorta and guinea-pig pulmonary artery with endothelium (André et al. 1999). The vasorelaxation action of polygodial was partly dependent on the release of nitric oxide (NO) or an NO-derived substance from the vascular endothelium through an activation of a guanylyl cyclase-dependent mechanism. They found that the action was not related with the opening of potassium (K^+) channels, release of prostacyclin, substance P, or with the activation of adenylyl cyclase-dependent mechanisms. Studies showed that polygodial exhibited vasorelaxant action in the rat portal vein (El Sayah et al. 2000). Polygodial, elicited graded in-vitro inhibition of the contractile response induced by potassium chloride and by phorbol ester. At the median inhibitory concentration (IC_{50}) level, polygodial was about 114- to 177-fold more active in inhibiting mediated contractions to senktide and phorbol ester. The vasorelaxant action was found to be associated with inhibition of calcium influx through voltage-sensitive channels and interaction with protein kinase C-dependent mechanisms. The study also confirmed that polygodial preferentially antagonized tachykinin-mediated contraction, especially the NK3-mediated responses.

Antihyperalgesic/Analgesic Activity

Mendes et al. (1998) found polygodial to have anti-hyperalgesic activity when evaluated in several models of inflammatory or capsaicin-induced neurogenic pain. Its actions involved, partly, an interaction with opioid pathway through a naloxone-sensitive mechanism, not related to non-specific peripheral or central depressant actions. Mendes et al. (2000) showed in animal studies that polygodial elicited marked systemic, spinal, and supraspinal antinociception in mice, mainly preventing the neurogenic pain produced by formalin and capsaicin. They postulated that the antinociception of polygodial could involve an interaction with

the opioid system, mainly kappa and delta subtypes, and depended on the activation of G(i/o) protein sensitive to pertussis toxin, $\alpha(1)$ -adrenoceptors, and the serotonergic system. Their results suggested that polygodial itself or its derivatives may have potential therapeutic value for the development of new analgesic drugs. Polygodial was reported to be 3-fold more active than another sesquiterpene drimane drimaniol in exhibiting antinociceptive action against acetic acid induced pain (Malheiros et al. 2001).

Antiinflammatory/Antiallergic Activity

Studies of Tratsk et al. (1997) confirmed that the active principle (later shown to be polygodial) present in the barks of *Drimys winteri* had oral anti-inflammatory and anti-allergic properties, supporting its reported medicinal use in Brazilian folk medicine for the management of airway diseases. Cunha et al. (2001) demonstrated that polygodial exhibited anti-inflammatory and anti-allergic in-vitro. In the guinea-pig trachea, polygodial elicited significant inhibition of bradykinin, 9,11-dideoxy-9 α ,11 α -methano-epoxy prostaglandin F2 α and KCl-induced contractions. When tested in the guinea-pig trachea from animals which had been actively sensitised to ovalbumin, polygodial produced time and concentration-dependent inhibition of ovalbumin-mediated contraction. In addition, polygodial inhibited contraction induced by compound 48/80 in the guinea-pig trachea from non-sensitised animals. The results suggested polygodial could be of potential value in the development of a new drug for the treatment of asthma, allergy and other inflammatory processes.

Polygodial inhibited both neutrophil infiltration and neutrophil superoxide production in an monosodium urate crystal-induced mouse model of gouty inflammation in the micromolar and submicromolar ranges (Martin et al. 2009). The results suggested its potential for development as anti-inflammatory agents for the treatment of neutrophil-driven inflammatory diseases including gout.

Antimicrobial Activity

Polygodial was found to have antifungal and antibacterial activities.

Polygodial exerted potent antifungal activity, comparable to amphotericin B, against yeast-like fungi *Candida albicans*, *Candida utilis*, *Candida krusei*, *Cryptococcus neoformans*, *Saccharomyces cerevisiae* and also filamentous fungi including *Trichophyton mentagrophytes*, *Trichophyton rubrum*, and *Penicillium marneffei* (Lee et al. 1999). Other fungi such as *Aspergillus fumigatus*, *Aspergillus flavus*, *Penicillium chrysogenum*, *Candida lipolytica*, and *Candida tropicalis* showed moderate to low susceptibility to polygodial. Based on killing kinetics against growing and nongrowing *Candida albicans*, polygodial showed potent and rapid fungicidal activity.

Studies with *Saccharomyces cerevisiae* showed that the antifungal mechanism was associated with the inhibition of plasma membrane H⁺-ATPase or derangement of the membrane (Kubo et al. 2005a). The primary antifungal action of polygodial arose from its ability to act as a surfactant that nonspecifically disrupted the lipid-protein interface of integral proteins, denaturing their functioned conformation. Once polygodial entered the cytoplasm by destroying the membrane barrier, it reacted with L-cysteine-containing cytoplasmic materials, such as a small molecule, glutathione, and a protein, alcohol dehydrogenase, to potentiate the antifungal action. Polygodial was found to exhibit a fungicidal activity against the food spoilage yeast, *Zygosaccharomyces bailii*, with the minimum fungicidal concentration (MFC) of 50 µg/mL (Kubo and Fujita 2005b). The primary mechanism involved was attributed to its ability to disrupt the native membrane-associated function of integral proteins as nonionic surface active agents (surfactants) followed by a decrease in plasma membrane fluidity. The fungicidal activity of polygodial was enhanced 128-fold in combination with a sublethal amount (equivalent of 1/2 MFC) of anethole and that of sorbic acid was enhanced 512-fold in combination with 1/2 MFC of polygodial. Polygodial showed strong antifungal

activity against dermatophytes *Epidermophyton floccosum* and *Trichophyton rubrum* (Malheiros et al. 2005). The combination of miconazole with polygodial exhibited strong synergism on both fungistatic and fungicidal action against the opportunistic fungal pathogen *Candida albicans* (Kubo et al. 2011).

Polygodial and (2E)-hexenal were found to possess antibacterial activity against the food borne bacterium, *Salmonella choleraesuis* with the minimum bactericidal concentrations (MBC) of 50 µg/mL and 100 µg/mL respectively (Kubo and Fujita 2001). The combination of polygodial and anethole exhibited strong synergism on their bacteriostatic action but only marginal synergism on their bactericidal action.

Attachment Inhibitory Activity

Polygodial, from a *Tasmania lanceolata* hexane leaf extract was found to be a highly potent attachment-inhibitor (Ban et al. 2000). The attachment-inhibiting activity of polygodial against the blue mussel was augmented 4-times when used in combination with sorbic acid, anethole, and indole.

Antiprotozoal Activity

Polygodial was found to have anti-leishmanial and anti-trypansomal activities (Corrêa et al. 2011). polygodial displayed activity against *Leishmania* spp. in the range between 22 and 62 µg/mL, and showed high parasite selectivity towards *Trypanosoma cruzi* trypomastigotes (2 µg/mL). It demonstrated a leishmanicidal effect, inducing intense ultrastructural damages in *Leishmania* in short-time incubation.

Antifeedant Activity

Polygodial had been reported to exhibit anti-feedant on larvae of *Leptinotarsa decemlineata* and *Spodoptera littoralis* (Caprioli et al. 1987), *Spodoptera littoralis*, *Leptinotarsa decemlineata*,

Myzus persicae and *Rhopalosiphum padi* (Moreno-Osorio et al. 2008).

Miscellaneous Activity

During the early colonial days in Australia, mountain pepper had been used in medicine as a stomachic, scurvy and as a substitute for Winter's bark (Lassak and McCarthy 2001).

Other Uses

The fruit can be used as a fish poison. Mountain pepper can be grown as a hedge in mild temperate areas and also makes an excellent windbreak in woodland. It can be grown as a garden plant.

Comments

Mountain pepper can be grown from seeds and stem cuttings which strike readily.

Selected References

- André E, Malheiros A, Cechinel-Filho V, Yunes RA, Calixto JB (1999) Mechanisms underlying the relaxation caused by the sesquiterpene polygodial in vessels from rabbit and guinea-pig. *Eur J Pharmacol* 386(1):47–53
- Ban T, Singh IP, Etoh H (2000) Polygodial, a potent attachment-inhibiting substance for the blue mussel, *Mytilus edulis galloprovincialis* from *Tasmannia lanceolata*. *Biosci Biotechnol Biochem* 64(12):2699–2701
- Caprioli V, Cimino G, Colle R, Gavagnin M, Sodano G, Spinella A (1987) Insect antifeedant activity and hot taste for humans of selected natural and synthetic 1,4-dialdehydes. *J Nat Prod* 50(2):146–151
- Corrêa DS, Tempone AG, Reimão JQ, Taniwaki NN, Romoff P, Fávero OA, Sartorelli P, Mecchi MC, Lago JH (2011) Anti-leishmanial and anti-trypanosomal potential of polygodial isolated from stem barks of *Drimys brasiliensis* Miers (Winteraceae). *Parasitol Res* 109(1):231–236
- Cunha FM, Fröde TS, Mendes GL, Malheiros A, Filho VC, Yunes RA, Calixto JB (2001) Additional evidence for the anti-inflammatory and anti-allergic properties of the sesquiterpene polygodial. *Life Sci* 70(2):159–169
- Department of primary industries, parks, water and environment. “*Tasmannia lanceolata*”. Department of primary industries, parks, water and environment website. Tasmanian Government. [http://www.dpiw.tas.gov.au/inter.nsf/Attachments/LJEM-7CV7BN/\\$FILE/Tasmannia%20lanceolata%20Notesheet.pdf](http://www.dpiw.tas.gov.au/inter.nsf/Attachments/LJEM-7CV7BN/$FILE/Tasmannia%20lanceolata%20Notesheet.pdf). Retrieved 13 Aug 2009
- Dragar VA, Garland SM, Menary RC (1988) Investigation of the variation in chemical composition of *Tasmannia lanceolata* solvent extracts. *J Agric Food Chem* 46(8):3210–3213
- El Sayah M, Filho VC, Yunes RA, Malheiros A, Calixto JB (2000) Action of polygodial on agonist-induced contractions of the rat portal vein in vitro. *J Cardiovasc Pharmacol* 35(4):670–675
- Floyd AG (1989) Rainforest trees of mainland South-eastern Australia. Inkata Press, Melbourne
- Fujita K, Kubo I (2005a) Multifunctional action of antifungal polygodial against *Saccharomyces cerevisiae*: involvement of pyrrole formation on cell surface in antifungal action. *Bioorg Med Chem* 13(24):6742–6747
- Fujita K, Kubo I (2005b) Naturally occurring antifungal agents against *Zygosaccharomyces bailii* and their synergism. *J Agric Food Chem* 53(13):5187–5191
- Konczak I, Zabarás D, Dunstan M, Aguas P (2010) Antioxidant capacity and phenolic compounds in commercially grown native Australian herbs and spices. *Food Chem* 122(1):260–266
- Kubo I, Fujita K (2001) Naturally occurring anti-*Salmonella* agents. *J Agric Food Chem* 49(12):5750–5754
- Kubo I, Fujita K, Lee SH (2001) Antifungal mechanism of polygodial. *J Agric Food Chem* 49(3):1607–1611
- Kubo I, Lee SH, Shimizu K (2011) Combination effect of miconazole with polygodial against *Candida albicans*. *Open J Med Microbiol* 1(1):7–11
- Lassak EV, McCarthy T (2001) Australian medicinal plants. New Holland, Reed
- Lee SH, Lee JR, Lunde CS, Kubo I (1999) In vitro antifungal susceptibilities of *Candida albicans* and other fungal pathogens to polygodial, a sesquiterpene dialdehyde. *Planta Med* 65(3):204–208
- Loder JW (1962) Occurrence of the sesquiterpenes polygodial and guaicol in the leaves of *Drymis lanceolata* (Poir.) Baill. *Aust J Chem* 15:389–390
- Malheiros A, Filho VC, Schmitt CB, Santos ARS, Scheidt C, Calixto JB, Monache FD, Yunes RA (2001) A sesquiterpene drimane with antinociceptive activity from *Drimys winteri* bark. *Phytochemistry* 57(1):103–107
- Malheiros A, Cechinel Filho V, Schmitt CB, Yunes RA, Escalante A, Svetaz L, Zacchino S, Delle Monache F (2005) Antifungal activity of drimane sesquiterpenes from *Drimys brasiliensis* using bioassay-guided fractionation. *J Pharm Pharm Sci* 8(2):335–339
- Martin WJ, Herst PM, Chia EW, Harper JL (2009) Sesquiterpene dialdehydes inhibit MSU crystal-induced superoxide production by infiltrating neutrophils in an in vivo model of gouty inflammation. *Free Radic Biol Med* 47(5):616–621

- Matsuda H, Pongpiriyadacha Y, Morikawa T, Kashima Y, Nakano K, Yoshikawa M (2002) Protective effects of polygodial and related compounds on ethanol-induced gastric mucosal lesions in rats: structural requirements and mode of action. *Bioorg Med Chem Lett* 12(3):477–482
- Menary RC, Drager VA, Garland SA (1999) *Tasmannia lanceolata* – Developing a new commercial flavour product. A report for the Rural Industries and Development Corporation, Publication No 99/124, Project No. UT-11A, RIRDC, Barton, ACT
- Mendes GL, Santos ARS, Campos MM, Tratsk KS, Yunes RA, Filho VC, Calixto JB (1998) Anti-hyperalgesic properties of the extract and of the main sesquiterpene polygodial isolated from the barks of *Drymis winteri* (Winteraceae). *Life Sci* 63(5):369–381
- Mendes GL, Santos AR, Malheiros A, Filho VC, Yunes RA, Calixto JB (2000) Assessment of mechanisms involved in antinociception caused by sesquiterpene polygodial. *J Pharmacol Exp Ther* 292(1):164–172
- Moreno-Osorio L, Cortés M, Armstrong V, Bailén M, González-Coloma A (2008) Antifeedant activity of some polygodial derivatives. *Z Naturforsch C* 63(3–4):215–220
- Pellow BJ, Pellow B, Henwood M, Carolin R (2009) Flora of the Sydney region. Sydney University Press, Sydney
- Pongpiriyadacha Y, Matsuda H, Morikawa T, Asao Y, Yoshikawa M (2003) Protective effects of polygodial on gastric mucosal lesions induced by necrotizing agents in rats and the possible mechanisms of action. *Biol Pharm Bull* 26:651–657
- Read C, Menary R (2000) Analysis of the contents of oil cells in *Tasmannia lanceolata* (Poir.) A. C. Smith (Winteraceae). *Ann Bot* 86:1193–1197
- Southwell IA, Brophy JJ (1992) Differentiation within the Australian *Tasmannia* by essential oil comparison. *Phytochemistry* 31(9):3073–3081
- Tratsk KS, Campos MM, Vaz ZR, Filho VC, Schlemper V, Yunes RA, Calixto JB (1997) Anti-allergic effects and oedema inhibition caused by the extract of *Drymis winteri*. *Inflamm Res* 46(12):509–514
- Vink W (1970) The Winteraceae of the old world. I. Pseudowintera and Drimys – morphology and taxonomy. *Blumea* 18:225–354
- Vink W (1988) Taxonomy in Winteraceae. *Taxonomy* 37(3):691–698
- Zhao J, Agboola S (2007) Functional properties of Australian bushfoods – a report for the Rural Industries Research and Development Corporation. RIRDC Publication No 07/030. RIRDC, Barton, ACT

Author's Blurb

TK Lim (Tong Kwee Lim) obtained his Bachelor and Masters in Agricultural Science from the University of Malaya and his Ph.D. (Botanical Sciences) from the University of Hawaii. He worked in the University of Agriculture Malaysia for 20 years as a lecturer and Associate Professor; as Principal Horticulturist for 9 years for the Department of Primary Industries and Fisheries, Darwin, Northern Territory; 6 years as Manager of the Asia and Middle East Team in Plant Biosecurity Australia, Department of Agriculture, Fisheries and Forestry, Australia; and 4 years as Research Program Manager with the Australian Centre for International Agriculture Research (ACIAR), Department of Foreign Affairs and Trade, Australia before he retired from public service. He has published over a 100 scientific papers including several books: “Guava in Malaysia: Production, Pest and Diseases”, “Durian Diseases and Disorders”, “Diseases of Mango in Malaysia”, chapters in books, international refereed journals, conference proceedings (as editor) and technical bulletins in the areas of plant pathology, crop protection, horticulture, agronomy and quarantine science. He was also a reviewer of scientific papers for several international scientific journals. As Principal Horticulturist in Darwin, he and his team were instrumental in establishing the horticultural industry in the Northern Territory, Australia,

especially on tropical fruits, vegetables, culinary herbs, spices/medicinal herbs and tropical flowers. During his tenure with Plant Biosecurity, he led a team responsible for conducting pest risk analyses and quarantine policy issues dealing with the import and export of plants and plant products into and out of Australia for the Middle East and Asian region. During his time with ACIAR, he oversaw and managed international research and development programs in plant protection and horticulture covering a wide array of crops that included fruits, plantation crops, vegetables, culinary and medicinal herbs and spices mainly in southeast Asia and the Pacific. In the course of his four decades of working career he has travelled extensively worldwide to many countries in South Asia, East Asia, southeast Asia, Middle East, Europe, the Pacific Islands, USA and England, and also throughout Malaysia and Australia. Since his tertiary education days he always had a strong passion for crops and took an avid interest in edible and medicinal plants. Over the four decades, he has taken several thousands of photographs of common, known and lesser known edible, medicinal and non-medicinal plants, amassed local literature, local indigenous knowledge, books, and has developed and established close rapport with many local researchers, scientists, growers and farmers during the course of his work and travels.

Medical Glossary

- AAD** Allergic airway disease, an inflammatory disorder of the airways caused by allergens.
- AAPH** 2,2'-azobis(2-amidinopropane) dihydrochloride, a water-soluble azo compound used extensively as a free radical generator, often in the study of lipid peroxidation and the characterization of antioxidants.
- Abeta aggregatio** Amyloid beta protein (Abeta) aggregation is associated with Alzheimer's disease (AD); it is a major component of the extracellular plaque found in AD brains.
- Abdominal distension** referring to generalised distension of most or all of the abdomen. Also referred to as stomach bloating often caused by a sudden increase in fibre from consumption of vegetables, fruits and beans.
- Ablation therapy** the destruction of small areas of myocardial tissue, usually by application of electrical or chemical energy, in the treatment of some tachyarrhythmias.
- Abortifacient** a substance that causes or induces abortion.
- Abortivum** a substance inducing abortion.
- Abscess** a swollen infected, inflamed area filled with pus in body tissues.
- ABTS** 2,2-azino-bis(3-ethylthiazoline-6-sulfonic acid), a type of mediator in chemical reaction kinetics of specific enzymes.
- ACAT** acyl CoA: cholesterol acyltransferase.
- ACE** see angiotensin-converting enzyme.
- ACTH (Adrenocorticotrophic hormone)** also known as 'corticotropin', is a polypeptide tropic hormone produced and secreted by the anterior pituitary gland.
- Acetogenins** natural products from the plants of the family Annonaceae, are very potent inhibitors of the NADH-ubiquinone reductase (Complex I) activity of mammalian mitochondria.
- Acetyl-CoA carboxylase (ACC)** enzyme that catalyzes the biotin-dependent carboxylation of acetyl-CoA to produce malonyl-CoA.
- Acetylcholinesterase (AChE)** is an enzyme that degrades (through its hydrolytic activity) the neurotransmitter acetylcholine, producing choline.
- Acne vulga'ris** also known as chronic acne, usually occurring in adolescence, with comedones (blackheads), papules (red pimples), nodules (inflamed acne spots), and pustules (small inflamed pus-filled lesions) on the face, neck, and upper part of the trunk.
- Acidosis** increased acidity, an excessively acid condition of the body fluids.
- Acquired immunodeficiency syndrome (AIDS)** an epidemic disease caused by an infection by human immunodeficiency virus (HIV-1, HIV-2), retrovirus that causes immune system failure and debilitation and is often accompanied by infections such as tuberculosis.
- Acridone** an organic compound based on the acridine skeleton, with a carbonyl group at the 9 position.
- ACTH** adrenocorticotrophic hormone (or corticotropin), a polypeptide tropic hormone produced and secreted by the anterior pituitary gland. It plays a role in the synthesis and secretion of gluco- and mineralo-corticosteroids and androgenic steroids.

- Activating transcription factor (ATF)** a protein (gene) that binds to specific DNA sequences regulating the transfer or transcription of information from DNA to mRNA.
- Activator protein-1 (AP-1)** a heterodimeric protein transcription factor that regulates gene expression in response to a variety of stimuli, including cytokines, growth factors, stress, and bacterial and viral infections. AP-1 in turn regulates a number of cellular processes including differentiation, proliferation, and apoptosis.
- Acyl-CoA dehydrogenases** A group of enzymes that catalyzes the initial step in each cycle of fatty acid β -oxidation in the mitochondria of cells.
- Adaptogen** a term used by herbalists to refer to a natural herb product that increases the body's resistance to stresses such as trauma, stress and fatigue.
- Adaptogenic** increasing the resistance of the body to stress.
- Addison's disease** is a rare endocrine disorder. It occurs when the adrenal glands cannot produce sufficient hormones (corticosteroids). It is also known as chronic adrenal insufficiency, hypocortisolism or hypocorticism.
- Adenocarcinoma** a cancer originating in glandular tissue.
- Adenoma** a benign tumour from a glandular origin.
- Adenopathy** abnormal enlargement or swelling of the lymph node.
- Adenosine receptors** a class of purinergic, G-protein coupled receptors with adenosine as endogenous ligand. In humans, there are four adenosine receptors. A_1 receptors and A_{2A} play roles in the heart, regulating myocardial oxygen consumption and coronary blood flow, while the A_{2A} receptor also has broader antiinflammatory effects throughout the body. These two receptors also have important roles in the brain, regulating the release of other neurotransmitters such as dopamine and glutamate, while the A_{2B} and A_3 receptors are located mainly peripherally and are involved in inflammation and immune responses.
- ADH** see alcohol dehydrogenase.
- Adipocyte** a fat cell involved in the synthesis and storage of fats.
- Adipocytokine** bioactive cytokines produced by adipose tissues.
- Adiponectin** a protein in humans that modulates several physiological processes, such as metabolism of glucose and fatty acids, and immune responses.
- Adipose tissues** body fat, loose connective tissue composed of adipocytes (fat cells).
- Adoptogen** containing smooth pro-stressors which reduce reactivity of host defense systems and decrease damaging effects of various stressors due to increased basal level of mediators involved in the stress response.
- Adrenal glands** star-shaped endocrine glands that sit on top of the kidneys.
- Adrenalectomized** having had the adrenal glands surgically removed.
- Adrenergic** having to do with adrenaline (epinephrine) and/or noradrenaline (norepinephrine).
- Adrenergic receptors** a class of G protein-coupled receptors that are targets of the noradrenaline (norepinephrine) and adrenaline (epinephrine).
- Adulterant** an impure ingredient added into a preparation.
- Advanced Glycation End products (AGEs)** resultant products of a chain of chemical reactions after an initial glycation reaction. AGEs may play an important adverse role in process of atherosclerosis, diabetes, aging and chronic renal failure.
- Aegilops** an ulcer or fistula in the inner corner of the eye.
- Afferent** something that so conducts or carries towards, such as a blood vessel, fibre, or nerve.
- Agammaglobulinaemia** an inherited disorder in which there are very low levels of protective immune proteins called immunoglobulins. Cf. x-linked agammaglobulinaemia.
- Agalactia** lack of milk after parturition (birth).
- Age-related macular degeneration (AMD)** a medical condition of elderly adults that results in a loss of vision in the center of the visual field (the macula) because of damage to the retina.
- Agglutinin** a protein substance, such as an antibody, that is capable of causing agglutination (clumping) of a particular antigen.
- Agglutination** clumping of particles.

- Agonist** a drug that binds to a receptor of a cell and triggers a response by the cell.
- Ague** a fever (such as from malaria) that is marked by paroxysms of chills, fever, and sweating that recurs with regular intervals.
- AHR** AhR, aryl hydrocarbon receptor, a cytosolic protein transcription factor.
- AIDS** see Acquired Immunodeficiency Syndrome.
- Akathisia** a movement disorder in which there is an urge or need to move the legs to stop unpleasant sensations. Also called restless leg syndrome, the disorder is often caused by long-term use of antipsychotic medications.
- AKT** serine/threonine kinase (also known as protein kinase B or PKB) plays a critical regulatory role in diverse cellular processes, including cancer progression and insulin metabolism.
- Akt signaling pathway** Akt are protein kinases involved in mammalian cellular signaling, inhibits apoptotic processes.
- Akt/FoxO pathway** Cellular processes involving Akt and FoxO transcription factors that play a role in angiogenesis and vasculogenesis.
- Alanine transaminase (ALT)** also called Serum Glutamic Pyruvate Transaminase (SGPT) or Alanine aminotransferase (ALAT), an enzyme present in hepatocytes (liver cells). When a cell is damaged, it leaks this enzyme into the blood.
- ALAT, (Alanine aminotransferase)** see Alanine transaminase.
- Albumin** water soluble proteins found in egg white, blood serum, milk, various animal tissues and plant juices and tissues.
- Albuminuria** excessive amount of albumin in the urine, a symptom of severe kidney disease.
- Aldose reductase, aldehyde reductase** an enzyme in carbohydrate metabolism that converts glucose to sorbitol.
- Alexipharmic** an antidote, remedy for poison.
- Alexiteric** a preservative against contagious and infectious diseases, and the effects of poisons.
- Alcohol dehydrogenase (ADH)** an enzyme involved in the break-down of alcohol.
- Algesic** endogenous substances involved in the production of pain that is associated with inflammation, e.g. serotonin, bradykinin and prostaglandins.
- Alkaline phosphatase (ALP)** an enzyme in the cells lining the biliary ducts of the liver. ALP levels in plasma will rise with large bile duct obstruction, intrahepatic cholestasis or infiltrative diseases of the liver. ALP is also present in bone and placental tissues.
- Allergenic** having the properties of an antigen (allergen), immunogenic.
- Allergic** pertaining to, caused, affected with, or the nature of the allergy.
- Allergic conjunctivitis** inflammation of the tissue lining the eyelids (conjunctiva) due to allergy.
- Allergy** a hypersensitivity state induced by exposure to a particular antigen (allergen) resulting in harmful immunologic reactions on subsequent exposures. The term is usually used to refer to hypersensitivity to an environmental antigen (atopic allergy or contact dermatitis) or to drug allergy.
- Allogeneic** cells or tissues which are genetically different because they are derived from separate individuals of the same species. Also refers to a type of immunological reaction that occurs when cells are transplanted into a genetically different recipient.
- Allografts** or homografts, a graft between individuals of the same species, but of different genotypes.
- Alloknesis** itch produced by innocuous mechanical stimulation.
- Allostasis** the process of achieving stability, or homeostasis, through physiological or behavioral change.
- Alopecia** is the loss of hair on the body.
- Alopeci areata** is a particular disorder affecting hair growth (loss of hair) in the scalp and elsewhere.
- ALP** see Alkaline phosphatase.
- Alpha-adrenoceptor** receptors postulated to exist on nerve cell membranes of the sympathetic nervous system in order to explain the specificity of certain agents that affect only some sympathetic activities (such as vasoconstriction and relaxation of intestinal muscles and contraction of smooth muscles).
- Alpha amylase α -amylase** a major form of amylase found in humans and other mammals that cleaves alpha-bonds of large sugar molecules.
- ALT** see Alanine transaminase.
- Alterative** a medication or treatment which gradually induces a change, and restores healthy functions without sensible evacuations.

- Alveolar macrophage** a vigorously phagocytic macrophage on the epithelial surface of lung alveoli that ingests carbon and other inhaled particulate matter. Also called conioophage or dust cell.
- Alzheimer's disease** a degenerative, organic, mental disease characterized by progressive brain deterioration and dementia, usually occurring after the age of 50.
- Amastigote** refers to a cell that does not have any flagella, used mainly to describe a certain phase in the life-cycle of trypanosome protozoans.
- Amenorrhea** the condition when a woman fails to have menstrual periods.
- Amidolytic** cleavage of the amide structure.
- Amoebiasis** state of being infected by amoeba such as *Entamoeba histolytica*.
- Amoebicidal** lethal to amoeba.
- AMPK (5' AMP-activated protein kinase)** or 5' adenosine monophosphate-activated protein kinase, enzyme that plays a role in cellular energy homeostasis.
- Amyloid bet (A β or Abeta)** a peptide of 39–43 amino acids that appear to be the main constituent of amyloid plaques in the brains of Alzheimer's disease patients.
- Amyloidosis** a disorder that results from abnormal deposition of the protein, amyloid, in various tissues of the body.
- Amyotrophic lateral sclerosis** or ALS, is a disease of the motor neurons in the brain and spinal cord that control voluntary muscle movement.
- Amyotrophy** progressive wasting of muscle tissues. *adj.* amyotrophic.
- Anaemia** a blood disorder in which the blood is deficient in red blood cells and in haemoglobin.
- Anaesthesia** condition of having sensation temporarily suppressed.
- Anaesthetic** a substance that decreases partially or totally nerve the sense of pain.
- Analeptic** a central nervous system (CNS) stimulant medication.
- Analgesia** term describing relief, reduction or suppression of pain. *adj.* analgetic.
- Analgesic** a substance that relieves or reduces pain.
- Anaphoretic** an antiperspirant.
- Anaphrodisiac** or antiaphrodisiac is something that reduces or blunts the libido.
- Anaphylaxis** a severe, life-threatening allergic response that may be characterized by symptoms such as reduced blood pressure, wheezing, vomiting or diarrhea.
- Anaphylactic** *adj.* see anaphylaxis.
- Anaphylotoxins** are fragments (C3a, C4a or C5a) that are produced during the pathways of the complement system. They can trigger release of substances of endothelial cells, mast cells or phagocytes, which produce a local inflammatory response.
- Anaplasia** a reversion of differentiation in cells and is characteristic of malignant neoplasms (tumours).
- Anaplastic** *adj.* see anaplasia.
- Anasarca** accumulation of great quantity of fluid in body tissues.
- Anencephaly** a cephalic disorder that results from a neural tube defect that occurs when the cephalic (head) end of the neural tube fails to close, resulting in the absence of a major portion of the brain, skull, and scalp.
- Androgen** male sex hormone in vertebrates. Androgens may be used in patients with breast cancer to treat recurrence of the disease.
- Android adiposity** centric fat distribution patterns with increased disposition towards the abdominal area, visceral fat – apple shaped cf gynoid adiposity.
- Andrology** branch of medicine concerned with the reproductive diseases in men.
- Aneugen** an agent that affects cell division and the mitotic spindle apparatus, causing the loss or gain of whole chromosomes, thereby inducing aneuploidy. *adj.* aneugenic.
- Angina pectoris, Angina** chest pain or chest discomfort that occurs when the heart muscle does not get enough blood.
- Angiogenic** *adj.* see angiogenesis.
- Angiogenesis** a physiological process involving the growth of new blood vessels from pre-existing vessels.
- Angiotensin** an oligopeptide hormone in the blood that causes blood vessels to constrict, and drives blood pressure up. It is part of the renin-angiotensin system.
- Angiotensin-converting enzyme (ACE)** an exopeptidase, a circulating enzyme that participates in the body's renin-angiotensin system (RAS) which mediates extracellular volume (i.e. that of the blood plasma, lymph and interstitial fluid), and arterial vasoconstriction.

- Angioplasty** medical procedure used to open obstructed or narrowed blood vessel resulting usually from atherosclerosis.
- Anisonucleosis** a morphological manifestation of nuclear injury characterized by variation in the size of the cell nuclei.
- Ankylosing spondylitis (AS)** is a type of inflammatory arthritis that targets the joints of the spine.
- Annexin V** or Annexin A5 is a member of the annexin family of intracellular proteins that binds to phosphatidylserine (PS) in a calcium-dependent manner.
- Annexitis** also called adnexitis, a pelvic inflammatory disease involving the inflammation of the ovaries or fallopian tubes.
- Anodyne** a substance that relieves or soothes pain by lessening the sensitivity of the brain or nervous system. Also called an analgesic.
- Anoikis** apoptosis that is induced by inadequate or inappropriate cell-matrix interactions.
- Anorectal** relating to the rectum and anus.
- Anorectics** appetite suppressants, substances which reduce the desire to eat. Used on a short term basis clinically to treat obesity. Also called anorexigenics.
- Anorexia** lack or loss of desire to eat.
- Anorexic** having no appetite to eat.
- Anorexigenics** see anorectics.
- Anoxia** absence of oxygen supply.
- Antagonist** a substance that acts against and blocks an action.
- Antalgic** a substance used to relieve a painful condition.
- Antecubital vein** This vein is located in the antecubital fossa -the area of the arm in front of the elbow.
- Anterior uveitis** is the most common form of ocular inflammation that often causes a painful red eye.
- Anthelmintic** an agent or substance that is destructive to worms and used for expulsion of internal parasitic worms in animals and humans.
- Anthocyanins** a subgroup of antioxidant flavonoids, are glucosides of anthocyanidins. Which are beneficial to health. They occur as water-soluble vacuolar pigments that may appear red, purple, or blue according to pH in plants.
- Anthrax** a bacterial disease of cattle and sheep that can be transmitted to man through unprocessed wool.
- Anthropometric** pertaining to the study of human body measurements.
- Antiamoebic** a substance that destroys or suppresses parasitic amoebae.
- Antiamyloidogenic** compounds that inhibit the formation of Alzheimer's β -amyloid fibrils (fA β) from amyloid β -peptide (A β) and destabilize fA β .
- Antianaphylactic** agent that can prevent the occurrence of anaphylaxis (life threatening allergic response).
- Antiangiogenic** a drug or substance used to stop the growth of tumours and progression of cancers by limiting the pathologic formation of new blood vessels (angiogenesis).
- Antiarrhythmic** a substance to correct irregular heartbeats and restore the normal rhythm.
- Antiasmatic** drug that treats or ameliorates asthma.
- Antiatherogenic** that protects against atherogenesis, the formation of atheromas (plaques) in arteries.
- Antibacterial** substance that kills or inhibits bacteria.
- Antibilious** an agent or substance which helps remove excess bile from the body.
- Antibiotic** a chemical substance produced by a microorganism which has the capacity to inhibit the growth of or to kill other microorganisms.
- Antiblenorrhagic** a substance that treats blenorrhagia a conjunctival inflammation resulting in mucus discharge.
- Antibody** a gamma globulin protein produced by a kind of white blood cell called the plasma cell in the blood used by the immune system to identify and neutralize foreign objects (antigen).
- Anticarcinomic** a substance that kills or inhibits carcinomas (any cancer that arises in epithelium/tissue cells).
- Anticephalalgic** headache-relieving or preventing.
- Anticestodal** a chemical destructive to tapeworms.
- Anticholesterolemic** a substance that can prevent the build up of cholesterol.
- Anticlastogenic** having a suppressing effect of chromosomal aberrations.

- Anticoagulant** a substance that thins the blood and acts to inhibit blood platelets from sticking together.
- Antidepressant** a substance that suppresses depression or sadness.
- Antidiabetic** a substance that prevents or alleviates diabetes. Also called antidiabetogenic.
- Antidiarrhoeal** having the property of stopping or correcting diarrhoea, an agent having such action.
- Antidote** a remedy for counteracting a poison.
- Antidopaminergic** a term for a chemical that prevents or counteracts the effects of dopamine.
- Antidrepanocytary** anti-sickle cell anaemia.
- Antidysenteric** an agent used to reduce or treat dysentery and diarrhea.
- Antidyslipidemic** agent that will reduce the abnormal amount of lipids and lipoproteins in the blood.
- Anti-edematous** reduces or suppresses edema.
- Antiemetic** an agent that stops vomiting and nausea.
- Anti-epileptic** a drug used to treat or prevent convulsions, anticonvulsant.
- Antifebrile** a substance that reduces fever, also called antipyretic.
- Antifeedant** preventing something from being eaten.
- Antifertility** agent that inhibits formation of ova and sperm and disrupts the process of fertilization (antizygotic).
- Anti-fibrosis** preventing/retarding the development of fibrosis i.e. excessive growth and activity of fibroblasts. t
- Antifilarial** effective against human filarial worms.
- Antifungal** an agent that kills or inhibits the growth of fungi.
- Antigen** a substance that prompts the production of antibodies and can cause an immune response. *adj.* antigenic.
- Antigenotoxic** an agent that inhibits DNA adduct formation, stimulates DNA repair mechanisms, and possesses antioxidant functions.
- Antiganacratia** anti- menstruation.
- Antigastralgalic** preventing or alleviating gastric colic.
- Antihematic** agent that stops vomiting.
- Antihemorrhagic** an agent which stops or prevents bleeding.
- Antihepatotoxic** counteracting injuries to the liver.
- Antitherpetic** having activity against Herpes Simplex Virus (HSV).
- Antihistamine** an agent used to counteract the effects of histamine production in allergic reactions.
- Antihyperalgesia** the ability to block enhanced sensitivity to pain, usually produced by nerve injury or inflammation, to nociceptive stimuli. *adj.* antihyperalgesic.
- Antihypercholesterolemi** term to describe lowering of cholesterol level in the blood or blood serum.
- Antihypercholesterolemic** agent that lowers cholesterol level in the blood or blood serum.
- Antihyperlidemic** promoting a reduction of lipid levels in the blood, or an agent that has this action.
- Antihypersensitive** a substance used to treat excessive reactivity to any stimuli.
- Antihypertensive** a drug used in medicine and pharmacology to treat hypertension (high blood pressure).
- Antiinflammatory** a substance used to reduce or prevent inflammation.
- Antileishmanial** inhibiting the growth and proliferation of *Leishmania* a genus of flagellate protozoans that are parasitic in the tissues of vertebrates.
- Antileprotic** therapeutically effective against leprosy.
- Antilithiatic** an agent that reduces or suppresses urinary calculi (stones) and acts to dissolve those already present.
- Antileukaemic** anticancer drugs that are used to treat leukemia.
- Antilithogenic** inhibiting the formation of calculi (stones).
- Antimalarial** an agent used to treat malaria and/or kill the malaria-causing organism, *Plasmodium* spp.
- Antimelanogenesis** obstruct production of melanin.
- Antimicrobial** a substance that destroys or inhibits growth of disease-causing bacteria, viruses, fungi and other microorganisms.
- Antimitotic** inhibiting or preventing mitosis.
- Antimutagenic** an agent that inhibits mutations.
- Antimycotic** antifungal.
- Antineoplastic** said of a drug intended to inhibit or prevent the maturation and proliferation of

- neoplasms that may become malignant, by targeting the DNA.
- Antineuralgic** a substance that stops intense intermittent pain, usually of the head or face, caused by neuralgia.
- Antinociception** reduction in pain: a reduction in pain sensitivity produced within neurons when an endorphin or similar opium-containing substance opioid combines with a receptor.
- Antinociceptive** having an analgesic effect.
- Antioxytotic** inhibiting premature labour. cf. tocolytic.
- Antinutrient** are natural or synthetic compounds that interfere with the absorption of nutrients and are commonly found in food sources and beverages.
- Antioestrogen** a substance that inhibits the biological effects of female sex hormones.
- Antipheidian** anti venoms of snake.
- Antiosteoporotic** substance that can prevent osteoporosis.
- Antiovolatory** substance suppressing ovulation.
- Antioxidant** a chemical compound or substance that inhibits oxidation and protects against free radical activity and lipid oxidation such as vitamin E, vitamin C, or beta-carotene (converted to vitamin B), carotenoids and flavonoids which are thought to protect body cells from the damaging effects of oxidation. Many foods including fruit and vegetables contain compounds with antioxidant properties. Antioxidants may also reduce the risks of cancer and age-related macular degeneration (AMD).
- Antipaludic** antimalarial.
- Antiperiodic** substance that prevents the recurrence of symptoms of a disease e.g. malaria.
- Antiperspirant** a substance that inhibits sweating. Also called antisudorific, anaphoretic.
- Antiphlogistic** a traditional term for a substance used against inflammation, an anti-inflammatory.
- Antiplatelet agent** drug that decreases platelet aggregation and inhibits thrombus formation.
- Antiplasmodial** suppressing or destroying plasmodia.
- Antiproliferative** preventing or inhibiting the reproduction of similar cells.
- Antiprostatic** drug to treat the prostate.
- Antiprotozoa** suppressing the growth or reproduction of protozoa.
- Antipruritic** alleviating or preventing itching.
- Antipyretic** a substance that reduces fever or quells it. Also known as antithermic.
- Antirheumatic** relieving or preventing rheumatism.
- Antiscorbutic** a substance or plant rich in vitamin C that is used to counteract scurvy.
- Antisecretory** inhibiting or diminishing secretion.
- Antisense** refers to antisense RNA strand because its sequence of nucleotides is the complement of message sense. When mRNA forms a duplex with a complementary antisense RNA sequence, translation of the mRNA into the protein is blocked. This may slow or halt the growth of cancer cells.
- Antiseptic** preventing decay or putrefaction, a substance inhibiting the growth and development of microorganisms.
- Anti-sickling agent** an agent used to prevent or reverse the pathological events leading to sickling of erythrocytes in sickle cell conditions.
- Antispasmodic** a substance that relieves spasms or inhibits the contraction of smooth muscles; smooth muscle relaxant, muscle-relaxer.
- Antispermatogetic** preventing or suppressing the production of semen or spermatozoa.
- Antisudorific** see antiperspirant.
- Antisyphilitic** a drug (or other chemical agent) that is effective against syphilis.
- Antithermic** a substance that reduces fever and temperature. Also known as antipyretic.
- Antithrombotic** preventing or interfering with the formation of thrombi.
- Antitoxin** an antibody with the ability to neutralize a specific toxin.
- Antitumoral** substance that acts against the growth, development or spread of a tumour.
- Antitussive** a substance that depresses coughing.
- Antiulcerogenic** an agent used to protect against the formation of ulcers, or is used for the treatment of ulcers.
- Antivenin** an agent used against the venom of a snake, spider, or other venomous animal or insect.
- Antivinous** an agent or substance that treats addiction to alcohol.
- Antiviral** substance that destroys or inhibits the growth and viability of infectious viruses.

- Antivomitive** a substance that reduces or suppresses vomiting.
- Antizygotic** see antifertility.
- Anuria** absence of urine production and excretion. *adj.* anuric.
- Anxiogenic** substance that causes anxiety.
- Anxiolytic** a drug prescribed for the treatment of symptoms of anxiety.
- APAF-1** apoptotic protease activating factor 1.
- Apelin** also known as APLN, a peptide which in humans is encoded by the APLN gene.
- Aperient** a substance that acts as a mild laxative by increasing fluids in the bowel.
- Aperitif** an appetite stimulant.
- Aphonia** loss of the voice resulting from disease, injury to the vocal cords, or various psychological causes, such as hysteria.
- Aphrodisiac** an agent that increases sexual activity and libido and/or improves sexual performance.
- Aphthae** white, painful oral ulcer of unknown cause.
- Aphthous ulcer** also known as a canker sore, is a type of oral ulcer, which presents as a painful open sore inside the mouth or upper throat.
- Aphthous stomatitis** a canker sore, a type of painful oral ulcer or sore inside the mouth or upper throat, caused by a break in the mucous membrane. Also called aphthous ulcer.
- Apnoea** suspension of external breathing.
- Apolipoprotein B (APOB)** primary apolipoprotein of low-density lipoproteins which is responsible for carrying cholesterol to tissues.
- Apoplexy** a condition in which the brain's function stops with loss of voluntary motion and sense.
- Apoprotein** the protein moiety of a molecule or complex, as of a lipoprotein.
- Appendicitis** is a condition characterized by inflammation of the appendix. Also called epityphlitis.
- Appetite stimulant** a substance to increase or stimulate the appetite. Also called aperitif.
- aPPT (Activated Partial Thromboplastin Time)** a blood test, a measure of the part of the blood clotting pathway.
- Apolipoprotein A-I (APOA1)** a major protein component of high density lipoprotein (HDL) in plasma. The protein promotes cholesterol efflux from tissues to the liver for excretion.
- Apolipoprotein B (APOB)** is the primary apolipoprotein of low-density lipoproteins (LDL or "bad cholesterol"), which is responsible for carrying cholesterol to tissues.
- Apolipoprotein E (APOE)** the apolipoprotein found on intermediate density lipoprotein and chylomicron that binds to a specific receptor on liver and peripheral cells.
- Apoptogenic** ability to cause death of cells.
- Apoptosis** death of cells.
- Apurinic lyase** a DNA enzyme that catalyses a chemical reaction.
- Arachidonate cascade** includes the cyclooxygenase (COX) pathway to form prostanoids and the lipoxygenase (LOX) pathway to generate several oxygenated fatty acids, collectively called eicosanoids.
- ARE** antioxidant response element, is a transcriptional control element that mediates expression of a set of antioxidant proteins.
- Ariboflavinosis** a condition caused by the dietary deficiency of riboflavin that is characterized by mouth lesions, seborrhea, and vascularization.
- Aromatase** an enzyme involved in the production of estrogen that acts by catalyzing the conversion of testosterone (an androgen) to estradiol (an estrogen). Aromatase is located in estrogen-producing cells in the adrenal glands, ovaries, placenta, testicles, adipose (fat) tissue, and brain.
- Aromatic** having a pleasant, fragrant odour.
- Aromatherapy** a form of alternative medicine that uses volatile liquid plant materials, such as essential oils and other scented compounds from plants for the purpose of affecting a person's mood or health.
- ARPE-19 cells** a human retinal pigment epithelial cell line with differentiated properties.
- Arrhythmias** abnormal heart rhythms that can cause the heart to pump less effectively. Also called dysrhythmias.
- Arsenicosis** see arsenism.
- Arsenism** an incommunicable disease resulting from the ingestion of ground water containing unsafe levels of arsenic, also known as arsenicosis.
- Arteriogenic erectile dysfunction** a penis dysfunction caused by the narrowing of the arteries in the penis, decreasing blood inflow to it, thus making erection impossible.

- Arteriosclerosis** imprecise term for various disorders of arteries, particularly hardening due to fibrosis or calcium deposition, often used as a synonym for atherosclerosis.
- Arthralgia** is pain in the joints from many possible causes.
- Arthritis** inflammation of the joints of the body.
- Aryl hydrocarbon receptor (AhR)** a ligand-activated transcription factor best known for mediating the toxicity of dioxin and other exogenous contaminants and is responsible for their toxic effects, including immunosuppression.
- ASATor AST** aspartate aminotransferase, see aspartate transaminase.
- ASBT** apical sodium dependent bile acid transporter, belongs to the solute carrier family (SLC) of transporters and is an important carrier protein expressed in the small intestine.
- Ascaris** a genus of parasitic intestinal round worms.
- Ascites** abnormal accumulation of fluid within the abdominal or peritoneal cavity.
- Ascorbic acid** See vitamin C.
- Aspartate transaminase (AST)** also called Serum Glutamic Oxaloacetic Transaminase (SGOT) or aspartate aminotransferase (ASAT) is similar to ALT in that it is another enzyme associated with liver parenchymal cells. It is increased in acute liver damage, but is also present in red blood cells, and cardiac and skeletal muscle and is therefore not specific to the liver.
- Asphyxia** ilure or suppression of the respiratory process due to obstruction of air flow to the lungs or to the lack of oxygen in inspired air.
- Asphyxiation** the process of undergoing asphyxia.
- Asthenia** a nonspecific symptom characterized by loss of energy, strength and feeling of weakness.
- Asthenopia** weakness or fatigue of the eyes, usually accompanied by headache and dimming of vision. *adj.* asthenopic.
- Asthma** a chronic illness involving the respiratory system in which the airway occasionally constricts, becomes inflamed, and is lined with excessive amounts of mucus, often in response to one or more triggers.
- Astringent** a substance that contracts blood vessels and certain body tissues (such as mucous membranes) with the effect of reducing secretion and excretion of fluids and/or has a drying effect.
- Astrocytes** collectively called astroglia, are characteristic star-shaped glial cells in the brain and spinal cord.
- Ataxia** (loss of co-ordination) results from the degeneration of nerve tissue in the spinal cord and of nerves that control muscle movement in the arms and legs.
- Ataxia telangiectasia and Rad3-related protein (ATR)** also known as Serine/threonine-protein kinase ATR, FRAP-related protein 1 (FRP1), is an enzyme encoded by the ATR gene. It is involved in sensing DNA damage and activating the DNA damage checkpoint, leading to cell cycle arrest.
- ATF-2** activating transcription factor 2.
- Athlete's foot** a contagious skin disease caused by parasitic fungi affecting the foot, hands, causing itching, blisters and cracking. Also called dermatophytosis.
- Atherogenic** having the capacity to start or accelerate the process of atherogenesis.
- Atherogenesis** the formation of lipid deposits in the arteries.
- Atheroma** a deposit or degenerative accumulation of lipid-containing plaques on the innermost layer of the wall of an artery.
- Atherosclerosis** the condition in which an artery wall thickens as the result of a build-up of fatty materials such as cholesterol.
- Atherothrombosis** medical condition characterized by an unpredictable, sudden disruption (rupture or erosion/fissure) of an atherosclerotic plaque, which leads to platelet activation and thrombus formation.
- Athymic mice** laboratory mice lacking a thymus gland.
- Atonic** lacking normal tone or strength.
- Atony** insufficient muscular tone.
- Atopic dermatitis** an inflammatory, non-contagious, pruritic skin disorder of unknown etiology; often called eczema.
- Atresia** a congenital medical condition in which a body orifice or passage in the body is abnormally closed or absent.
- Atretic ovarian follicles** an involuted or closed ovarian follicle.
- Atrial fibrillation** is the most common cardiac arrhythmia (abnormal heart rhythm) and

involves the two upper chambers (atria) of the heart.

Attention-deficit hyperactivity disorder (ADHD, ADD or AD/HD) is a neurobehavioral developmental disorder, primarily characterized by the co-existence of attentional problems and hyperactivity.

Auditory brainstem response (ABR) also called brainstem evoked response (BSER) is an electrical signal evoked from the brainstem of a human by the presentation of a sound such as a click.

Augmerosen a drug that may kill cancer cells by blocking the production of a protein that makes cancer cells live longer. Also called bcl-2 antisense oligonucleotide.

Auricular of or relating to the auricle or the ear in general.

Aurones [2-benzylidenebenzofuran-3(2H)-ones] are the secondary plant metabolites and is a subgroup of flavonoids. See flavonoids.

Autoantibodies antibodies manufactured by the immune system that mistakenly target and damage specific tissues and organs of the body.

Autolysin an enzyme that hydrolyzes and destroys the components of a biological cell or a tissue in which it is produced.

Autonomic disorder a neurological disease in which the autonomic nervous system ceases to function properly.

Autophagy digestion of the cell contents by enzymes in the same cell.

Autopsy examination of a cadaver to determine or confirm the cause of death.

Avenanthramides low molecular weight, soluble phenolic compounds found in oats.

Avidity Index describes the collective interactions between antibodies and a multivalent antigen.

Avulsed teeth is tooth that has been knocked out.

Ayurvedic traditional Hindu system of medicine based largely on homeopathy and naturopathy.

Azoospermia is the medical condition of a male not having any measurable level of sperm in his semen.

Azotaemia a higher than normal blood level of urea or other nitrogen containing compounds in the blood.

B-cell activating factor (BAFF) also called tumor necrosis factor ligand superfamily member 13B. It plays an important role in the proliferation and differentiation of B cells.

Babesia a protozoan parasite (malaria-like) of the blood that causes a hemolytic disease known as Babesiosis.

Babesiosis malaria-like parasitic disease caused by *Babesia*, a genus of protozoal piroplasms.

Bactericidal lethal to bacteria.

Balanitis is an inflammation of the glans (head) of the penis.

BALB/c mice Balb/c mouse was developed in 1923 by McDowell. It is a popular strain and is used in many different research disciplines, but most often in the production of monoclonal antibodies.

Balm aromatic oily resin from certain trees and shrubs used in medicine.

Baroreceptor a type of interoceptor that is stimulated by pressure changes, as those in blood vessel wall.

Barrett's esophagus (Barrett esophagitis) a disorder in which the lining of the esophagus is damaged by stomach acid.

Basophil a type of white blood cell with coarse granules within the cytoplasm and a bilobate (two-lobed) nucleus.

Bax/Bad proapoptotic proteins.

BCL-2 a family of apoptosis regulator proteins in humans encoded by the B-cell lymphoma 2 (BCL-2) gene.

BCL-2 antisense oligonucleotide see augmereson.

BCR/ABL a chimeric oncogene, from fusion of BCR and ABL cancer genes associated with chronic myelogenous leukemia.

Bechic a remedy or treatment of cough.

Bed nucleus of the stria terminalis (BNST) act as a relay site within the hypothalamic-pituitary-adrenal axis and regulate its activity in response to acute stress.

Belching, or burping refers to the noisy release of air or gas from the stomach through the mouth.

Beri-beri is a disease caused by a deficiency of thiamine (vitamin B₁) that affects many systems of the body, including the muscles, heart, nerves, and digestive system.

- Beta-carotene** naturally-occurring retinol (vitamin A) precursor obtained from certain fruits and vegetables with potential antineoplastic and chemopreventive activities. As an antioxidant, beta carotene inhibits free-radical damage to DNA. This agent also induces cell differentiation and apoptosis of some tumour cell types, particularly in early stages of tumorigenesis, and enhances immune system activity by stimulating the release of natural killer cells, lymphocytes, and monocytes.
- Beta-catenin** is a multifunctional oncogenic protein that contributes fundamentally to cell development and biology, it has been implicated as an integral component in the Wnt signaling pathway.
- Beta cells** a type of cell in the pancreas in areas called the islets of Langerhans.
- Beta glucans** polysaccharides of D-glucose monomers linked by β -glycosidic bonds, (1 $\rightarrow$ 3), (1 $\rightarrow$ 4)- β -D-glucan, soluble, viscous component of fibres found in cereals like oats.
- Beta-thalassemia** an inherited blood disorder that reduces the production of hemoglobin.
- Beta-lactamase** enzymes produced by some bacteria that are responsible for their resistance to beta-lactam antibiotics like penicillins.
- BHT** butylated hydroxytoluene (phenolic compound), an antioxidant used in foods, cosmetics, pharmaceuticals, and petroleum products.
- Bifidobacterium** is a genus of Gram-positive, non-motile, often branched anaerobic bacteria. Bifidobacteria are one of the major genera of bacteria that make up the gut flora. Bifidobacteria aid in digestion, are associated with a lower incidence of allergies and also prevent some forms of tumour growth. Some bifidobacteria are being used as probiotics.
- Bifidogenic** promoting the growth of (beneficial) bifidobacteria in the intestinal tract.
- Bile** fluid secreted by the liver and discharged into the duodenum where it is integral in the digestion and absorption of fats.
- Bilharzia, bilharziosis** see Schistosomiasis.
- Biliary** relating to the bile or the organs in which the bile is contained or transported.
- Biliary infections** infection of organ(s) associated with bile, comprise: (a) acute cholecystitis: an acute inflammation of the gallbladder wall; (b) cholangitis: inflammation of the bile ducts.
- Biliousness** old term used in the eighteenth and nineteenth centuries pertaining to bad digestion, stomach pains, constipation, and excessive flatulence.
- Bilirubin** a breakdown product of heme (a part of haemoglobin in red blood cells) produced by the liver that is excreted in bile which causes a yellow discoloration of the skin and eyes when it accumulates in those organs.
- Biotin** also known as vitamin B7. See vitamin B7.
- Bitter** a medicinal agent with a bitter taste and used as a tonic, alternative or appetizer.
- Blackhead** see comedone.
- Blackwater fever** dangerous complication of malarial whereby the red blood cells burst in the blood stream (haemolysis) releasing haemoglobin directly into the blood.
- Blain** see chilblain.
- Blastocyst** blastocyst is an embryonic structure formed in the early embryogenesis of mammals, after the formation of the morula, but before implantation.
- Blastocystotoxic** agent that suppresses further development of the blastocyst through to the ovum stage.
- Blebbing** Bulging e.g. membrane blebbing also called membrane bulging or ballooning.
- Bleeding diathesis** is an unusual susceptibility to bleeding (hemorrhage) due to a defect in the system of coagulation.
- Blennorrhagia** gonorrhea.
- Blennorrhea** inordinate discharge of mucus, especially a gonorrheal discharge from the urethra or vagina.
- Blepharitis** inflammation of the eyelids.
- Blister** thin vesicle on the skin containing serum and caused by rubbing, friction or burn.
- Blood brain barrier (BBB)** is a separation of circulating blood and cerebrospinal fluid (CSF) in the central nervous system (CNS). It allows essential metabolites, such as oxygen and glucose, to pass from the blood to the brain and central nervous system (CNS) but blocks most molecules that are more massive than about 500 daltons.
- Boil** localized pyrogenic, painful infection, originating in a hair follicle.
- Borborygmus** rumbling noise caused by the muscular contractions of peristalsis, the

process that moves the contents of the stomach and intestines downward.

Bowman Birk inhibitors type of serine proteinase inhibitor.

Bouillon a broth in French cuisine.

Bradycardia as applied to adult medicine, is defined as a resting heart rate of under 60 beats per minute.

Bradyphrenia referring to the slowness of thought common to many disorders of the brain.

Brain derived neurotrophic factor (BDNF) a protein member of the neurotrophin family that plays an important role in the growth, maintenance, function and survival of neurons. The protein molecule is involved in the modulation of cognitive and emotional functions and in the treatment of a variety of mental disorders.

Bright's disease chronic nephritis.

Bronchial inflammation see bronchitis.

Bronchiectasis a condition in which the airways within the lungs (bronchial tubes) become damaged and widened.

Bronchitis is an inflammation of the main air passages (bronchi) to your lungs.

Bronchoalveolar lavage (BAL) a medical procedure in which a bronchoscope is passed through the mouth or nose into the lungs and fluid is squirted into a small part of the lung and then recollected for examination.

Bronchopneumonia or bronchial pneumonia; inflammation of the lungs beginning in the terminal bronchioles.

Broncho-pulmonary relating to the bronchi and lungs.

Bronchospasm is a difficulty in breathing caused by a sudden constriction of the muscles in the walls of the bronchioles as occurs in asthma.

Brown fat brown adipose tissue (BAT) in mammals, its primary function is to generate body heat in animals or newborns that do not shiver.

Bubo inflamed, swollen lymph node in the neck or groin.

Buccal of or relating to the cheeks or the mouth cavity.

Bullae blisters; circumscribed, fluid-containing, elevated lesions of the skin, usually more than 5 mm in diameter.

Bursitis condition characterized by inflammation of one or more bursae (small sacs) of synovial fluid in the body.

C fibres afferent fibres found in the nerve of the somatic sensory system.

c-FOS a cellular proto-oncogene belonging to the immediate early gene family of transcription factors.

C-jun NH(2)-terminal kinase enzymes that belong to the family of the MAPK superfamily of protein kinases. These kinases mediate a plethora of cellular responses to such stressful stimuli, including apoptosis and production of inflammatory and immunoregulatory cytokines in diverse cell systems. *cf*: MAPK.

c-Jun-I (Ser 73) substrate of JNK-1 activated by phosphorylation at Ser73.

c-Jun II (Ser 63) substrate of JNK-1 activated by phosphorylation at Ser63.

C-reactive protein a protein found in the blood the levels of which rise in response to inflammation.

c-Src a cellular non-receptor tyrosine kinase.

CAAT element-binding proteins-alpha (c/EBP-akpha) regulates gene expression in adipocytes in the liver.

Cachexia physical wasting with loss of weight, muscle atrophy, fatigue, weakness caused by disease.

Caco-2 cell line a continuous line of heterogeneous human epithelial colorectal adenocarcinoma cells.

Cadaver a dead body, corpse.

Ca²⁺ ATPase (PMCA) is a transport protein in the plasma membrane of cells that serves to remove calcium (Ca²⁺) from the cell.

Calcitonin gene related peptide (CGRP) is a 37-amino acid neuropeptide that is abundant in the sensory neurons which innervate bone.

Calcium (Ca) is the most abundant mineral in the body found mainly in bones and teeth. It is required for muscle contraction, blood vessel expansion and contraction, secretion of hormones and enzymes, and transmitting impulses throughout the nervous system. Dietary sources include milk, yoghurt, cheese, Chinese cabbage, kale, broccoli, some green leafy vegetables, fortified cereals, beverages and soybean products.

- Calcium ATPase** is a form of P-ATPase which transfers calcium after a muscle has contracted.
- Calcium channel blockers (CCBs)** a class of drugs and natural substances that disrupt the calcium (Ca^{2+}) conduction of calcium channels.
- Calciuria** abnormal presence of calcium in the urine.
- Calculosis** the tendency or deposition to form calculi or stones.
- Calculus (calculi)** hardened, mineral deposits that can form a blockage in the urinary system.
- Calculi infection** most calculi arise in the kidney when urine becomes supersaturated with a salt that is capable of forming solid crystals. Symptoms arise as these calculi become impacted within the ureter as they pass toward the urinary bladder.
- Caligo** dimness or obscurity of sight, dependent upon a speck on the cornea.
- Calmodulin** is a Calcium Modulated protein that can bind to and regulate a multitude of different protein targets, thereby affecting many different cellular functions.
- cAMP dependent pathway** cyclic adenosine monophosphate is a G protein-coupled receptor triggered signaling cascade used in cell communication in living organisms.
- CAMP factor** diffusible, heat-stable, extracellular protein produced by Group B *Streptococcus* that enhances the hemolysis of sheep erythrocytes by *Staphylococcus aureus*. It is named after Christie, Atkins, and Munch-Peterson, who described it in 1944.
- Cancer** a malignant neoplasm or tumour in any part of the body.
- Candidiasis** infections caused by members of the fungus genus *Candida* that range from superficial, such as oral thrush and vaginitis, to systemic and potentially life-threatening diseases.
- Canker** see chancre.
- Carboxypeptidase** an enzyme that hydrolyzes the carboxy-terminal (C-terminal) end of a peptide bond. It is synthesized in the pancreas and secreted into the small intestine.
- Carbuncle** is an abscess larger than a boil, usually with one or more openings draining pus onto the skin.
- Carcinogenesis** production of carcinomas. *adj.* carcinogenic.
- Carcinoma** any malignant cancer that arises from epithelial cells.
- Carcinosarcoma** a rare tumour containing carcinomatous and sarcomatous components.
- Cardiac** relating to, situated near or affecting the heart.
- Cardiac asthma** acute attack of dyspnoea with wheezing resulting from a cardiac disorder.
- Cardiac hypertrophy** is a thickening of the heart muscle (myocardium) resulting in a decrease chamber size, including the left and right ventricles. common causes of cardiac hypertrophy include high blood pressure (hypertension) and heart valve stenosis.
- Cardialgia** heartburn.
- Cardinolides** cardiac glycosides with a 5-membered lactone ring in the side chain of the steroid aglycone.
- Cardinolide glycoside** cardenolides that contain structural groups derived from sugars.
- Cardioactive** having an effect on the heart.
- Cardiogenic shock** is characterized by a decreased pumping ability of the heart that causes a shock like state associated with an inadequate circulation of blood due to primary failure of the ventricles of the heart to function effectively.
- Cardiomyocytes** cardiac muscle cells.
- Cardiomyopathy** heart muscle disease.
- Cardiopathy** disease or disorder of the heart.
- Cardioplegia** stopping the heart so that surgical procedures can proceed in a still and bloodless field.
- Cardiotonic** something which strengthens, tones, or regulates heart functions without overt stimulation or depression.
- Cardiovascular** pertaining to the heart and blood vessels.
- Caries** tooth decay, commonly called cavities.
- Cariogenic** leading to the production of caries.
- Carminative** substance that stops the formation of intestinal gas and helps expel gas that has already formed, relieving flatulence: relieving flatulence or colic by expelling gas.
- Carnitine palmitoyltransferase I (CPT1)** also known as carnitine acyltransferase I or CAT1

- is a mitochondrial enzyme, involved in converting long chain fatty acid into energy.
- Carotenes** are a large group of intense red and yellow pigments found in all plants; these are hydrocarbon carotenoids (subclass of tetraterpenes) and the principal carotene is beta-carotene which is a precursor of vitamin A.
- Carotenoids** a class of natural fat-soluble pigments found principally in plants, belonging to a subgroup of terpenoids containing 8 isoprene units forming a C40 polyene chain. Carotenoids play an important potential role in human health by acting as biological antioxidants. See also carotenes.
- Carotenodermia** yellow skin discoloration caused by excess blood carotene.
- Carpopedal spasm** spasm of the hand or foot, or of the thumbs and great toes.
- Capases** cysteine-aspartic acid proteases, are a family of cysteine proteases, which play essential roles in apoptosis (programmed cell death), necrosis and inflammation.
- Catalase (CAT)** enzyme in living organism that catalyses the decomposition of hydrogen peroxide to water and oxygen.
- Catalepsy** indefinitely prolonged maintenance of a fixed body posture; seen in severe cases of catatonic schizophrenia.
- Catamenia** menstruation.
- Cataplasia** Degenerative reversion of cells or tissue to a less differentiated form.
- Cataplasm** a medicated poultice or plaster. A soft moist mass, often warm and medicated, that is spread over the skin to treat an inflamed, aching or painful area, to improve the circulation.
- Cataractogenesis** formation of cataracts.
- Catarrh, Catarrhal** inflammation of the mucous membranes especially of the nose and throat.
- Catechins** are polyphenolic antioxidant plant metabolites. They belong to the family of flavonoids; tea is a rich source of catechins. See flavonoids.
- Catecholamines** hormones that are released by the adrenal glands in response to stress.
- Cathartic** is a substance which accelerates defecation.
- Caustic** having a corrosive or burning effect.
- Cauterization** a medical term describing the burning of the body to remove or close a part of it.
- Caveolae** tiny (50–100 nm) invaginations of the plasma membrane of the cell.
- cdc2 Kinase** a member of the cyclin-dependent protein kinases (CDKs).
- CDKs** cyclin-dependent protein kinases, a family of serine/threonine kinases that mediate many stages in mitosis.
- CD 28** is one of the molecules expressed on T cells that provide co-stimulatory signals, which are required for T cell (lymphocytes) activation.
- CD31** also known as PECAM-1 (Platelet Endothelial Cell Adhesion Molecule-1), a member of the immunoglobulin superfamily, that mediates cell-to-cell adhesion.
- CD36** an integral membrane protein found on the surface of many cell types in vertebrate animals.
- CD40** an integral membrane protein found on the surface of B lymphocytes, dendritic cells, follicular dendritic cells, hematopoietic progenitor cells, epithelial cells, and carcinomas.
- CD68** a glycoprotein expressed on monocytes/macrophages which binds to low density lipoprotein.
- Cecal ligation** tying up the cecum.
- Celiac disease** an autoimmune disorder of the small intestine, triggered in genetically susceptible individuals by ingested gluten from wheat, rye, barley, and other closely related cereal grains; Peptides resulting from partially digested gluten of wheat, barley or rye cause inflammation of the small intestinal mucosa.
- Cell adhesion molecules (CAM)** glycoproteins located on the surface of cell membranes involved with binding of other cells or with the extra-cellular matrix.
- Cellular respiration** is the set of the metabolic reactions and processes that take place in organisms' cells to convert biochemical energy from nutrients into adenosine triphosphate (ATP), and then release waste products. The reactions involved in respiration are catabolic reactions that involve the oxidation of one molecule and the reduction of another.
- Cellulitis** a bacterial infection of the skin that tends to occur in areas that have been damaged or inflamed.
- Central nervous system** part of the vertebrate nervous system comprising the brain and spinal cord.

- Central venous catheter** a catheter placed into the large vein in the neck, chest or groin.
- Cephalagia** pain in the head, a headache.
- Cephalic** relating to the head.
- Ceramide oligosides** oligosides with an N-acetyl-sphingosine moiety.
- Cercariae** a free-swimming larva of the parasitic schistosome worm that has a tail, and suckers on its head for penetration into a host.
- Cerebral embolism** a blockage of blood flow through a vessel in the brain by a blood clot that formed elsewhere in the body and traveled to the brain.
- Cerebral ischemia** is the localized reduction of blood flow to the brain or parts of the brain due to arterial obstruction or systematic hyperfusion.
- Cerebral infarction** is the ischemic kind of stroke due to a disturbance in the blood vessels supplying blood to the brain.
- Cerebral tonic** substance that can alleviate poor concentration and memory, restlessness, uneasiness, and insomnia.
- Cerebrosides** are glycosphingolipids which are important components in animal muscle and nerve cell membranes.
- Cerebrovascular disease** is a group of brain dysfunctions related to disease of the blood vessels supplying the brain.
- Cerumen** ear wax, a yellowish waxy substance secreted in the ear canal of humans and other mammals.
- cFLIP** cellular FLICE-inhibitory protein, an inhibitor of death ligand-induced apoptosis.
- cGMP** cyclic guanosine monophosphate is a cyclic nucleotide derived from guanosine triphosphate (GTP). cGMP is a common regulator of ion channel conductance, glycogenolysis, and cellular apoptosis. It also relaxes smooth muscle tissues.
- CGRP calcitonin gene-related peptide** a vasodilator neuropeptide that is expressed in a subgroup of small neurons in the dorsal root, trigeminal and vagal ganglia. This neuropeptide has been postulated to play a role in the pathophysiology of migraine.
- Chalcones** a subgroup of flavonoids.
- Chancre** a painless lesion formed during the primary stage of syphilis.
- Chemoembolization** a procedure in which the blood supply to the tumour is blocked surgically or mechanically and anticancer drugs are administered directly into the tumour.
- Chemokines** are chemotactic cytokines, which stimulate migration of inflammatory cells towards tissue sites of inflammation.
- Chemonociceptors** nociceptors or sensory peripheral neurons that are sensitive to chemical stimuli.
- Chemosensitizer** a drug that makes tumour cells more sensitive to the effects of chemotherapy.
- Chemosis** edema of the conjunctiva of the eye.
- Chickenpox** is also known as varicella, is a highly contagious illness caused by primary infection with varicella zoster virus (VZV). The virus causes red, itchy bumps on the body.
- Chilblains** small, itchy, painful lumps that develop on the skin. They develop as an abnormal response to cold. Also called perniosis or blain.
- Chlorosis** iron deficiency anemia characterized by greenish yellow colour.
- Cholagogue** is a medicinal agent which promotes the discharge of bile from the system.
- Cholecalciferol** a form of vitamin D, also called vitamin D3. See vitamin D.
- Cholecyst** gall bladder.
- Cholecystitis** inflammation of the gall bladder.
- Cholecystokinin** a peptide hormone that plays a key role in facilitating digestion in the small intestine.
- Cholera** an infectious gastroenteritis caused by enterotoxin-producing strains of the bacterium *Vibrio cholera* and characterized by severe, watery diarrhea.
- Choleretic** stimulation of the production of bile by the liver.
- Cholestasis** a condition caused by rapidly developing (acute) or long-term (chronic) interruption in the excretion of bile.
- Cholesterol** a soft, waxy, steroid substance found among the lipids (fats) in the bloodstream and in all our body's cells.
- Cholethiasis** presence of gall stones (calculi) in the gall bladder.
- Choline** a water soluble, organic compound, usually grouped within the Vitamin B complex. It is an essential nutrient and is needed for physiological functions such as structural integrity and signaling roles for cell membranes,

cholinergic neuro-transmission (acetylcholine synthesis).

Cholinergic activated by or capable of liberating acetylcholine, especially in the parasympathetic nervous system.

Cholinergic system a system of nerve cells that uses acetylcholine in transmitting nerve impulses.

Cholinomimetic having an action similar to that of acetylcholine; called also parasympathomimetic.

Chronotropic affecting the time or rate, as the rate of contraction of the heart.

Choriocarcinoma a quick-growing malignant, trophoblastic, aggressive cancer that occurs in a woman's uterus (womb).

Chromium (Cr) is required in trace amounts in humans for sugar and lipid metabolism. Its deficiency may cause a disease called chromium deficiency. It is found in cereals, legumes, nuts and animal sources.

Chromosome long pieces of DNA found in the center (nucleus) of cells.

Chronic persisting over extended periods.

Chronic Obstructive Pulmonary Disease (COPD) a progressive disease that makes it hard to breathe.

Chronic venous insufficiency (CVI) a medical condition where the veins cannot pump enough oxygen-poor blood back to the heart.

Chyle a milky bodily fluid consisting of lymph and emulsified fats, or free fatty acids.

Chylomicrons are large lipoprotein particles that transport dietary lipids from the intestines to other locations in the body. Chylomicrons are one of the five major groups of lipoproteins (chylomicrons, VLDL, IDL, LDL, HDL) that enable fats and cholesterol to move within the water-based solution of the bloodstream.

Chylorus milky (having fat emulsion).

Chyluria also called chylous urine, is a medical condition involving the presence of chyle (emulsified fat) in the urine stream, which results in urine appearing milky.

Chymase member of the family of serine proteases found primarily in mast cell.

Chymopapain an enzyme derived from papaya, used in medicine and to tenderize meat.

Cicatrizant the term used to describe a product that promotes healing through the formation of scar tissue.

C-Kit Receptor a protein-tyrosine kinase receptor that is specific for stem cell factor. this interaction is crucial for the development of hematopoietic, gonadal, and pigment stem cells.

Cirrhosis chronic liver disease characterized by replacement of liver tissue by fibrous scar tissue and regenerative nodules/lumps leading progressively to loss of liver function.

Clastogen is an agent that can cause one of two types of structural changes, breaks in chromosomes that result in the gain, loss, or rearrangements of chromosomal segments. *adj.* clastogenic.

Claudication limping, impairment in walking.

Climacterium refers to menopause and the bodily and mental changes associated with it.

Clonic seizures consist of rhythmic jerking movements of the arms and legs, sometimes on both sides of the body.

Clonus a series of involuntary muscular contractions and relaxations.

Clyster enema.

C-myc codes for a protein that binds to the DNA of other genes and is therefore a transcription factor.

CNS Depressant anything that depresses, or slows, the sympathetic impulses of the central nervous system (i.e., respiratory rate, heart rate).

Coagulopathy a defect in the body's mechanism for blood clotting, causing susceptibility to bleeding.

Cobalamin vitamin B12. See vitamin B12.

Co-carcinogen a chemical that promotes the effects of a carcinogen in the production of cancer.

Cold an acute inflammation of the mucous membrane of the respiratory tract especially of the nose and throat caused by a virus and accompanied by sneezing and coughing.

Collagen protein that is the major constituent of cartilage and other connective tissue; comprises the amino acids hydroxyproline, proline, glycine, and hydroxylysine.

Collagenases enzymes that break the peptide bonds in collagen.

Colic a broad term which refers to episodes of uncontrollable, extended crying in a baby who is otherwise healthy and well fed.

Colitis inflammatory bowel disease affecting the tissue that lines the gastrointestinal system.

- Collyrium** a lotion or liquid wash used as a cleanser for the eyes, particularly in diseases of the eye.
- Colorectal** relating to the colon or rectum.
- Coma** a state of unconsciousness from which a patient cannot be aroused.
- Comedone** a blocked, open sebaceous gland where the secretions oxidize, turning black. Also called blackhead.
- Comitogen** agent that is considered not to induce cell growth alone but to promote the effect of the mitogen.
- Concoction** a combination of crude ingredients that is prepared or cooked together.
- Condyloma, Condylomata acuminata** genital warts, venereal warts, anal wart or anogenital wart, a highly contagious sexually transmitted infection caused by epidermotropic human papillomavirus (HPV).
- Conglutination** becoming stuck together.
- Conjunctival hyperemia** enlarged blood vessels in the eyes.
- Conjunctivitis** sore, red and sticky eyes caused by eye infection.
- Constipation** a very common gastrointestinal disorder characterised by the passing of hard, dry bowel motions (stools) and difficulty of bowel motion.
- Constitutive androstane receptor (CAR, NR113)** is a nuclear receptor transcription factor that regulates drug metabolism and homeostasis.
- Consumption** term used to describe wasting of tissues including but not limited to tuberculosis.
- Consumptive** afflicted with or associated with pulmonary tuberculosis.
- Contraceptive** an agent that reduces the likelihood of or prevents conception.
- Contraindication** a condition which makes a particular treatment or procedure inadvisable.
- Contralateral muscle** muscle of opposite limb (leg or arm).
- Contralateral rotation** rotation occurring or originating in a corresponding part on an opposite side.
- Contusion** another term for a bruise. A bruise, or contusion, is caused when blood vessels are damaged or broken as the result of a blow to the skin.
- Convulsant** a drug or physical disturbance that induces convulsion.
- Convulsion** rapid and uncontrollable shaking of the body.
- Coolant** that which reduces body temperature.
- Copper (Cu)** is essential in all plants and animals. It is found in a variety of enzymes, including the copper centers of cytochrome C oxidase and the enzyme superoxide dismutase (containing copper and zinc). In addition to its enzymatic roles, copper is used for biological electron transport. Because of its role in facilitating iron uptake, copper deficiency can often produce anemia-like symptoms. Dietary sources include curry powder, mushroom, nuts, seeds, wheat germ, whole grains and animal meat.
- Copulation** to engage in coitus or sexual intercourse. *adj.* copulatory.
- Cordial** a preparation that is stimulating to the heart.
- Corn** or callus is a patch of hard, thickened skin on the foot that is formed in response to pressure or friction.
- Corticosteroids** a class of steroid hormones that are produced in the adrenal cortex, used clinically for hormone replacement therapy, for suppressing ACTH secretion, for suppression of immune response and as antineoplastic, anti-allergic and anti-inflammatory agents.
- Corticosterone** a 21-carbon steroid hormone of the corticosteroid type produced in the cortex of the adrenal glands.
- Cortisol** is a corticosteroid hormone made by the adrenal glands.
- Cornification** is the process of forming an epidermal barrier in stratified squamous epithelial tissue.
- Coryza** a word describing the symptoms of a head cold. It describes the inflammation of the mucus membranes lining the nasal cavity which usually gives rise to the symptoms of nasal congestion and loss of smell, among other symptoms.
- COX-1** see cyclooxygenase-1.
- COX-2** see cyclooxygenase-2.
- CpG islands** genomic regions that contain a high frequency of CpG sites.
- CpG sites** the cytosine-phosphate-guanine nucleotide that links two nucleosides together in DNA.
- cPLA(2)** cytosolic phospholipases A2, these phospholipases are involved in cell signaling processes, such as inflammatory response.

- CPY1B1, CPY1A1** a member of the cytochrome P450 superfamily of heme-thiolate monooxygenase enzymes.
- Corticosterone** a 21-carbon corticosteroid hormone produced in the cortex of the adrenal glands that functions in the metabolism of carbohydrates and proteins.
- Creatin** a nitrogenous organic acid that occurs naturally in vertebrates and helps to supply energy to muscle.
- Creatine phosphokinase (CPK, CK)** enzyme that catalyses the conversion of creatine and consumes adenosine triphosphate (ATP) to create phosphocreatine and adenosine diphosphate (ADP).
- CREB** cAMP response element-binding, a protein that is a transcription factor that binds to certain DNA sequences called cAMP response elements.
- Crohn Disease** an inflammatory disease of the intestines that affect any part of the gastrointestinal tract.
- Crossover study** a longitudinal, balance study in which participants receive a sequence of different treatments or exposures.
- Croup** is an infection of the throat (larynx) and windpipe (trachea) that is caused by a virus (Also called laryngotracheobronchitis).
- Cryptorchidism (cryptorchism)** a developmental defect characterized by the failure of one or both testes to move into the scrotum as the male fetus develops.
- Curettage** surgical procedure in which a body cavity or tissue is scraped with a sharp instrument or aspirated with a cannula.
- Cutaneous** pertaining to the skin.
- CXC8** also known as interleukin 8, IL-8.
- Cyanogenesis** generation of cyanide. *adj.* cyanogenetic.
- Cyclooxygenase (COX)** an enzyme that is responsible for the formation of prostanoids - prostaglandins, prostacyclins, and thromboxanes that are each involved in the inflammatory response. Two different COX enzymes existed, now known as COX-1 and COX-2.
- Cyclooxygenase-1 (COX-1)** is known to be present in most tissues. In the gastrointestinal tract, COX-1 maintains the normal lining of the stomach. The enzyme is also involved in kidney and platelet function.
- Cyclooxygenase-2 (COX-2)** is primarily present at sites of inflammation.
- Cysteine proteases** are enzymes that degrade polypeptides possessing a common catalytic mechanism that involves a nucleophilic cysteine thiol in a catalytic triad. They are found in fruits like papaya, pineapple, and kiwifruit.
- Cystitis** a common urinary tract infection that occurs when bacteria travel up the urethra, infect the urine and inflame the bladder lining.
- Cystorrhea** discharge of mucus from the bladder.
- Cytochrome bc-1 complex** ubiquinol:cytochrome c oxidoreductase.
- Cytochrome P450 3A CYP3A** a very large and diverse superfamily of heme-thiolate proteins found in all domains of life. This group of enzymes catalyzes many reactions involved in drug metabolism and synthesis of cholesterol, steroids and other lipids.
- Cytokine** non-antibody proteins secreted by certain cells of the immune system which carry signals locally between cells. They are a category of signaling molecules that are used extensively in cellular communication.
- Cytopathic** any detectable, degenerative changes in the host cell due to infection.
- Cytoprotective** protecting cells from noxious chemicals or other stimuli.
- Cytosolic** relates to the fluid of the cytoplasm in cells.
- Cytostatic** preventing the growth and proliferation of cells.
- Cytotoxic** of or relating to substances that are toxic to cells; cell-killing.
- D- galactosamine** an amino sugar with unique hepatotoxic properties in animals.
- Dandruff** scurf, dead, scaly skin among the hair.
- Dartre** condition of dry, scaly skin.
- Debility** weakness, relaxation of muscular fibre.
- Debridement** is the process of removing non-living tissue from pressure ulcers, burns, and other wounds.
- Debriding agent** substance that cleans and treats certain types of wounds, burns, ulcers.
- Deciduogenic** relating to the uterus lining that is shed off at childbirth.
- Decidual stromal cells** like endometrial glands and endothelium, express integrins that bind basement components.

- Decoction** a medical preparation made by boiling the ingredients.
- Decongestant** a substance that relieves or reduces nasal or bronchial congestion.
- Deep venous thrombosis** is a blood clot that forms in a vein deep inside a part of the body.
- Defibrinated plasma** blood whose plasma component has had fibrinogen and fibrin removed.
- Degranulation** cellular process that releases antimicrobial cytotoxic molecules from secretory vesicles called granules found inside some cells.
- Delayed afterdepolarizations (DADs)** abnormal depolarization that begins during phase 4 – after repolarization is completed, but before another action potential would normally occur.
- Delirium** is common, sudden severe confusion and rapid changes in brain function that occur with physical or mental illness; it is reversible and temporary.
- Demulcent** an agent that soothes internal membranes. Also called emollient.
- Dendritic cells** are immune cells and form part of the mammalian immune system, functioning as antigen presenting cells.
- Dentition** a term that describes all of the upper and lower teeth collectively.
- Deobstruent** a medicine which removes obstructions; also called an aperient.
- Deoxyypyridinoline (Dpd)** a crosslink product of collagen molecules found in bone and excreted in urine during bone degradation.
- Depilatory** an agent for removing or destroying hair.
- Depressant** a substance that diminish functional activity, usually by depressing the nervous system.
- Depurative** an agent used to cleanse or purify the blood, it eliminates toxins and purifies the system.
- Dermatitis** inflammation of the skin causing discomfort such as eczema.
- Dermatitis herpetiformis** an autoimmune chronic blistering skin disorder characterised by blisters filled with a watery fluid.
- Dermatophyte** a fungus parasitic on the skin.
- Dermatosis** is a broad term that refers to any disease of the skin, especially one that is not accompanied by inflammation.
- Dermonecrotic** pertaining to or causing necrosis of the skin.
- Desquamation** the shedding of the outer layers of the skin.
- Detoxifier** a substance that promotes the removal of toxins from a system or organ.
- Diabetes** a metabolic disorder associated with inadequate secretion or utilization of insulin and characterized by frequent urination and persistent thirst. See diabetes mellitus.
- Diabetes mellitus (DM)** (sometimes called “sugar diabetes”) is a set of chronic, metabolic disease conditions characterized by high blood sugar (glucose) levels that result from defects in insulin secretion, or action, or both. Diabetes mellitus appears in two forms.
- Diabetes mellitus type I** (formerly known as juvenile onset diabetes), caused by deficiency of the pancreatic hormone insulin as a result of destruction of insulin-producing beta cells of the pancreas. Lack of insulin causes an increase of fasting blood glucose that begins to appear in the urine above the renal threshold.
- Diabetes mellitus type II** (formerly called non-insulin-dependent diabetes mellitus or adult-onset diabetes), the disorder is characterized by high blood glucose in the context of insulin resistance and relative insulin deficiency in which insulin is available but cannot be properly utilized.
- Diabetic neuropathy** a neuropathic disorder that is associated with diabetes mellitus. It affects all peripheral nerves including pain fibers, motor neurons and the autonomic nervous system.
- Diabetic retinopathy** damage to the retina caused by complications of diabetes mellitus, which can eventually lead to blindness.
- Diads** two adjacent structural units in a polymer molecule.
- Dialysis** is a method of removing toxic substances (impurities or wastes) from the blood when the kidneys are unable to do so.
- Diaphoresis** is profuse sweating commonly associated with shock and other medical emergency conditions.
- Diaphoretic** a substance that induces perspiration. Also called sudorific.
- Diaphyseal** pertaining to or affecting the shaft of a long bone (diaphysis).
- Diaphysis** the main or mid section (shaft) of a long bone.

Diarrhoea a profuse, frequent and loose discharge from the bowels.

Diastolic referring to the time when the heart is in a period of relaxation and dilatation (expansion). *cf.* systolic.

Dieresis surgical separation of parts.

Dietary fibre is a term that refers to a group of food components that pass through the stomach and small intestine undigested and reach the large intestine virtually unchanged. Scientific evidence suggest that a diet high in dietary fibre can be of value for treating or preventing such disorders as constipation, irritable bowel syndrome, diverticular disease, hiatus hernia and haemorrhoids. Some components of dietary fibre may also be of value in reducing the level of cholesterol in blood and thereby decreasing a risk factor for coronary heart disease and the development of gallstones. Dietary fibre is beneficial in the treatment of some diabetics.

Digalactosyl diglycerides are the major lipid components of chloroplasts.

Diosgenin a steroid-like substance that is involved in the production of the hormone progesterone, extracted from roots of *Dioscorea* yam.

Dipsia sensation of dryness in the mouth and throat related to a desire to drink.

Dipsomania pathological use of alcohol.

Discutient an agent (as a medicinal application) which serves to disperse morbid matter.

Disinfectant an agent that prevents the spread of infection, bacteria or communicable disease.

Distal sensory polyneuropathy (DSPN) or peripheral neuropathy, is the most common neurological problem in HIV disease. DSPN also represents a complex symptom that occurs because of peripheral nerve damage related to advanced HIV disease.

Diuresis increased urination.

Diuretic a substance that increases urination (diuresis).

Diverticular disease is a condition affecting the large bowel or colon and is thought to be caused by eating too little fibre.

DMBA 7,12-Dimethylbenzanthracene. A polycyclic aromatic hydrocarbon found in tobacco smoke that is a potent carcinogen.

DNA deoxyribonucleic acid, a nucleic acid that contains the genetic instructions used in the

development and functioning of all known living organisms.

DOCA desoxycorticosterone acetate - a steroid chemical used as replacement therapy in Addison's disease.

Dopamine a catecholamine neurotransmitter that occurs in a wide variety of animals, including both vertebrates and invertebrates.

Dopaminergic relating to, or activated by the neurotransmitter, dopamine.

Double blind refer to a clinical trial or experiment in which neither the subject nor the researcher knows which treatment any particular subject is receiving.

Douche a localised spray of liquid directed into a body cavity or onto a part.

DPPH 2,2 diphenyl -1- picryl-hydrazyl - a crystalline, stable free radical used as an inhibitor of free radical reactions.

Dracunculiasis also called guinea worm disease (GWD), is a parasitic infection caused by the nematode, *Dracunculus medinensis*.

Dropsy an old term for the swelling of soft tissues due to the accumulation of excess water. *adj.* dropsical.

Drusen tiny yellow or white deposits of extracellular materials in the retina of the eye or on the optic nerve head.

DT diaphorase also called DTD or NAD(P) H:quinone oxidoreductase, is an obligate two-electron reductase which bioactivates chemotherapeutic quinones.

Dysentery (formerly known as flux or the bloody flux) is a disorder of the digestive system that results in severe diarrhea containing mucus and blood in the feces. It is caused usually by a bacterium called *Shigella*.

Dysesthesia an unpleasant abnormal sensation produced by normal stimuli.

Dysgeusia distortion of the sense of taste.

Dyskinesia the impairment of the power of voluntary movement, resulting in fragmentary or incomplete movements. *adj.* dyskinetic.

Dyslipidemia abnormality in or abnormal amount of lipids and lipoproteins in the blood.

Dysmenorrhea is a menstrual condition characterized by severe and frequent menstrual cramps and pain associated with menstruation.

Dysmotility syndrome a vague, descriptive term used to describe diseases of the muscles of the gastrointestinal tract (esophagus, stomach, small and large intestines).

Dysphagia indigestion followed by nausea.

Dyspepsia refers to a symptom complex of epigastric pain or discomfort. It is often defined as chronic or recurrent discomfort centered in the upper abdomen and can be caused by a variety of conditions. *cf.* functional dyspepsia.

Dysphagia swallowing disorder.

Dysphonia a voice disorder, an impairment in the ability to produce voice sounds using the vocal organs.

Dysplasia refers to abnormality in development.

Dyspnoea shortness of breath, difficulty in breathing.

Dysrhythmias see arrhythmias.

Dystocia abnormal or difficult child birth or labour.

Dystonia a neurological movement disorder characterized by prolonged, repetitive muscle contractions that may cause twisting or jerking movements of muscles.

Dysuria refers to difficult and painful urination.

E- Selectin also known as endothelial leukocyte adhesion molecule-1 (ELAM-1), CD62E, a member of the selectin family. It is transiently expressed on vascular endothelial cells in response to IL-1 beta and TNF-alpha.

EC 50 median effective concentration that produces desired effects in fifty percent of the test population.

Ecbolic a drug (as an ergot alkaloid) that tends to increase uterine contractions and that is used especially to facilitate delivery.

Ecchymosis skin discoloration caused by the escape of blood into the tissues from ruptured blood vessels.

ECG see electrocardiography.

EC-SOD extracellular superoxide dismutase, a tissue enzyme mainly found in the extracellular matrix of tissues. It participates in the detoxification of reactive oxygen species by catalyzing the dismutation of superoxide radicals.

Ectrodactyly involves the absence of one or more central digits of the hand or foot.

Eczema is broadly applied to a range of persistent skin conditions. These include dryness and recurring skin rashes which are charac-

terized by one or more of these symptoms: redness, skin edema, itching and dryness, crusting, flaking, blistering, cracking, oozing, or bleeding.

Eczematous rash dry, scaly, itchy rash.

ED₅₀ is defined as the dose producing a response that is 50% of the maximum obtainable.

Edema formerly known as dropsy or hydropsy, is characterized swelling caused by abnormal accumulation of fluid beneath the skin, or in one or more cavities of the body. It usually occurs in the feet, ankles and legs, but it can involve the entire body.

Edematogenic producing or causing edema.

EGFR proteins epidermal growth factor receptor (EGFR) proteins - Protein kinases are enzymes that transfer a phosphate group from a phosphate donor onto an acceptor amino acid in a substrate protein.

EGR-1 early growth response 1, a human gene.

Eicosanoids are signaling molecules made by oxygenation of arachidonic acid, a 20-carbon essential fatty acid, includes prostaglandins and related compounds.

Elastase a serine protease that also hydrolyses amides and esters.

Electrocardiography or ECG, is a transthoracic interpretation of the electrical activity of the heart over time captured and externally recorded by skin electrodes.

Electromyogram (EMG) a test used to record the electrical activity of muscles. An electromyogram (EMG) is also called a myogram.

Electuary a medicinal paste composed of powders, or other medical ingredients, incorporated with sweeteners to hide the taste, suitable for oral administration.

Elephantiasis a disorder characterized by chronic thickened and edematous tissue on the genitals and legs due to various causes.

Embrocation lotion or liniment that relieves muscle or joint pains.

Embryotoxic term that describes any chemical which is harmful to an embryo.

Emesis vomiting, throwing up.

Emetic an agent that induces vomiting, *cf.* antiemetic.

Emetocathartic causing vomiting and purging.

Emmenagogue a substance that stimulates, initiates, and/or promotes menstrual flow.

- Emmenagogues are used in herbal medicine to balance and restore the normal function of the female reproductive system.
- Emollient** an agent that has a protective and soothing action on the surfaces of the skin and membranes.
- Emphysema** a long-term, progressive disease of the lungs that primarily causes shortness of breath.
- Emulsion** a preparation formed by the suspension of very finely divided oily or resinous liquid in another liquid.
- Encephalitis** inflammation of the brain.
- Encephalomalacia** cerebral softening, a localized softening of the brain substance, due to hemorrhage or inflammation.
- Encephalopathy** a disorder or disease of the brain.
- Endocrine** *adj.* of or relating to endocrine glands or the hormones secreted by them.
- Endocytosis** is the process by which cells absorb material (molecules such as proteins) from outside the cell by engulfing it with their cell membrane.
- Endometrial cancer** cancer that arises in the endometrium, the lining of the uterus (womb).
- Endometriosis** is a common and often painful disorder of the female reproductive system in which the endometrium, the tissue that normally lines the womb (uterus), grows outside the uterus. The two most common symptoms of endometriosis are pain and infertility.
- Endometritis** refers to inflammation of the endometrium, the inner lining of the uterus.
- Endometrium** the inner lining of the uterus.
- Endoplasmic reticulum** is a network of tubules, vesicles and sacs around the nucleus that are interconnected.
- Endostatin** a naturally-occurring 20-kDa C-terminal protein fragment derived from type XVIII collagen. It is reported to serve as an anti-angiogenic agent that inhibits the formation of the blood vessels that feed cancer tumours.
- Endosteum** the thin layer of cells lining the medullary cavity of a bone.
- Endosteul** pertaining to the endosteum.
- Endothelial progenitor cells** population of rare cells that circulate in the blood with the ability to differentiate into endothelial cells, the cells that make up the lining of blood vessels.
- Endothelin** any of a group of vasoconstrictive peptides produced by endothelial cells that constrict blood vessels and raise blood pressure.
- Endotoxemia** the presence of endotoxins in the blood, which may result in shock. *adj.* endotoxemic.
- Endotoxin** toxins associated with certain bacteria, unlike an 'exotoxin' that is not secreted in soluble form by live bacteria, but is a structural component in the bacteria which is released mainly when bacteria are lysed.
- Encephalocele** protrusion of brain tissue through a congenital fissure in the skull.
- Enema** liquid injected into the rectum either as a purgative or medicine. Also called clyster.
- Enophthalmos** a condition in which the eye falls back into the socket and inhibits proper eyelid function.
- Enteral** term used to describe the intestines or other parts of the digestive tract.
- Enteral administration** involves the esophagus, stomach, and small and large intestines (i.e., the gastrointestinal tract).
- Enteritis** refers to inflammation of the small intestine.
- Enterocolic disorder** inflamed bowel disease.
- Enterocytes** tall columnar cells in the small intestinal mucosa that are responsible for the final digestion and absorption of nutrients.
- Enterohemorrhagic** causing bloody diarrhea and colitis, said of pathogenic microorganisms.
- Enterohepatonephropathy** hepatorenal lesions accompanied by renal failure.
- Enterolactone** a lignin formed by the action of intestinal bacteria on lignan precursors found in plants; acts as a phytoestrogen.
- Enteropooling** increased fluids and electrolytes within the lumen of the intestines due to increased levels of prostaglandins.
- Enterotoxigenic** of or being an organism containing or producing an enterotoxin.
- Enterotoxin** is a protein toxin released by a microorganism in the intestine.
- Entheogen** a substance taken to induce a spiritual experience.
- Enuresis** bed-wetting, a disorder of elimination that involves the voluntary or involuntary release of urine into bedding, clothing, or other inappropriate places.

- Envenomation** is the entry of venom into a person's body, and it may cause localised or systemic poisoning.
- Eosinophilia** the state of having a high concentration of eosinophils (eosinophil granulocytes) in the blood.
- Eosinophils** (or, less commonly, acidophils), are white blood cells that are one of the immune system components.
- Epididymis** a structure within the scrotum attached to the backside of the testis and whose coiled duct provides storage, transit and maturation of spermatozoa.
- Epididymitis** a medical condition in which there is inflammation of the epididymis.
- Epigastralgia** pain in the epigastric region.
- Epigastric discomfort** bloated abdomen, swelling of abdomen, abdominal distension.
- Epilepsy** a common chronic neurological disorder that is characterized by recurrent unprovoked seizures.
- Epileptiform** resembling epilepsy or its manifestations. *adj.* epileptiformic.
- Epileptogenesis** a process by which a normal brain develops epilepsy, a chronic condition in which seizures occur. *adj.* epileptogenic.
- Episiotomy** a surgical incision through the perineum made to enlarge the vagina and assist childbirth.
- Epithelioma** a usually benign skin disease most commonly occurring on the face, around the eyelids and on the scalp.
- Epitope** a single antigenic site on a protein against which an antibody reacts.
- Epitrochlearis** the superficial-most muscle of the arm anterior surface.
- Epistaxis** acute hemorrhage from the nostril, nasal cavity, or nasopharynx (nose-bleed).
- Epstein Barr Virus** herpes virus that is the causative agent of infectious mononucleosis. It is also associated with various types of human cancers.
- ERbeta** estrogen receptor beta, a nuclear receptor which is activated by the sex hormone, estrogen.
- Ergocalciferol** a form of vitamin D, also called vitamin D2. See vitamin D.
- Ergonic** increasing capacity for bodily or mental labor especially by eliminating fatigue symptoms.
- ERK (extracellular signal regulated kinases)** widely expressed protein kinase intracellular signaling molecules which are involved in functions including the regulation of meiosis, mitosis, and post mitotic functions in differentiated cells.
- Eructation** the act of belching or of casting up wind from the stomach through the mouth.
- Eruption** a visible rash or cutaneous disruption.
- Erysipelas** is an intensely red *Streptococcus* bacterial infection that occurs on the face and lower extremities.
- Erythema** abnormal redness and inflammation of the skin, due to vasodilation.
- Erythema multiforme** is a skin disorder due to an allergic reaction or infection; characterised by fever, general ill feeling, skin itching, joint aches, and multiple skin lesions.
- Erythematous** characterized by erythema.
- Erythroleukoplakia** an abnormal patch of red and white tissue that forms on mucous membranes in the mouth and may become cancer. Tobacco (smoking and chewing) and alcohol may increase the risk of erythroleukoplakia.
- Erythropoietin (EPO)** a hormone produced by the kidney that promotes the formation of red blood cells (erythrocytes) in the bone marrow.
- Eschar** a slough or piece of dead tissue that is cast off from the surface of the skin.
- Escharotic** capable of producing an eschar; a caustic or corrosive agent.
- Estradiol** is the predominant sex hormone present in females, also called oestradiol.
- Estrogen** female hormone produced by the ovaries that play an important role in the estrous cycle in women.
- Estrogen receptor (ER)** is a protein found in high concentrations in the cytoplasm of breast, uterus, hypothalamus, and anterior hypophysis cells; ER levels are measured to determine a breast CA's potential for response to hormonal manipulation.
- Estrogen receptor positive (ER+)** means that estrogen is causing the tumour to grow, and that the breast cancer should respond well to hormone suppression treatments.
- Estrogen receptor negative (ER-)** tumour is not driven by estrogen and need another test to determine the most effective treatment.

- Estrogenic** relating to estrogen or producing estrus.
- Estrus** sexual excitement or heat of female; or period of this characterized by changes in the sex organs.
- Euglycaemia** normal blood glucose concentration.
- Eupeptic** conducive to digestion.
- Exanthematous** characterized by or of the nature of an eruption or rash.
- Excitotoxicity** is the pathological process by which neurons are damaged and killed by glutamate and similar substances.
- Excipient** a pharmacologically inert substance used as a diluent or vehicle for the active ingredients of a medication.
- Exocytosis** the cellular process by which cells excrete waste products or chemical transmitters.
- Exophthalmos or exophthalmia or proptosis** is a bulging of the eye anteriorly out of the orbit. *adj.* exophthalmic.
- Exotoxin** a toxin secreted by a microorganism and released into the medium in which it grows.
- Expectorant** an agent that increases bronchial mucous secretion by promoting liquefaction of the sticky mucous and expelling it from the body.
- Exteroceptive** responsiveness to stimuli that are external to an organism.
- Extrapyramidal side effects** are a group of symptoms (tremor, slurred speech, akathisia, dystonia, anxiety, paranoia and bradyphrenia) that can occur in persons taking antipsychotic medications.
- Extravasation** discharge or escape, as of blood from the vein into the surrounding tissues; discharge or escape from a vessel or channel.
- Fabry disease** is a rare X-linked (inherited) lysosomal storage disease caused by alpha-galactosidase A deficiency, which can cause a wide range of systemic symptoms such as pain in the extremities, papules on the lower body parts, cornea clouding, fatigue, neuropathy, renal and cardiac complications.
- FAC chemotherapy** fluorouracil, doxorubicin (adriamycin), and cyclophosphamide chemotherapy.
- FADD** Fas-associated protein with death domain, the protein encoded by this gene is an adaptor molecule which interacts with other death cell surface receptors and mediates apoptotic signals.
- Familial amyloid polyneuropathy (FAP)** also called Corino de Andrade's disease, a neurodegenerative autosomal dominant genetically transmitted, fatal, incurable disease.
- Familial adenomatous polyposis (FAP)** is an inherited condition in which numerous polyps form mainly in the epithelium of the large intestine.
- Familial dysautonomia** a genetic disorder that affects the development and survival of autonomic and sensory nerve cells.
- Fanconi syndrome** is a disease of the proximal renal tubes which certain substances normally absorbed into the bloodstream by the kidneys are released into the urine instead.
- FasL or CD95L** Fas ligand is a type-II transmembrane protein that belongs to the tumour necrosis factor (TNF) family.
- FAS: fatty acid synthase (FAS)** a multi-enzyme that plays a key role in fatty acid synthesis.
- Fas molecule** a member of the Tumour Necrosis Factor Receptors, that mediates apoptotic signal in many cell types.
- Fauces** the passage leading from the back of the mouth into the pharynx.
- Favus** a chronic skin infection, usually of the scalp, caused by the fungus, *Trichophyton schoenleinii* and characterized by the development of thick, yellow crusts over the hair follicles. Also termed tinea favosa.
- Febrifuge** an agent that reduces fever. Also called an antipyretic.
- Febrile** pertaining to or characterized by fever.
- Febrile neutropenia** the development of fever, often with other signs of infection, in an individual with neutropenia, an abnormally low number of neutrophil granulocytes in the blood.
- Fetotoxic** toxic to the fetus.
- Fibrates** hypolipidemic agents primarily used for decreasing serum triglycerides, while increasing High density lipoprotein (HDL).
- Fibril** a small slender fibre or filament.
- Fibrin** insoluble protein that forms the essential portion of the blood clot.
- Fibrinolysis** a normal ongoing process that dissolves fibrin and results in the removal of small blood clots.
- Fribinolytic** causing the dissolution of fibrin by enzymatic action.

Fibroblast type of cell that synthesizes the extracellular matrix and collagen, the structural framework (stroma) for animal tissues, and play a critical role in wound healing.

Fibrogenic promoting the development of fibres.

Fibromyalgia a common and complex chronic, body-wide pain disorder that affects people physically, mentally and socially. Symptoms include debilitating fatigue, sleep disturbance, and joint stiffness. Also referred to as FM or FMS.

Fibronectin a high-molecular weight (~440 kDa) glycoprotein of the extracellular matrix (ECM) that adheres to membrane-spanning receptor proteins called integrins.

Fibrosarcoma a malignant tumour derived from fibrous connective tissue and characterized by immature proliferating fibroblasts or undifferentiated anaplastic spindle cells.

Fibrosis the formation of fibrous tissue as a reparative or reactive process.

Filarial pertaining to a thread-like nematode worm.

Filariasis a parasitic and infectious tropical disease that is caused by thread-like filarial nematode worms in the superfamily Filarioidea.

Fistula an abnormal connection between two parts inside of the body.

Fistula-in-ano a track connecting the internal anal canal to the skin surrounding the anal orifice.

5'-Nucleotidase (5'-ribonucleotide phosphohydrolase), an intrinsic membrane glycoprotein present as an ectoenzyme in a wide variety of mammalian cells, hydrolyzes 5'-nucleotides to their corresponding nucleosides.

Flatulence is the presence of a mixture of gases known as flatus in the digestive tract of mammals expelled from the rectum. Excessive flatulence can be caused by lactose intolerance, certain foods or a sudden switch to a high fibre.

Flavans a subgroup of flavonoids. See flavonoids.

Flavanols a subgroup of flavonoids, are a class of flavonoids that use the 2-phenyl-3,4-dihydro-2H-chromen-3-ol skeleton. These compounds include the catechins and the catechin gallates. They are found in chocolate, fruits and vegetables. See flavonoids.

Flavanones a subgroup of flavonoids, constitute >90% of total flavonoids in citrus. The major dietary flavanones are hesperetin, naringenin and eriodictyol.

Flavivirus A family of viruses transmitted by mosquitoes and ticks that cause some important diseases, including dengue, yellow fever, tick-borne encephalitis and West Nile fever.

Flavones a subgroup of flavonoids based on the backbone of 2-phenylchromen-4-one (2-phenyl-1-benzopyran-4-one). Flavones are mainly found in cereals and herbs.

Flavonoids (or bioflavonoids) are a group of polyphenolic antioxidant compounds in that are occur in plant as secondary metabolites. They are responsible for the colour of fruit and vegetables. Twelve basic classes (chemical types) of flavonoids have been recognized: flavones, isoflavones, flavans, flavanones, flavanols, flavanolols, anthocyanidins, catechins (including proanthocyanidins), leucoanthocyanidins, chalcones, dihydrochalcones, and aurones. Apart from their antioxidant activity, flavonoids are known for their ability to strengthen capillary walls, thus assisting circulation and helping to prevent and treat bruising, varicose veins, bleeding gums and nosebleeds, heavy menstrual bleeding and are also anti-inflammatory.

Flourine F is an essential chemical element that is required for maintenance of healthy bones and teeth and to reduce tooth decay. It is found in sea weeds, tea, water, seafood and dairy products.

Fluorosis a dental health condition caused by a child receiving too much fluoride during tooth development.

Flux an excessive discharge of fluid.

FMD (Flow Mediated Dilation) a measure of endothelial dysfunction which is used to evaluate cardiovascular risk.

Focal adhesion kinase (FAK) is a protein tyrosine kinase which is recruited at an early stage to focal adhesions and which mediates many of the downstream regulatory responses.

Follicle stimulating hormone (FSH) a hormone produced by the pituitary gland. In women, it helps control the menstrual cycle and the production of eggs by the ovaries.

Follicular atresia the break-down of the ovarian follicles.

Fomentation treatment by the application of war, moist substance.

Fontanelle soft spot on an infant's skull.

Forkhead box-O transcription factors (FOXOs) are a family of transcription factors that play important roles in regulating the expression of genes involved in cell growth, proliferation, differentiation, and longevity. It also play an important role in tumour suppression by regulating the expression of genes involved in stress resistance, DNA damage repair, cell cycle arrest and apoptosis.

Framboesia see yaws.

FRAP ferric reducing ability of plasma, an assay used to assess antioxidant property.

Friedreich's ataxia is a genetic inherited disorder that causes progressive damage to the nervous system resulting in symptoms ranging from muscle weakness and speech problems to heart disease. *cf.* ataxia.

Fulminant hepatitis acute liver failure.

Functional Dyspepsia a non-ulcer condition that causes an upset stomach or pain or discomfort in the upper belly, near the ribs.

Functional food is any fresh or processed food claimed to have a health-promoting or disease-preventing property beyond the basic function of supplying nutrients. Also called medicinal food.

Furuncle is a skin disease caused by the infection of hair follicles usually caused by *Staphylococcus aureus*, resulting in the localized accumulation of pus and dead tissue.

Furunculosis skin condition characterized by persistent, recurring boils.

GABA gamma aminobutyric acid, required as an inhibitory neurotransmitter to block the transmission of an impulse from one cell to another in the central nervous system, which prevents over-firing of the nerve cells. It is used to treat both epilepsy and hypertension.

GADD 152 a pro-apoptotic gene.

Galctifuge or lactifuge, causing the arrest of milk secretion.

Galactagogue a substance that promotes the flow of milk.

Galactophoritis inflammation of the milk ducts.

Galactopoietic increasing the flow of milk; milk-producing.

Gall baldder a small, pear-shaped muscular sac, located under the right lobe of the liver, in

which bile secreted by the liver is stored until needed by the body for digestion. Also called cholecyst, cholecystis.

Gallic Acid Equivalent (GAE) measures the total phenol content in terms of the standard Gallic acid by the Folin-Ciocalteu assay.

Galphai proteins or G alpha I proteins are heterotrimeric guanine nucleotide-regulatory (G) proteins associated with a variety of intracellular membranes and specific plasma membrane domains.

Gamma GT (GGT) Gamma-glutamyl transpeptidase, a liver enzyme.

Gastralgia (heart burn) - pain in the stomach or abdominal region. It is caused by excess of acid, or an accumulation of gas, in the stomach.

Gastric pertaining to or affecting the stomach.

Gastric emptying refers to the speed at which food and drink leave the stomach.

Gastritis inflammation of the stomach.

Gastrocnemius muscle the big calf muscle at the rear of the lower leg.

Gastrotonic (Gastroprotective) substance that strengthens, tones, or regulates gastric functions (or protects from injury) without overt stimulation or depression.

Gavage forced feeding.

Gene silencing suppression of the expression of a gene.

Genotoxic describes a poisonous substance which harms an organism by damaging its DNA thereby capable of causing mutations or cancer.

Genotoxin a chemical or other agent that damages cellular DNA, resulting in mutations or cancer.

Geriatrics is a sub-specialty of internal medicine that focuses on health care of elderly people.

Gestational hypertension development of arterial hypertension in a pregnant woman after 20 weeks gestation.

Ghrelin a gastrointestinal peptide hormone secreted by epithelial cells in the stomach lining, it stimulates appetite, gastric emptying, and increases cardiac output.

Gingival Index an index describing the clinical severity of gingival inflammation as well as its location.

Gingivitis refers to gingival inflammation induced by bacterial biofilms (also called plaque) adherent to tooth surfaces.

- Gin-nan sitotoxism** toxicity caused by ingestion of ginkgotoxin and characterised mainly by epileptic convulsions, paralysis of the legs and loss of consciousness.
- GIP** gastric inhibitory polypeptide also known as the glucose-dependent insulintropic peptide, a member of the secretin family of hormones.
- Glaucoma** a group of eye diseases in which the optic nerve at the back of the eye is slowly destroyed, leading to impaired vision and blindness.
- Gleet** a chronic inflammation (as gonorrhea) of a bodily orifice usually accompanied by an abnormal discharge.
- Glial cells** support, non-neuronal cells in the central nervous system that maintain homeostasis, form myelin and provide protection for the brain's neurons.
- Glioma** is a type of tumour that starts in the brain or spine. It is called a glioma because it arises from glial cells.
- Glioblastoma** common and most lethal form of brain tumor.
- Glioblastoma multiforme** most common and most aggressive type of primary brain tumour in humans, involving glial cells.
- Glomerulonephritis (GN)** a renal disease characterized by inflammation of the glomeruli, or small blood vessels in the kidneys. Also known as glomerular nephritis. *adj.* glomerulonephritic.
- Glomerulosclerosis** a hardening (fibrosis) of the glomerulus in the kidney.
- Glossal** pertaining to the tongue.
- GLP-1** glucagon-like peptide-1.
- Glucagon-like peptide-1 (GLP-1)** is derived from the transcription product of the proglucagon gene, reduces insulin requirement in diabetes mellitus and promotes satiety.
- Gluconeogenesis** a metabolic pathway that results in the generation of glucose from non-carbohydrate carbon substrates such as lactate. *adj.* gluconeogenic.
- Glucose transporter type 4 (GLUT 4)** insulin-regulated glucose transporter found in adipose tissues and striated muscles that modulates insulin-related translocation into the cell.
- Glucose transporters** (GLUT or SLC2A family) are a family of membrane proteins found in most mammalian cells.
- Glucosuria or glycosuria** is the excretion of glucose into the urine.
- Glucosyltransferase** an enzyme that enable the transfer of glucose.
- Glucuronidation** a phase II detoxification pathway occurring in the liver in which glucuronic acid is conjugated with toxins.
- Glutamic Oxaloacetate Transaminase (GOT)** catalyzes the transfer of an amino group from an amino acid (Glu) to a 2-keto-acid to generate a new amino acid and the residual 2-keto-acid of the donor amino acid.
- Glutamic pyruvate transaminase (GPT)** see Alanine aminotransferase.
- Glutathione (GSH)** a tripeptide produced in the human liver and plays a key role in intermediary metabolism, immune response and health. It plays an important role in scavenging free radicals and protects cells against several toxic oxygen-derived chemical species.
- Glutathione peroxidase (GPX)** the general name of an enzyme family with peroxidase activity whose main biological role is to protect the organism from oxidative damage.
- Glutathione S-transferase (GST)** a major group of detoxification enzymes that participate in the detoxification of reactive electrophilic compounds by catalysing their conjugation to glutathione.
- Glycaemic index (GI)** measures carbohydrates according to how quickly they are absorbed and raise the glucose level of the blood.
- Glycaemic load (GL)** is a ranking system for carbohydrate content in food portions based on their glycaemic index and the amount of available carbohydrate, i.e. $GI \times \text{available carbohydrate} / 100$. Glycemic load combines both the quality and quantity of carbohydrate in one 'number'. It's the best way to predict blood glucose values of different types and amounts of food.
- Glycation or glycosylation** a chemical reaction in which glycosyl groups are added to a protein to produce a glycoprotein.
- Glycogenolysis** is the catabolism of glycogen by removal of a glucose monomer through cleavage with inorganic phosphate to produce glucose-1-phosphate.
- Glycometabolism** metabolism (oxidation) of glucose to produce energy.
- Glycosuria** or glucosuria is an abnormal condition of osmotic diuresis due to excretion of glucose by the kidneys into the urine.

- Glycosylases** a family of enzymes involved in base excision repair.
- Goitre** an enlargement of the thyroid gland leading to swelling of the neck or larynx.
- Goitrogen** substance that suppresses the function of the thyroid gland by interfering with iodine uptake, causing enlargement of the thyroid, i.e. goiter.
- Goitrogenic** *adj.* causing goiter.
- Gonadotroph** a basophilic cell of the anterior pituitary specialized to secrete follicle-stimulating hormone or luteinizing hormone.
- Gonadotropins** protein hormones secreted by gonadotrope cells of the pituitary gland of vertebrates.
- Gonorrhoea** a common sexually transmitted bacterial infection caused by the bacterium *Neisseria gonorrhoeae*.
- Gout** a disorder caused by a build-up of a waste product, uric acid, in the bloodstream. Excess uric acid settles in joints causing inflammation, pain and swelling.
- G-protein-coupled receptors (GPCRs)** constitute the largest family of cell-surface molecules involved in signal transmission. These receptors play key physiological roles and their dysfunction results in several diseases.
- Granulation** the condition or appearance of being granulated (becoming grain-like).
- Gravel** sand-like concretions of uric acid, calcium oxalate, and mineral salts formed in the passages of the biliary and urinary tracts.
- Gripe water** is a home remedy for babies with colic, gas, teething pain or other stomach ailments. Its ingredients vary, and may include alcohol, bicarbonate, ginger, dill, fennel and chamomile.
- Grippe** an epidemic catarrh; older term for influenza.
- GSH** see Glutathione.
- GSH-Px** Glutathione peroxidase, general name of an enzyme family with peroxidase activity whose main biological role is to protect the organism from oxidative damage.
- GSSG** glutathione disulfides are biologically important intracellular thiols, and alterations in the GSH/GSSG ratio are often used to assess exposure of cells to oxidative stress.
- GSTM** glutathione S transferase M1, a major group of detoxification enzymes.
- GSTM 2** glutathione S transferase M2, a major group of detoxification enzymes.
- G2-M cell cycle** the phase where the cell prepare for mitosis and where chromatids and daughter cells separate.
- Gynecopathy** any or various diseases specific to women.
- Gynoid adiposity** fat distribution mainly to the hips and thighs, pear shaped.
- Haemagogic** promoting a flow of blood.
- Haematemesis, Hematemesis** is the vomiting of blood.
- Haematinic** improving the quality of the blood, its haemoglobin level and the number of erythrocytes.
- Haematochezia** passage of stools containing blood.
- Haematochyluria, hematochyluria** the discharge of blood and chyle (emulsified fat) in the urine, see also chyluria.
- Haematoma, hematoma** a localized accumulation of blood in a tissue or space composed of clotted blood.
- Haematometra, hematometra** a medical condition involving bleeding of or near the uterus.
- Haematopoiesis, hematopoiesis** formation of blood cellular components from the haematopoietic stem cells.
- Haematopoietic** *adj.* relating to the formation and development of blood cells.
- Haematuria, Hematuria** is the presence of blood in the urine. Hematuria is a sign that something is causing abnormal bleeding in a person's genitourinary tract.
- Haeme oxygenase** (HO-1, encoded by Hmox1) is an inducible protein activated in systemic inflammatory conditions by oxidant stress, an enzyme that catalyzes degradation of heme.
- Haemochromatosis** iron overload in the body with a hereditary or primary cause.
- Haemodialysis, Hemodialysis** a method for removing waste products such as potassium and urea, as well as free water from the blood when the kidneys are in renal failure.
- Haemolysis** lysis of red blood cells and the release of haemoglobin into the surrounding fluid (plasma). *adj.* haemolytic.
- Haemoptysis, hemoptysis** is the coughing up of blood from the respiratory tract. The blood

- can come from the nose, mouth, throat, and the airway passages leading to the lungs.
- Haemorrhage, hemaorrhage** bleeding, discharge of blood from blood vessels.
- Haemorrhoids, Hemorrhoids** a painful condition in which the veins around the anus or lower rectum are enlarged, swollen and inflamed. Also called piles.
- Haemostasis, hemostasis** a complex process which causes the bleeding process to stop.
- Haemostatic, hemostatic** something that stops bleeding.
- Halitosis** (bad breath) a common condition caused by sulfur-producing bacteria that live within the surface of the tongue and in the throat.
- Hallucinogen** drug that produces hallucinogen.
- Hallucinogenic** inducing hallucinations.
- Haplotype** a set of alleles of closely linked loci on a chromosome that tend to be inherited together.
- Hapten** a small molecule that can elicit an immune response only when attached to a large carrier such as a protein.
- HATs** histone acetyl transferases, enzymes that regulate the acetylation of histones and transcription factors, playing a major role in the growth and differentiation of cells.
- HbA1c** glycosylated haemoglobin.
- HBeAg** hepatitis B e antigen.
- HBsAg** hepatitis B s antigen.
- Heartburn** burning sensation in the stomach and esophagus caused by excessive acidity of the stomach fluids.
- Heat rash** any condition aggravated by heat or hot weather such as intertrigo.
- Heat Shock Chaperones (HSC)** ubiquitous molecules involved in the modulation of protein conformational and complexation states, associated with heat stress or other cellular stress response.
- Heat Shock Proteins (HSP)** a group of functionally related proteins the expression of which is increased when the cells are exposed to elevated temperatures or other cellular stresses.
- Helminthiasis** a disease in which a part of the body is infested with worms such as pinworm, roundworm or tapeworm.
- Hemagglutination** a specific form of agglutination that involves red blood cells.
- Hemagglutination-inhibition test** measures of the ability of soluble antigen to inhibit the agglutination of antigen-coated red blood cells by antibodies.
- Hemagglutinin** refers to a substance that causes red blood cells to agglutinate.
- Hemangioma** blood vessel.
- Hematocrit** is a blood test that measures the percentage of the volume of whole blood that is made up of red blood cells.
- Hematopoietic** pertaining to the formation of blood or blood cells.
- Hematopoietic stem cell** is a cell isolated from the blood or bone marrow that can renew itself, and can differentiate to a variety of specialized cells.
- Heme oxygenase-1 (HO-1)** an enzyme that catalyses the degradation of heme; an inducible stress protein, confers cytoprotection against oxidative stress in-vitro and in-vivo.
- Hemoglobinopathies** genetic defects that produce abnormal hemoglobins and anemia.
- Hemolytic anemia** anemia due to hemolysis, the breakdown of red blood cells in the blood vessels or elsewhere in the body.
- Hemorheology** study of blood flow and its elements in the circulatory system. *adj.* hemorheological.
- Hemorrhagic colitis** an acute gastroenteritis characterized by overtly bloody diarrhea that is caused by *Escherichia coli* infection.
- Hemolytic-uremic syndrome** is a disease characterized by hemolytic anemia, acute renal failure (uremia) and a low platelet count.
- Hepa-1c1c7** a type of hepatoma cells.
- Hepatalgia** pain or discomfort in the liver area.
- Hepatomegaly** condition of enlarged liver.
- Hepatectomy** the surgical removal of part or all of the liver.
- Hepatic** relating to the liver.
- Hepatic cirrhosis** affecting the liver, characterize by hepatic fibrosis and regenerative nodules.
- Hepatic fibrosis** is overly profuse wound healing in which excessive connective tissue builds up in the liver.
- Hepatitis** inflammation of the liver.
- Hepatitis A** (formerly known as infectious hepatitis) is an acute infectious disease of the liver caused by the hepatovirus hepatitis A virus.

Hepatocarcinogenesis represents a linear and progressive cancerous process in the liver in which successively more aberrant monoclonal populations of hepatocytes evolve.

Hepatocellular carcinoma (HCC) also called malignant hepatoma, is a primary malignancy (cancer) of the liver.

Hepatocytolysis cytotoxicity (dissolution) of liver cells.

Hepatoma cancer of the liver.

Hepatopathy a disease or disorder of the liver.

Hepatoprotective (liver protector) a substance that helps protect the liver from damage by toxins, chemicals or other disease processes.

Hepatoregenerative a compound that promotes hepatocellular regeneration, repairs and restores liver function to optimum performance.

Hepatotonic (liver tonic) a substance that is tonic to the liver - usually employed to normalize liver enzymes and function.

Hernia occurs when part of an internal organ bulges through a weak area of muscle.

HER- 2 human epidermal growth factor receptor 2, a protein giving higher aggressiveness in breast cancer, also known as ErbB-2, ERBB2.

Herpes a chronic inflammation of the skin or mucous membrane characterized by the development of vesicles on an inflammatory base.

Herpes simplex virus 1 and 2 – (HSV-1 and HSV-2) are two species of the herpes virus family which cause a variety of illnesses/infections in humans such cold sores, chickenpox or varicella, shingles or herpes zoster (VZV), cytomegalovirus (CMV), and various cancers, and can cause brain inflammation (encephalitis). HSV-1 is commonly associated with herpes outbreaks of the face known as cold sores or fever blisters, whereas HSV-2 is more often associated with genital herpes. They are also called Human Herpes Virus 1 and 2 (HHV-1 and HHV-2) and are neurotropic and neuroinvasive viruses; they enter and hide in the human nervous system, accounting for their durability in the human body.

Herpes zoster or simply zoster, commonly known as shingles and also known as zona, is a viral disease characterized by a painful skin rash with blisters.

Herpes Zoster Ophthalmicus (HZO) is a viral ocular disease characterized by a painful skin

rash in one or more dermatome distributions of the fifth cranial nerve, shared by the eye and orbit.

Heterophobia term used to describe irrational fear of, aversion to, or discrimination against heterosexuals.

HDL-C (HDL Cholesterol) high density lipoprotein-cholesterol, also called “good cholesterol”. See also high-density lipoprotein.

Hiatus hernia occurs when the upper part of the stomach pushes its way through a tear in the diaphragm.

High-density lipoprotein (HDL) is one of the five major groups of lipoproteins which enable cholesterol and triglycerides to be transported within the water based blood stream. HDL can remove cholesterol from atheroma within arteries and transport it back to the liver for excretion or re-utilization—which is the main reason why HDL-bound cholesterol is sometimes called “good cholesterol”, or HDL-C. A high level of HDL-C seems to protect against cardiovascular diseases. cf. LDL.

HGPRT, HPRT (hypoxanthine-guanine phosphoribosyl transferase) an enzyme that catalyzes the conversion of 5-phosphoribosyl-1-pyrophosphate and hypoxanthine, guanine, or 6-mercaptopurine to the corresponding 5'-mononucleotides and pyrophosphate. The enzyme is important in purine biosynthesis as well as central nervous system functions.

Hippocampus a ridge in the floor of each lateral ventricle of the brain that consists mainly of gray matter.

Hippocampal pertaining to the hippocampus.

Hirsutism a condition where women have excess facial and body hair that is dark and coarse.

Histaminergic liberated or activated by histamine, relating to the effects of histamine at histamine receptors of target tissues.

Histaminergic receptors are types of G-protein coupled receptors with histamine as their endogenous ligand.

HIV see Human immunodeficiency virus.

Hives (urticaria) is a skin rash characterised by circular wheals of reddened and itching skin.

HLA human leukocyte antigen system, name of the major histocompatibility complex (MHC) in humans.

- HLA-DQB1** human leucocyte antigen beta chain.
- HLA-DR** a major histocompatibility complex (MHC) class II cell surface receptor encoded by the human leukocyte antigen complex on chromosome 6 region 6p21.31.
- HMG-CoAr** 3-hydroxy-3-methyl-glutaryl-CoA reductase or (HMGR) is the rate-controlling enzyme (EC 1.1.1.88) of the mevalonate pathway.
- HMG-CoA** 3-hydroxy-3-methylglutaryl-coenzyme A, an intermediate in the mevalonate pathway.
- Hodgkin's disease** disease characterized by enlargement of the lymph glands, spleen and anemia.
- Homeodomain transcription factor** a protein domain encoded by a homeobox. Homeobox genes encode transcription factors which typically switch on cascades of other genes.
- Homeostasis** the maintenance of a constant internal environment of a cell or an organism, despite fluctuations in the external.
- Homeotherapy** treatment or prevention of disease with a substance similar but not identical to the causative agent of the disease.
- Homocysteine** an amino acid in the blood.
- Homograft** see allograft.
- Hormonal (female)** substance that has a hormone-like effect similar to that of estrogen and/or a substance used to normalize female hormone levels.
- Hormonal (male)** substance that has a hormone-like effect similar to that of testosterone and/or a substance used to normalize male hormone levels.
- HRT** hormone replacement therapy, the administration of the female hormones, oestrogen and progesterone, and sometimes testosterone.
- HSP27** is an ATP-independent, 27 kDa heat shock protein chaperone that confers protection against apoptosis.
- HSP90** a 90 kDa heat shock protein chaperone that has the ability to regulate a specific subset of cellular signaling proteins that have been implicated in disease processes.
- hTERT – (TERT)** telomerase reverse transcriptase is a catalytic subunit of the enzyme telomerase in humans. It exerts a novel protective function by binding to mitochondrial DNA, increasing respiratory chain activity and protecting against oxidative stress-induced damage.
- HT29 cells** are human intestinal epithelial cells which produce the secretory component of Immunoglobulin A (IgA), and carcinoembryonic antigen (CEA).
- Human cytomegalovirus (HCMV)** a DNA herpes virus which is the leading cause of congenital viral infection and mental retardation.
- Human factor X** a coagulation factor also known by the eponym Stuart-Prower factor or as thrombokinase, is an enzyme involved in blood coagulation. It synthesized in the liver and requires vitamin K for its synthesis.
- Human immunodeficiency virus (HIV)** a retrovirus that can lead to acquired immunodeficiency syndrome (AIDS), a condition in humans in which the immune system begins to fail, leading to life-threatening opportunistic infections.
- Humoral immune response (HIR)** is the aspect of immunity that is mediated by secreted antibodies (as opposed to cell-mediated immunity, which involves T lymphocytes) produced in the cells of the B lymphocyte lineage (B cell).
- HUVEC** human umbilical vein endothelial cells.
- Hyaluronidase** enzymes that catalyse the hydrolysis of certain complex carbohydrates like hyaluronic acid and chondroitin sulfates.
- Hydatidiform** a rare mass or growth that forms inside the uterus at the beginning of a pregnancy.
- Hydrocholeretic** an agent that stimulates an increased output of bile of low specific gravity.
- Hydrogogue** a purgative that causes an abundant watery discharge from the bowel.
- Hydronephrosis** is distension and dilation of the renal pelvis and calyces, usually caused by obstruction of the free flow of urine from the kidney.
- Hydrophobia** a viral neuroinvasive disease that causes acute encephalitis (inflammation of the brain) in warm-blooded animals. Also called rabies.
- Hydropsy** see dropsy.
- Hydrothorax** accumulation of serous fluid in the pleural cavity.

- Hyperaemia** the increase of blood flow to different tissues in the body.
- Hyperalgesia** an increased sensitivity to pain (enhanced pricking pain), which may be caused by damage to nociceptors or peripheral nerves.
- Hyperammonemia, hyperammonaemia** a metabolic disturbance characterised by an excess of ammonia in the blood.
- Hypercalciuria** (*Idiopathic*) presence of excess calcium in the urine without obvious cause.
- Hypercholesterolemia** high levels of cholesterol in the blood that increase a person's risk for cardiovascular disease leading to stroke or heart attack.
- Hyperemia** is the increased blood flow that occurs when tissue is active.
- Hyperemesis** severe and persistent nausea and vomiting (morning sickness) during pregnancy.
- Hyperfibrinogenemia** excessive fibrinogen in the blood.
- Hyperglycaemia hyperglycemic** high blood sugar; is a condition in which an excessive amount of glucose circulates in the blood plasma.
- Hyperglycemic** a substance that raises blood sugar levels.
- Hyperhomocysteinemia** is a medical condition characterized by an abnormally large level of homocysteine in the blood.
- Hyperinsulinemia** a condition in which there are excess levels of circulating insulin in the blood; also known as pre-diabetes.
- Hyperkalemia** is an elevated blood level of the electrolyte potassium.
- Hyperknesis** enhanced itch to pricking.
- Hyperleptinemia** increased serum leptin level.
- Hyperlipoproteinemia** a metabolic disorder characterized by abnormally elevated concentrations of lipid/lipoprotein in the plasma; also known as hyperlipidemia and hyperlipemia.
- Hypermethylation** an increase in the inherited methylation of cytosine and adenosine residues in DNA.
- Hyperphagia** or polyphagia abnormally large ingestion of food beyond that needed for basic energy requirements.
- Hyperpiesia** persistent and pathological high blood pressure for which no specific cause can be found.
- Hyperplasia** increased cell production in a normal tissue or organ.
- Hyperprebeta-lipoproteinaemia** increased concentrations of pre-beta-lipoproteins in the blood.
- Hyperpropulsion** using water pressure as a force to move objects; used to dislodge calculi in the urethra.
- Hyperpyrexia** is an abnormally high fever.
- Hypertension** commonly referred to as "high blood pressure" or HTN, is a medical condition in which the arterial blood pressure is chronically elevated.
- Hypertensive** characterized or caused by increased tension or pressure as abnormally high blood pressure.
- Hypertonia** abnormal increase in muscle tension and a reduced ability of the muscle to stretch.
- Hypertriglyceridaemia or hypertriglycemia** a disorder that causes high triglycerides in the blood.
- Hypertrophy** enlargement or overgrowth of an organ.
- Hyperuricemia** is a condition characterized by abnormally high level of uric acid in the blood.
- Hypoadiponectinemia** the state of having too low level of adiponectin, a major metabolic endocrine, responsible for regulating things like glucose uptake and lipolysis (the breakdown of fat deposits); low adiponectin, is a risk factor for both Type II Diabetes and metabolic syndrome.
- Hypoalbuminemia** a medical condition where levels of albumin in blood serum are abnormally low.
- Hypocalcemic tetany** a disease caused by an abnormally low level of calcium in the blood and characterized by hyperexcitability of the neuromuscular system and results in carpopedal spasms.
- Hypochlorhydria** refer to states where the production of gastric acid in the stomach is absent or low.
- Hypocholesterolemic** (cholesterol-reducer), a substance that lowers blood cholesterol levels.
- Hypocitraturia** low amount of citrate in the urine, an important risk factor for kidney stone formation.
- Hypocorticism** see Addison's disease.

Hypocortisolism see Addison's disease.

Hypoesthesia (or hypesthesia) refers to a reduced sense of touch or sensation, or a partial loss of sensitivity to sensory stimuli.

Hypoglycemic an agent that lowers the concentration of glucose (sugar) in the blood.

Hypoperfusion decreased blood flow through an organ, characterized by an imbalance of oxygen demand and oxygen delivery to tissues.

Hypophagic under-eating.

Hypospadias an abnormal birth defect in males in which the urethra opens on the under surface of the penis.

Hypotensive characterised by or causing diminished tension or pressure, as abnormally low blood pressure.

Hypothermia a condition in which an organism's temperature drops below that required for normal metabolism and body functions.

Hypothermic relating to hypothermia, with subnormal body temperature.

Hypoxaemia is the reduction of oxygen specifically in the blood.

Hypoxia a shortage of oxygen in the body. *adj.* hypoxic.

ICAM-1 (Inter-Cellular Adhesion Molecule 1) also known as CD54 (Cluster of Differentiation 54), is a protein that in humans is encoded by the ICAM1 gene.

IC₅₀ the median maximal inhibitory concentration; a measure of the effectiveness of a compound in inhibiting biological or biochemical function.

I.C.V. (intra-cerebroventricular) injection of chemical into the right lateral ventricle of the brain.

Iceterus jaundice, yellowish pigmentation of the skin.

Ichthyotoxic a substance which is poisonous to fish.

Icteric hepatitis an infectious syndrome of hepatitis characterized by jaundice, nausea, fever, right-upper quadrant pain, enlarged liver and transaminitis (increase in alanine aminotransferase (ALT) and/or aspartate aminotransferase (AST)).

Icterus neonatorum jaundice in newborn infants.

Idiopathic of no apparent physical cause.

Idiopathic sudden sensorineural hearing loss (ISSHL) is sudden hearing loss where clinical assessment fails to reveal a cause.

I.g. gastric intubation, insertion of Levin tube through the nasal passage to the stomach.

IgE Immunoglobulin E – a class of antibody that plays a role in allergy.

IGFs insulin-like growth factors, polypeptides with high sequence similarity to insulin.

IgG Immunoglobulin G – the most abundant immunoglobulin (antibody) and is one of the major activators of the complement pathway.

IgM Immunoglobulin M - primary antibody against A and B antigens on red blood cells.

IKAP is a scaffold protein of the Ikaros-Kappa-Beta kinase complex and a regulator for kinases involved in pro-inflammatory cytokine signaling.

IKappa B or IκB-beta, a protein of the NF-Kappa-B inhibitor family.

Ileus a temporary disruption of intestinal peristalsis due to non-mechanical causes.

Immune modulator a substance that affects or modulates the functioning of the immune system.

Immunodeficiency a state in which the immune system's ability to fight infectious disease is compromised or entirely absent.

Immunogenicity the property enabling a substance to provoke an immune response, *adj.* immunogenic.

Immunoglobulin class switching **Ig class switching** a biological mechanism that changes a B cell's production of antibody from one class to another.

Immunomodulatory capable of modifying or regulating one or more immune functions.

Immunoreactive reacting to particular antigens or haptens.

Immunostimulant agent that stimulates an immune response.

Immunosuppression involves a process that reduces the activation or efficacy of the immune system.

Immunotoxin a man-made protein that consists of a targeting portion linked to a toxin.

Impaired glucose tolerance (IGT) a pre-diabetic state of dysglycemia associated with insulin resistance, increased risk of cardiovascular pathology and also a risk factor for mortality.

Impetigo a contagious, bacterial skin infection characterized by blisters that may itch, caused

by a *Streptococcus* bacterium or *Staphylococcus aureus* and mostly seen in children.

Impotence a sexual dysfunction characterized by the inability to develop or maintain an erection of the penis.

Incontinence (fecal) the inability to control bowel's movement.

Incontinence (Urine) the inability to control urine excretion.

Incretin a group of gastrointestinal hormones that cause an increase in the amount of insulin released from the beta cells of the islets of Langerhans after a meal; members include GIP and GLP-1.

Index of structural atypia (ISA) index of structural abnormality.

Induration hardened, as a soft tissue that becomes extremely firm, sclerosis.

Infarct an area of living tissue that undergoes necrosis as a result of obstruction of local blood supply.

Infarction is the process of tissue death (necrosis) caused by blockage of the tissue's blood supply.

Inflammation a protective response of the body to infection, irritation or other injury, aimed at destroying or isolating the injuries and characterized by redness, pain, warmth and swelling.

Influenza a viral infection that affects mainly the nose, throat, bronchi and occasionally, lungs.

Infusion a liquid extract obtained by steeping something (e.g. herbs) that are more volatile or dissolve readily in water, to release their active ingredients without boiling.

Inguinal hernia a hernia into the inguinal canal of the groin.

Inhalant a medicinal substance that is administered as a vapor into the upper respiratory passages.

iNOS, inducible nitric oxide synthases through its product, nitric oxide (NO), may contribute to the induction of germ cell apoptosis. It plays a crucial role in early sepsis-related microcirculatory dysfunction.

Inotropic affecting the force of muscle contraction.

Insecticide an agent that destroys insects. *adj.* insecticidal.

Insomnia a sleeping disorder characterized by the inability to fall asleep and/or the

inability to remain asleep for a reasonable amount of time.

Insulin a peptide hormone composed of 51 amino acids produced in the islets of Langerhans in the pancreas causes cells in the liver, muscle, and fat tissue to take up glucose from the blood, storing it as glycogen in the liver and muscle. Insulin deficiency is often the cause of diabetes and exogenous insulin is used to control diabetes.

Insulin homeostasis blood sugar regulation.

Insulin-like growth factors (IGFs) polypeptides with high sequence similarity to insulin. They are part of a complex system that cells employ to communicate with their physiologic environment.

Insulin-mimetic to act like insulin.

Insulin resistance a condition where the natural hormone insulin becomes less effective at reducing blood sugars.

Insulinogenic associated with or stimulating the production of insulin.

Insulinotropic stimulating or affecting the production and activity of insulin.

Integrase an enzyme produced by a retrovirus (such as HIV) that enables its genetic material to be integrated into the DNA of the infected cell.

Interferons (IFNs) are natural cell-signaling glycoproteins known as cytokines produced by the cells of the immune system of most vertebrates in response to challenges such as viruses, parasites and tumour cells.

Interleukins a group of naturally occurring proteins and is a subset of a larger group of cellular messenger molecules called cytokines, which are modulators of cellular behavior.

Interleukin-1 (IL-1) a cytokine that could induce fever, control lymphocytes, increase the number of bone marrow cells and cause degeneration of bone joints. Also called endogenous pyrogen, lymphocyte activating factor, haemo-poietin-1 and mononuclear cell factor, amongst others that IL-1 is composed of two distinct proteins, now called IL-1 α and IL-1 β .

Interleukin 1 Beta (IL-1 β) a cytokine protein produced by activated macrophages. cytokine is an important mediator of the inflammatory response, and is involved in a variety of cellular activities, including cell proliferation, differentiation, and apoptosis.

Interleukin 2 (IL-2) a type of cytokine immune system signaling molecule that is instrumental in the body's natural response to microbial infection.

Interleukin-2 receptor (IL-2R) a heterotrimeric protein expressed on the surface of certain immune cells, such as lymphocytes, that binds and responds to a cytokine called IL-2.

Interleukin-6 (IL-6) an interleukin that acts as both a pro-inflammatory and anti-inflammatory cytokine.

Interleukin 8 (I- 8) a cytokine produced by macrophages and other cell types such as epithelial cells and is one of the major mediators of the inflammatory response.

Intermediate-density lipoproteins (IDL) is one of the five major groups of lipoproteins (chylomicrons, VLDL, IDL, LDL, and HDL) that enable fats and cholesterol to move within the water-based solution of the bloodstream. IDL is further degraded to form LDL particles and, like LDL, can also promote the growth of atheroma and increase cardiovascular diseases.

Intermittent claudication an aching, crampy, tired, and sometimes burning pain in the legs that comes and goes, caused by peripheral vascular disease. It usually occurs with walking and disappears after rest.

Interoceptive relating to stimuli arising from within the body.

Interstitium the space between cells in a tissue.

Interstitial pertaining to the interstitium.

Intertrigo an inflammation (rash) caused by microbial infection in skin folds.

Intima innermost layer of an artery or vein.

Intoxicant substance that produce drunkenness or intoxication.

Intracavernosal within the corpus cavernosum, columns of erectile tissues forming the body of the penis.

Intraperitoneal (i.p.) the term used when a chemical is contained within or administered through the peritoneum (the thin, transparent membrane that lines the walls of the abdomen).

Intrathecal (i.t.) through the theca of the spinal cord into the subarachnoid space.

Intromission the act of putting one thing into another.

Intubation refers to the placement of a tube into an external or internal orifice of the body.

Iodine (I) is an essential chemical element that is important for hormone development in the human body. Lack of iodine can lead to an enlarged thyroid gland (goitre) or other iodine deficiency disorders including mental retardation and stunted growth in babies and children. Iodine is found in dairy products, seafood, kelp, seaweeds, eggs, some vegetables and iodized salt.

IP see Intraperitoneal.

IP3R3 (inositol 1,4,5-triphosphate receptor type 3) is an intracellular calcium release channel that mediates calcium release from the endoplasmic reticulum.

Iron (Fe) is essential to most life forms and to normal human physiology. In humans, iron is an essential component of proteins involved in oxygen transport and for haemoglobin. It is also essential for the regulation of cell growth and differentiation. A deficiency of iron limits oxygen delivery to cells, resulting in fatigue, poor work performance, and decreased immunity. Conversely, excess amounts of iron can result in toxicity and even death. Dietary sources include, certain cereals, dark green leafy vegetables, dried fruit, legumes, seafood, poultry and meat.

Ischemia an insufficient supply of blood to an organ, usually due to a blocked artery.

Ischuria retention or suppression of urine.

Isoflavones a subgroup of flavonoids in which the basic structure is a 3-phenyl chromane skeleton. They act as phytoestrogens in mammals. See flavonoids.

Isomers substances that are composed of the same elements in the same proportions and hence have the same molecular formula but differ in properties because of differences in the arrangement of atoms.

Isoprostanes unique prostaglandin-like compounds generated in vivo from the free radical-catalysed peroxidation of essential fatty acids.

Jamu traditional Indonesian herbal medicine.

Jaundice refers to the yellow color of the skin and whites of the eyes caused by excess bilirubin in the blood.

JNK (Jun N-terminal Kinase), also known as Stress Activated Protein Kinase (SAPK), belongs to the family of MAP kinases.

- Jurkat cells** a line of T lymphocyte cells that are used to study acute T cell leukemia.
- KB cell** a cell line derived from a human carcinoma of the nasopharynx, used as an assay for antineoplastic (anti-tumour) agents.
- Kaliuresis** the presence of excess potassium in the urine.
- Kallikreins** peptidases (enzymes that cleave peptide bonds in proteins), a subgroup of the serine protease family; they liberate kinins from kininogens. Kallikreins are targets of active investigation by drug researchers as possible biomarkers for cancer.
- Kaposi sarcoma** a cancerous tumour of the connective tissues caused by the human herpesvirus 8 and is often associated with AIDS.
- Kaposi sarcoma herpes virus (KSHV)** also known as human herpesvirus-8, is a gamma 2 herpesvirus or rhadinovirus. It plays an important role in the pathogenesis of Kaposi sarcoma (KS), multicentric Castleman disease (MCD) of the plasma cell type, and primary effusion lymphoma and occurs in HIV patients.
- Karyolysis** dissolution and disintegration of the nucleus when a cell dies.
- Karyorrhexis** destructive fragmentation of the nucleus of a dying cell whereby its chromatin disintegrates into formless granules.
- Keratin** a sulphur-containing protein which is a major component in skin, hair, nails, hooves, horns, and teeth.
- Keratinocyte** is the major constituent of the epidermis, constituting 95% of the cells found there.
- Keratinophilic** having an affinity for keratin.
- Keratitis** inflammation of the cornea.
- Keratomalacia** an eye disorder that leads to a dry cornea.
- Kidney stones** (calculi) are hardened mineral deposits that form in the kidney.
- Kinin** is any of various structurally related polypeptides, such as bradykinin, that act locally to induce vasodilation and contraction of smooth muscle.
- Kininogen** either of two plasma α 2-globulins that are kinin precursors.
- Ki-67** human protein associated with cell proliferation.
- Knockout** gene knockout is a genetic technique in which an organism is engineered to carry genes that have been made inoperative.
- Kunitz protease inhibitors** a type of protein contained in legume seeds which functions as a protease inhibitor.
- Kupffer cells** are resident macrophages of the liver and play an important role in its normal physiology and homeostasis as well as participating in the acute and chronic responses of the liver to toxic compounds.
- L-Dopa** (L-3,4-dihydroxyphenylalanine) is an amino acid that is formed in the liver and converted into dopamine in the brain.
- Labour** process of childbirth involving muscular contractions.
- Lacrimation** secretion and discharge of tears.
- Lactagogue** an agent that increases or stimulates milk flow or production. Also called a galactagogue.
- Lactate dehydrogenase (LDH)** enzyme that catalyzes the conversion of lactate to pyruvate.
- Lactation** secretion and production of milk.
- Lactic acidosis** is a condition caused by the buildup of lactic acid in the body. It leads to acidification of the blood (acidosis), and is considered a distinct form of metabolic acidosis.
- LAK cell** a lymphokine-activated killer cell i.e. a white blood cell that has been stimulated to kill tumour cells.
- Laminin** a glycoprotein component of connective tissue basement membrane that promotes cell adhesion.
- Laparotomy** a surgical procedure involving an incision through the abdominal wall to gain access into the abdominal cavity. *adj.* laparotomized.
- Larvacidal** an agent which kills insect or parasite larva.
- Laryngitis** is an inflammation of the larynx.
- Laxation** bowel movement.
- Laxatives** substances that are used to promote bowel movement.
- LC 50** median lethal concentration, see LD₅₀.
- LD₅₀** median lethal dose - the dose required to kill half the members of a tested population. Also called LC 50 (median lethal concentration).
- LDL** see low-density lipoprotein.
- LDL Cholesterol** see low-density lipoprotein.
- LDL receptor (LDLr)** a low-density lipoprotein receptor gene.

- Lectins** are sugar-binding proteins that are highly specific for their sugar moieties, that agglutinate cells and/or precipitate glycoconjugates. They play a role in biological recognition phenomena involving cells and proteins.
- Leishmaniasis** a disease caused by protozoan parasites that belong to the genus *Leishmania* and is transmitted by the bite of certain species of sand fly.
- Lenitive** palliative.
- Lenticular opacity** also known as or related to cataract.
- Leprosy** a chronic bacterial disease of the skin and nerves in the hands and feet and, in some cases, the lining of the nose. It is caused by the *Mycobacterium leprae*. Also called Hansen's disease.
- Leptin** is a 16 kDa protein hormone with important effects in regulating body weight, metabolism and reproductive function.
- Lequesne Algofunctional Index** is a widespread international instrument (10 questions survey) and recommended by the World Health Organization (WHO) for outcome measurement in hip and knee diseases such as osteoarthritis.
- Leucocyte** white blood corpuscles, colourless, without haemoglobin that help to combat infection.
- Leucoderma** a skin abnormality characterized by white spots, bands and patches on the skin; they can also be caused by fungus and tinea. Also see vitiligo.
- Leucorrhoea** commonly known as whites, refers to a whitish discharge from the female genitals.
- Leukemia, leukaemia** a cancer of the blood or bone marrow and is characterized by an abnormal proliferation (production by multiplication) of blood cells, usually white blood cells (leukocytes).
- Leukemogenic** relating to leukemia, causing leukemia.
- Leukocytopenia** abnormal decrease in the number of leukocytes (white blood cells) in the blood.
- Leukomyelopathy** any diseases involving the white matter of the spinal cord.
- Leukopenia** a decrease in the number of circulating white blood cells.
- Leukoplakia** condition characterized by white spots or patches on mucous membranes, especially of the mouth and vulva.
- Leukotriene** a group of hormones that cause the inflammatory symptoms of hay-fever and asthma.
- Luteolysis** degeneration of the corpus luteum and ovarian luteinized tissues. adj. luteolytic.
- Levarterenol** see Norepinephrine.
- LexA repressor** or Repressor LexA is repressor enzyme that represses SOS response genes coding for DNA polymerases required for repairing DNA damage.
- Libido** sexual urge.
- Lichen planus** a chronic mucocutaneous disease that affects the skin, tongue, and oral mucosa.
- Ligroin** a volatile, inflammable fraction of petroleum, obtained by distillation and used as a solvent.
- Limbic system complex** set of brain structures, including the hypothalamus, amygdala, hippocampus, anterior thalamic nuclei, septum, limbic cortex and fornix that control various functions such as emotion, behaviour, motivation, memory and olfaction.
- Liniment** liquid preparation rubbed on skin, used to relieve muscular aches and pains.
- Linterized starch** starch that has undergone prolonged acid treatment.
- Lipodiatic** having lipid and lipoprotein lowering property.
- Lipodystrophy** a medical condition characterized by abnormal or degenerative conditions of the body's adipose tissue.
- Lipogenesis** is the process by which acetyl-CoA is converted to fats.
- Lipolysis** is the breakdown of fat stored in fat cells in the body.
- Lipoxygenase** enzyme that catalyzes the oxidation of polyunsaturated fatty acids to form a peroxide of the acid.
- Liposomes** artificially prepared vesicles made of lipid bilayer.
- Lipotoxicity** refers to tissues diseases that may occur when fatty acids spillover in excess of the oxidative needs of those tissues and enhances metabolic flux into harmful pathways of nonoxidative metabolism.

- Lipotropic** refers to compounds that help catalyse the breakdown of fat during metabolism in the body. e.g. chlorine and lecithin.
- Lipoxygenase** a family of iron-containing enzymes that catalyse the dioxygenation of polyunsaturated fatty acids in lipids containing a *cis,cis*-1,4- pentadiene structure.
- Lithiasis** formation of urinary calculi (stones) in the renal system (kidneys, ureters, urinary bladder, urethra) can be of any one of several compositions.
- Lithogenic** promoting the formation of calculi (stones).
- Lithontriptic** removes stones from kidney, gall bladder.
- Liver X receptors** nuclear hormones that function as central transcriptional regulators for lipid homeostasis.
- Lotion** a liquids suspension or dispersion of chemicals for external application to the body.
- Lovo cells** colon cancer cells.
- Low-density lipoprotein (LDL)** is a type of lipoprotein that transports cholesterol and triglycerides from the liver to peripheral tissues. High levels of LDL cholesterol can signal medical problems like cardiovascular disease, and it is sometimes called “bad cholesterol.
- LRP1** low-density lipoprotein receptor-related protein-1, plays a role in intracellular signaling functions as well as in lipid metabolism.
- LTB4** a type of leukotriene, a major metabolite in neutrophil polymorphonuclear leukocytes. It stimulates polymorphonuclear cell function (degranulation, formation of oxygen-centered free radicals, arachidonic acid release, and metabolism). It induces skin inflammation.
- Luciferase** is a generic name for enzymes commonly used in nature for bioluminescence.
- Lumbago** is the term used to describe general lower back pain.
- Lung abscess** necrosis of the pulmonary tissue and formation of cavities containing necrotic debris or fluid caused by microbial infections.
- Lusitropic** an agent that affects diastolic relaxation.
- Lutein** a carotenoid, occurs naturally as yellow or orange pigment in some fruits and leafy vegetables. It is one of the two carotenoids contained within the retina of the eye. Within the central macula, zeaxanthin predominates, whereas in the peripheral retina, lutein predominates.
- Lutein is necessary for good vision and may also help prevent or slow down atherosclerosis, the thickening of arteries, which is a major risk for cardiovascular disease.
- Luteinising hormone (LH)** a hormone produced by the anterior pituitary gland. In females, it triggers ovulation. In males, it stimulates the production of testosterone to aid sperm maturation.
- Luteolysis** is the structural and functional degradation of the corpus luteum (CL) that occurs at the end of the luteal phase of both the estrous and menstrual cycles in the absence of pregnancy.
- Lymphadenitis-cervical** inflammation of the lymph nodes in the neck, usually caused by an infection.
- Lymphatitis** inflammation of lymph vessels and nodes.
- Lymphadenopathy** a term meaning “disease of the lymph nodes – lymph node enlargement.
- Lymphadenomegaly** is the enlargement of the lymph node/nodes.
- Lymphoblastic** pertaining to the production of lymphocytes.
- Lymphocyte** a small white blood cell (leucocyte) that plays a large role in defending the body against disease. Lymphocytes are responsible for immune responses. There are two main types of lymphocytes: B cells and T cells. Lymphocytes secrete products (lymphokines) that modulate the functional activities of many other types of cells and are often present at sites of chronic inflammation.
- Lymphocyte B cells** the B cells make antibodies that attack bacteria and toxins.
- Lymphocyte T cells** T cells attack body cells themselves when they have been taken over by viruses or have become cancerous.
- Lymphoma** a type of cancer involving cells of the immune system, called lymphocytes.
- Lymphopenia** abnormally low number of lymphocytes in the blood.
- Lysosomes** are small, spherical organelles containing digestive enzymes (acid hydrolases) and other proteases (cathepsins).
- Maceration** softening or separating of parts by soaking in a liquid.
- Macrophage** a type of large leukocyte that travels in the blood but can leave the bloodstream

and enter tissue; like other leukocytes it protects the body by digesting debris and foreign cells.

Macular degeneration a disease that gradually destroys the macula, the central portion of the retina, reducing central vision.

Macules small circumscribed changes in the color of skin that are neither raised (elevated) nor depressed.

Maculopapular describes a rash characterized by raised, spotted lesions.

Magnesium (Mg) is the fourth most abundant mineral in the body and is essential to good health. It is important for normal muscle and nerve function, steady heart rhythm, immune system, and strong bones. Magnesium also helps regulate blood sugar levels, promotes normal blood pressure, and is known to be involved in energy metabolism and protein synthesis and plays a role in preventing and managing disorders such as hypertension, cardiovascular disease, and diabetes. Dietary sources include legumes (e.g. soya bean and by-products), nuts, whole unrefined grains, fruit (e.g. banana, apricots), okra and green leafy vegetables.

MAK cell macrophage-activated killer cell, activated macrophage that is much more phagocytic than monocytes.

Malaise a feeling of weakness, lethargy or discomfort as of impending illness.

Malaria is an infection of the blood by *Plasmodium* parasite that is carried from person to person by mosquitoes. There are four species of malaria parasites that infect man: *Plasmodium falciparum*, so called 'malignant tertian fever', is the most serious disease, *Plasmodium vivax*, causing a relapsing form of the disease, *Plasmodium malariae*, and *Plasmodium ovale*.

Malassezia a fungal genus (previously known as *Pityrosporum*) classified as yeasts, naturally found on the skin surfaces of many animals including humans. It can cause hypopigmentation on the chest or back if it becomes an opportunistic infection.

Mammalian target of rapamycin (mTOR) pathway that regulates mitochondrial oxygen consumption and oxidative capacity.

Mammogram an x-ray of the breast to detect tumours.

Mandibular relating to the mandible, the human jaw bone.

Manganese is an essential element for health. It is an important constituent of some enzymes and an activator of other enzymes in physiologic processes. Manganese superoxide dismutase (MnSOD) is the principal antioxidant enzyme in the mitochondria. Manganese-activated enzymes play important roles in the metabolism of carbohydrates, amino acids, and cholesterol. Manganese is the preferred cofactor of enzymes called glycosyltransferases which are required for the synthesis of proteoglycans that are needed for the formation of healthy cartilage and bone. Dietary sources include whole grains, fruit, legumes (soybean and by-products), green leafy vegetables, beetroot and tea.

MAO activity monoamine oxidase activity.

MAPK (Mitogen-activated protein kinase) these kinases are strongly activated in cells subjected to osmotic stress, UV radiation, dysregulated K⁺ currents, RNA-damaging agents, and a multitude of other stresses, as well as inflammatory cytokines, endotoxin, and withdrawal of a trophic factor. The stress-responsive MAPKs mediate a plethora of cellular responses to such stressful stimuli, including apoptosis and production of inflammatory and immunoregulatory cytokines in diverse cell systems.

Marasmus is one of the three forms of serious protein-energy malnutrition.

Mastectomy surgery to remove a breast.

Masticatory a substance chewed to increase salivation. Also called sialogue.

Mastitis a bacterial infection of the breast which usually occurs in breastfeeding mothers.

Matrix metalloproteinases (MMP) a member of a group of enzymes that can break down proteins, such as collagen, that are normally found in the spaces between cells in tissues (i.e., extracellular matrix proteins). Matrix metalloproteinases are involved in wound healing, angiogenesis, and tumour cell metastasis. See also metalloproteinase.

MBC minimum bacterial concentration - the lowest concentration of antibiotic required to kill an organism.

MCP-1 monocyte chemotactic protein-1, plays a role in the recruitment of monocytes to sites

- of infection and injury. It is a member of small inducible gene (SIG) family.
- MDA** malondialdehyde is one of the most frequently used indicators of lipid peroxidation.
- Measles** an acute, highly communicable rash illness due to a virus transmitted by direct contact with infectious droplets or, less commonly, by airborne spread.
- Mechanonociceptors** sensory neurons that are mechanically sensitive found in all of the paraspinal connective tissues including ligament, joint capsule, annulus fibrosus of the intervertebral disk, muscle, tendon, and skin. They respond to a noxious (damaging) mechanical load.
- Medial Preoptic Area** is located at the rostral end of the hypothalamus, it is important for the regulation of male sexual behavior.
- Megaloblastic anemia** an anemia that results from inhibition of DNA synthesis in red blood cell production, often due to a deficiency of vitamin B12 or folate and is characterized by many large immature and dysfunctional red blood cells (megaloblasts) in the bone marrow.
- Melaene (melena)** refers to the black, "tarry" feces that are associated with gastrointestinal hemorrhage.
- Melanogenesis** production of melanin by living cells.
- Melanoma** malignant tumour of melanocytes which are found predominantly in skin but also in the bowel and the eye and appear as pigmented lesions.
- Melatonin** a hormone produced in the brain by the pineal gland, it is important in the regulation of the circadian rhythms of several biological functions.
- Menarche** the first menstrual cycle, or first menstrual bleeding, in female human beings.
- Menorrhagia** heavy or prolonged menstruation, too-frequent menstrual periods.
- Menopausal** refer to permanent cessation of menstruation.
- Menses** see menstruation.
- Menstruation** the approximately monthly discharge of blood from the womb in women of childbearing age who are not pregnant. Also called menses. *adj.* menstrual.
- Mesangial cells** are specialized cells around blood vessels in the kidneys, at the mesangium.
- Mesothelioma** is an aggressive cancer affecting the membrane lining of the lungs and abdomen.
- Metabolic syndrome (MetS)** represents a combination of cardiometabolic risk factors, including visceral obesity, glucose intolerance or type 2 diabetes, elevated triglycerides, reduced HDL cholesterol, and hypertension.
- Metabonome** complete set of metabolically regulated elements in cells.
- Metalloproteinase** enzymes that breakdown proteins and requiring zinc or calcium atoms for proper function.
- Metallothionein (MT)** a family of cysteine-rich, low molecular weight (500 to 14000 Da) proteins.
- Meta-analysis** a statistical procedure that combines the results of several studies that address a set of related research hypotheses.
- Metaphysis** is the portion of a long bone between the epiphyses and the diaphysis of the femur.
- Metaphyseal** pertaining to the metaphysis.
- Metaplasia** transformation of one type of one mature differentiated cell type into another mature differentiated cell type.
- Metastasis** is the movement or spreading of cancer cells from one organ or tissue to another.
- Metetrus** the quiescent period of sexual inactivity between oestrus cycles.
- Metropotosis** the slipping or falling out of place of an organ (as the uterus).
- Metrorrhagia** uterine bleeding at irregular intervals, particularly between the expected menstrual periods.
- Mevinolin** a potent inhibitor of 3-hydroxy-3-methylglutaryl coenzyme A reductase (HMG-CoA reductase).
- MHC** acronym for major histocompatibility complex, a large cluster of genes found on the short arm of chromosome 6 in most vertebrates that encodes MHC molecules. MHC molecules play an important role in the immune system and autoimmunity.
- MHC 11 molecules** Class II MHC molecules belong to a group of molecules known as the Immunoglobulin Supergene Family, which includes immunoglobulins, T-cell receptors, CD4, CD8, and others.

- MIC** minimum inhibitory concentration - lowest concentration of an antimicrobial that will inhibit the visible growth of a microorganism.
- Micelle** a submicroscopic aggregation of molecules.
- Micellization** formation process of micelles.
- Microangiopathy** (or microvascular disease) is an angiopathy affecting small blood vessels in the body.
- Microfilaria** a pre-larval parasitic worm of the family Onchocercidae, found in the vector and in the blood or tissue fluid of human host.
- Micronuclei** small particles consisting of acentric fragments of chromosomes or entire chromosomes, which lag behind at anaphase of cell division.
- Microsomal PGE2 synthase** is the enzyme that catalyses the final step in prostaglandin E2 (PGE2) biosynthesis.
- Microvasculature** the finer vessels of the body, as the arterioles, capillaries, and venules.
- Micturition** urination, act of urinating.
- Migraine** a neurological syndrome characterized by altered bodily perceptions, severe, painful headaches, and nausea.
- Mimosine** is an alkaloid, β -3-hydroxy-4 pyridone amino acid, it is a toxic non-protein free amino acid and is an antinutrient.
- Mineral apposition rate** MAR, rate of addition of new layers of mineral on the trabecular surfaces of bones.
- Miscarriage** spontaneous abortion.
- Mitochondrial complex I** the largest enzyme in the mitochondrial respiratory oxidative phosphorylation system.
- Mitochondrial permeability transition (MPT)** is an increase in the permeability of the mitochondrial membranes to molecules of less than 1500 Daltons in molecular weight. MPT is one of the major causes of cell death in a variety of conditions.
- Mitogen** an agent that triggers mitosis, elicit all the signals necessary to induce cell proliferation.
- Mitogenic** able to induce mitosis or transformation.
- Mitogenicity** process of induction of mitosis.
- Mitomycin** a chemotherapy drug that is given as a treatment for several different types of cancer, including breast, stomach, oesophagus and bladder cancers.
- Mitosis** cell division in which the nucleus divides into nuclei containing the same number of chromosomes.
- MMP** matrix metalloproteinases, a group of peptidases involved in degradation of the extracellular matrix (ECM).
- Mnestic** pertaining to memory.
- Molecular docking** is a key tool in structural molecular biology and computer-assisted drug design.
- Molluscidal** destroying molluscs like snails.
- Molt 4 cells** MOLT4 cells are lymphoblast-like in morphology and are used for studies of apoptosis, tumour cytotoxicity, tumorigenicity, as well as for antitumour testing.
- Molybdenum (Mo)** is an essential element that forms part of several enzymes such as xanthine oxidase involved in the oxidation of xanthine to uric acid and use of iron. Molybdenum concentrations also affect protein synthesis, metabolism, and growth. Dietary sources include meat, green beans, eggs, sunflower seeds, wheat flour, lentils, and cereal grain.
- Monoamine oxidase A (MAOA)** is an isozyme of monoamine oxidase. It preferentially deaminates norepinephrine (noradrenaline), epinephrine (adrenaline), serotonin, and dopamine.
- Monoaminergic** of or pertaining to neurons that secrete monoamine neurotransmitters (e.g., dopamine, serotonin).
- Monoclonal antibodies** are produced by fusing single antibody-forming cells to tumour cells grown in culture.
- Monocyte** large white blood cell that ingest microbes, other cells and foreign matter.
- Monogalactosyl diglyceride** are the major lipid components of chloroplasts.
- Monorrhagia** is heavy bleeding and that's usually defined as periods lasting longer than 7 days or excessive bleeding.
- Morbidity** a diseased state or symptom or can refer either to the incidence rate or to the prevalence rate of a disease.
- Morelloflavone** a biflavonoid extracted from *Garcinia dulcis*, has shown antioxidative, antiviral, and anti-inflammatory properties.
- Morphine** the major alkaloid of opium and a potent narcotic analgesic.

- MTTP** microsomal triglyceride transfer protein that is required for the assembly and secretion of triglyceride -rich lipoproteins from both enterocytes and hepatocytes.
- MUC 5AC** mucin 5AC, a secreted gel-forming protein mucin with a high molecular weight of about 641 kDa.
- Mucositis** painful inflammation and ulceration of the mucous membranes lining the digestive tract.
- Mucous** relating to mucus.
- Mucolytic** capable of reducing the viscosity of mucus, or an agent that so acts.
- Mucus** viscid secretion of the mucous membrane.
- Multidrug resistance (MDR)** ability of a living cell to show resistance to a wide variety of structurally and functionally unrelated compounds.
- Muscarinic receptors** are G protein-coupled acetylcholine receptors found in the plasma membranes of certain neurons and other cells.
- Mutagen** an agent that induces genetic mutation by causing changes in the DNA.
- Mutagenic** capable of inducing mutation (used mainly for extracellular factors such as X-rays or chemical pollution).
- Myalgia** muscle pain.
- Myc** codes for a protein that binds to the DNA of other genes and is therefore a transcription factor, found on chromosome 8 in human.
- Mycosis** an infection or disease caused by a fungus.
- Myelocyte** is a young cell of the granulocytic series, occurring normally in bone marrow, but not in circulating blood.
- Myeloid leukaemia (Chronic)** a type of cancer that affects the blood and bone marrow, characterized by excessive number of white blood cells.
- Myeloma** cancer that arise in the plasma cells a type of white blood cells.
- Myeloperoxidase (MPO)** is a peroxidase enzyme most abundantly present in neutrophil granulocytes (a subtype of white blood cells). It is an inflammatory enzyme produced by activated leukocytes that predicts risk of coronary heart disease.
- Myeloproliferative disorder** disease of the bone marrow in which excess cells are produced.
- Myelosuppressive** causing bone marrow suppression.
- Myelotoxicity** state of being toxic to myeloid tissues, the bone marrow.
- Myocardial** relating to heart muscles tissues.
- Myocardial infarction (MI)** is the rapid development of myocardial necrosis caused by a critical imbalance between oxygen supply and demand of the myocardium.
- Myocardial ischemia** an intermediate condition in coronary artery disease during which the heart tissue is slowly or suddenly starved of oxygen and other nutrients.
- Myocardial lipidosis** is the accumulation of fat droplets in myocardial fibers.
- Myoclonus** brief, involuntary twitching of a muscle or a group of muscles.
- Myogenesis** the formation of muscular tissue, especially during embryonic development.
- Myopathy** a muscular disease wherein the muscle fibres do not function for any one of many reasons, resulting in muscular weakness.
- Myopia** near – or short-sightedness.
- Myosarcoma** a malignant muscle tumour.
- Myotonia dystrophica** an inherited disorder of the muscles and other body systems characterized by progressive muscle weakness, prolonged muscle contractions (myotonia), clouding of the lens of the eye (cataracts), cardiac abnormalities, balding, and infertility.
- Myotube** a developing skeletal muscle fiber or cell with a tubular appearance and a centrally located nucleus.
- Myringosclerosis** also known as tympanosclerosis or intratympanic tympanosclerosis, is a condition caused by calcification of collagen tissues in the tympanic membrane of the middle ear.
- Mytonia** a symptom of certain neuromuscular disorders characterized by the slow relaxation of the muscles after voluntary contraction or electrical stimulation.
- Myotube** a developing skeletal muscle fibre with a tubular appearance.
- N-nitrosomorpholine** a human carcinogen.
- N-nitrosoproline** an indicator for N-nitrosation of amines.
- NADPH** The reduced form of nicotinamide adenine dinucleotide phosphate that serves as an electron carrier.

NAFLD Non-alcoholic fatty liver disease.

Narcotic an agent that produces narcosis, in moderate doses it dulls the senses, relieves pain and induces sleep; in excessive dose it cause stupor, coma, convulsions and death.

Nasopharynx upper part of the alimentary continuous with the nasal passages.

Natriorexia excessive intake of sodium evoked by sodium depletion. *adj.* natriorexic, natriorexigenic.

Natriuresis the discharge of excessive large amount of sodium through urine. *adj.* natriuretic.

Natural killer cells (NK cells) a type of cytotoxic lymphocyte that constitute a major component of the innate immune system.

Natural killer T (NKT) cells a heterogeneous group of T cells that share properties of both T cells and natural killer (NK) cells.

Nausea sensation of unease and discomfort in the stomach with an urge to vomit.

Necropsy see autopsy.

Necrosis morphological changes that follow cell death, usually involving nuclear and cytoplasmic changes.

Neointima a new or thickened layer of arterial intima formed especially on a prosthesis or in atherosclerosis by migration and proliferation of cells from the media.

Neonatal *adj.* of or relating to newborn infants or an infant.

Neoplasia abnormal growth of cells, which may lead to a neoplasm, or tumour.

Neoplasm tumour any new and abnormal growth, specifically one in which cell multiplication is uncontrolled and progressive. Neoplasms may be benign or malignant.

Neoplastic transformation conversion of a tissue with a normal growth pattern into a malignant tumour.

Neovasculture formation of new blood vessels.

Nephrectomised kidneys surgically removed.

Nephrectomy surgical removal of the kidney.

Nephric relating to or connected with a kidney.

Nephrin is a protein necessary for the proper functioning of the renal filtration barrier.

Nephritic syndrome is a collection of signs (known as a syndrome) associated with disorders affecting the kidneys, more specifically glomerular disorders.

Nephritis is inflammation of the kidney.

Nephrolithiasis process of forming a kidney stone in the kidney or lower urinary tract.

Nephropathy a disorder of the kidney.

Nephrotic syndrome nonspecific disorder in which the kidneys are damaged, causing them to leak large amounts of protein from the blood into the urine.

Nephrotoxicity poisonous effect of some substances, both toxic chemicals and medication, on the kidney.

Nerve growth factor (NGF) a small protein that induces the differentiation and survival of particular target neurons (nerve cells).

Nervine a nerve tonic that acts therapeutically upon the nerves, particularly in the sense of a sedative that serves to calm ruffled nerves.

Neural tube defects (NTDs) are common birth defects of the brain and spinal cord.

NEU 4 sialidase this protein belongs to a family of glycohydrolytic enzymes, which remove terminal sialic acid residues from various sialo derivatives, such as glycoproteins, glycolipids, oligosaccharides, and gangliosides.

Neuralgia is a sudden, severe painful disorder of the nerves.

Neuraminidase glycoside hydrolase enzymes that cleaves the glycosidic linkages of neuraminic acids.

Neuraminidase inhibitors a class of antiviral drugs targeted at the influenza viruses whose mode of action consists of blocking the function of the viral neuraminidase protein, thus preventing the virus from reproducing.

Neurasthenia a condition with symptoms of fatigue, anxiety, headache, impotence, neuralgia and impotence.

Neurasthenic a substance used to treat nerve pain and/or weakness (i.e. neuralgia, sciatica, etc).

Neurite refers to any projection from the cell body of a neuron.

Neuritis an inflammation of the nerve characterized by pain, sensory disturbances and impairment of reflexes. *adj.* neuritic.

Neuritogenesis the first step of neuronal differentiation, takes place as nascent neurites bud from the immediate postmitotic neuronal soma.

Neuroblastoma a common extracranial cancer that forms in nerve tissues, common in infancy.

- Neuroendocrine** *adj.* of, relating to, or involving the interaction between the nervous system and the hormones of the endocrine glands.
- Neurogenesis** process by which neurons are generated from neural stem and progenitor cells.
- Neurogenic** originating from the nerves of the nervous system.
- Neuroleptic** refers to the effects on cognition and behavior of antipsychotic drugs that reduce confusion, delusions, hallucinations, and psychomotor agitation in patients with psychoses.
- Neuroma** is a growth or tumour of nerve tissue.
- Neuropharmacological** relating the effects of drugs on the neurosystem.
- Neuroradiology** is a subspecialty of radiology focusing on the diagnosis and characterization of abnormalities of the central and peripheral nervous system. *adj.* neuroradiologic.
- Neurotrophic** relating to neurotrophs i.e. the nutrition and maintenance of nervous tissue.
- Neutropenia** a disorder of the blood, characterized by abnormally low levels of neutrophils.
- Neutrophil** type of white blood cell, specifically a form of granulocyte.
- Neutrophin** protein that induce the survival, development and function of neurons.
- NF-kappa B (NF-kB)** nuclear factor kappa B, is an ubiquitous rapid response transcription factor in cells involved in immune and inflammatory reactions.
- Niacin** vitamin B3. See vitamin B3.
- Niacinamide** an amide of niacin, also known as nicotinamide. See vitamin B3.
- NIH3T3 cells** a mouse embryonic fibroblast cell line used in the cultivation of keratinocytes.
- Niosomes** are novel, vesicular, drug delivery systems composed of nonionic surfactants instead of phospholipids; they are capable of entrapping hydrophilic and hydrophobic drugs.
- Nitrogen (N)** is an essential building block of amino and nucleic acids and proteins and is essential to all living organisms. Protein rich vegetables like legumes are rich food sources of nitrogen.
- NK cells** natural killer cells, a type of cytotoxic lymphocyte that constitute a major component of the innate immune system.
- NK1.1+ T (NKT) cells** a type of natural killer T (NKT) cells. See natural killer T cells.
- NMDA receptor** N-methyl-D-aspartate receptor, the predominant molecular device for controlling synaptic plasticity and memory function. A brain receptor activated by the amino acid glutamate, which when excessively stimulated may cause cognitive defects in Alzheimer's disease.
- Nociceptive** causing pain, responding to a painful stimulus.
- Nociceptors** specialized peripheral sensory neurons that responds to potentially damaging stimuli by sending nerve signals to the spinal cord and brain.
- Non-osteogenic** fibromata of bone a benign tumour of bone which show no evidence of ossification.
- Non-alcoholic fatty liver disease** one cause of a fatty liver, occurring when fat is deposited (steatosis) in the liver not due to excessive alcohol use.
- Nootropics** are substances which are claimed to boost human cognitive abilities (the functions and capacities of the brain). Also popularly referred to as "smart drugs", "smart nutrients", "cognitive enhancers" and "brain enhancers".
- Noradrenalin** see Norepinephrine.
- Norepinephrine** a substance, both a hormone and neurotransmitter, secreted by the adrenal medulla and the nerve endings of the sympathetic nervous system to cause vasoconstriction and increases in heart rate, blood pressure, and the sugar level of the blood. Also called levarterenol, noradrenalin.
- Normoglycaemic** having the normal amount of glucose in the blood.
- Normotensive** having normal blood pressure.
- Nosebo** a harmless substance that when taken by a patient is associated with unpleasant or harmful effects due to negative expectations or the psychological state of the person.
- Nosocomial infections** infections which are a result of treatment in a hospital or a healthcare service unit, but secondary to the patient's original condition.
- NPC1L1** Niemann-Pick C1-Like 1 gene that plays a major role in cholesterol homeostasis. It is critical for the uptake of cholesterol across the plasma membrane of the intestinal enterocyte.

Nrf2 NF-E2-related factor 2, a transcription factor that activates ARE-containing genes.

Nrf2/ARE pathway plays an important role in inducing phase II detoxifying enzymes and antioxidant proteins and has been considered a potential target for cancer chemoprevention because it eliminates harmful reactive oxygen species or reactive intermediates generated from carcinogens.

Nuclear factor erythroid 2-related factor 2 (Nrf2) a transcription factor that plays a major role in response to oxidative stress by binding to antioxidant-responsive elements that regulate many hepatic phase I and II enzymes as well as hepatic efflux transporters.

Nucleosomes fundamental repeating subunits of all eukaryotic chromatin, consisting of a DNA chain coiled around a core of histones.

Nulliparous term used to describe a woman who has never given birth.

Nyctalopia night blindness, impaired vision in dim light and in the dark, due to impaired function of certain specialized vision cells.

Nystagmus fast, involuntary movements of the eyes.

Nycturia excessive urination at night; especially common in older men.

Occludin a novel integral membrane protein localizing at tight junctions *cf* tight junction.

Occlusion closure or blockage (as of a blood vessel).

Occlusive peripheral arterial disease (PAOD) also known as peripheral vascular disease (PVD), or peripheral arterial disease (PAD) refers to the obstruction of large arteries not within the coronary, aortic arch vasculature, or brain. PVD can result from atherosclerosis, inflammatory processes leading to stenosis, an embolism, or thrombus formation.

Oculomotor nerve the third of twelve paired cranial nerves.

Odds ratio a statistical measure of effect size, describing the strength of association or non-independence between two binary data values.

Odontalgia toothache. *adj.* odontalgic.

Odontopathy any disease of the teeth.

Oedema see edema.

Oligoarthritis an inflammation of two, three or four joints.

Oligonucleosome a series of nucleosomes.

Oligospermia or oligozoospermia refers to semen with a low concentration of sperm, commonly associated with male infertility.

Oliguria decreased production of urine.

Oligoanuria insufficient urine volume to allow for administration of necessary fluids, etc.

Omega 3 fatty acids are essential polyunsaturated fatty acids that have in common a final carbon–carbon double bond in the n–3 position. Dietary sources of omega-3 fatty acids include fish oil and certain plant/nut oils. The three most nutritionally important omega 3 fatty acids are alpha-linolenic acid, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Research indicates that omega 3 fatty acids are important in health promotion and disease and can help prevent a wide range of medical problems, including cardiovascular disease, depression, asthma, and rheumatoid arthritis.

Omega 6 fatty acids are essential polyunsaturated fatty acids that have in common a final carbon–carbon double bond in the n–6 position. Omega-6 fatty acids are considered essential fatty acids (EFAs) found in vegetable oils, nuts and seeds. They are essential to human health but cannot be made in the body. Omega-6 fatty acids – found in vegetable oils, nuts and seeds – are a beneficial part of a heart-healthy eating. Omega-6 and omega-3 PUFA play a crucial role in heart and brain function and in normal growth and development. Linoleic acid (LA) is the main omega-6 fatty acid in foods, accounting for 85–90% of the dietary omega-6 PUFA. Other omega 6 acids include gamma-linolenic acid or GLA, sometimes called gamoleic acid, eicosadienoic acid, arachidonic acid and docosadienoic acid.

Omega 9 fatty acids are not essential polyunsaturated fatty acids that have in common a final carbon–carbon double bond in the n–9 position. Some n–9s are common components of animal fat and vegetable oil. Two n–9 fatty acids important in industry are: oleic acid (18:1, n–9), which is a main component of olive oil and erucic acid (22:1, n–9), which is found in rapeseed, wallflower seed, and mustard seed.

- Oncogenes** genes carried by tumour viruses that are directly and solely responsible for the neoplastic (tumorous) transformation of host cells.
- Oncosis** accidental cell death, also referred to as swelling necrosis.
- Ophthalmia** severe inflammation of eye, or the conjunctiva or deeper structures of the eye. Also called ophthalmitis.
- Ophthalmia (Sympathetic)** inflammation of both eyes following trauma to one eye.
- Ophthalmopathy** an autoimmune disease where the thyroid gland is overactive leading to ocular manifestations.
- Opiate** drug derived from the opium plant.
- Opioid receptors** a group of G-protein coupled receptors located in the brain and various organs that bind opiates or opioid substances.
- Optic placode** an ectodermal placode from which the lens of the embryonic eye develops; also called lens placode.
- ORAC (Oxygen radical absorbance capacity)** a method of measuring antioxidant capacities in biological samples.
- Oral submucous fibrosis** a chronic debilitating disease of the oral cavity characterized by inflammation and progressive fibrosis of the submucosa tissues.
- Oral thrush** an infection of yeast fungus, *Candida albicans*, in the mucous membranes of the mouth.
- Orchidectomy** surgery to remove one or both testicles.
- Orchidectomised** with testis removed.
- Orchitis** an acute painful inflammatory reaction of the testis secondary to infection by different bacteria and viruses.
- Orexigenic** increasing or stimulating the appetite.
- Orofacial dyskinesia** abnormal involuntary movements involving muscles of the face, mouth, tongue, eyes, and occasionally, the neck—may be unilateral or bilateral, and constant or intermittent.
- Oropharyngeal** relating to the oropharynx.
- Oropharynx** part of the pharynx between the soft palate and the epiglottis.
- Ostalgia, Ostealgia** pain in the bones. Also called osteodynia.
- Osteoarthritis** is the deterioration of the joints that becomes more common with age.
- Osteoarthritis** chronic noninflammatory bone disease.
- Osteoblast** a mononucleate cell that is responsible for bone formation.
- Osteoblastic** relating to osteoblasts.
- Osteocalcin** a noncollagenous protein found in bone and dentin, also referred to as bone gamma-carboxyglutamic acid-containing protein.
- Osteoclasts** a kind of bone cell that removes bone tissue by removing its mineralized matrix.
- Osteoclastogenesis** the production of osteoclasts.
- Osteodynia** pain in the bone.
- Osteogenic** derived from or composed of any tissue concerned in bone growth or repair.
- Osteomalacia** refers to the softening of the bones due to defective bone mineralization.
- Osteomyelofibrosis** a myeloproliferative disorder in which fibrosis and sclerosis finally lead to bone marrow obliteration.
- Osteopenia** reduction in bone mass, usually caused by a lowered rate of formation of new bone that is insufficient to keep up with the rate of bone destruction.
- Osteoporosis** a disease of bone that leads to an increased risk of fracture.
- Osteoprotegerin** also called osteoclastogenesis inhibitory factor (OCIF), a cytokine, which can inhibit the production of osteoclasts.
- Osteosarcoma** a malignant bone tumour. Also called osteogenic sarcoma.
- Otalgia** earache, pain in the ear.
- Otic placode** a thickening of the ectoderm on the outer surface of a developing embryo from which the ear develops.
- Otitis** inflammation of the inner or outer parts of the ear.
- Otorrhea** running drainage (discharge) exiting the ear.
- Otopathy** disease of the ear.
- Ovariectomised** with one or two ovaries removed.
- Ovariectomy** surgical removal of one or both ovaries.
- Oxidation** the process of adding oxygen to a compound, dehydrogenation or increasing the electro-negative charge.
- Oxidoreductase activity** catalysis of an oxidation-reduction (redox) reaction, a reversible chemical reaction. One substrate acts as a hydrogen or electron donor and becomes

oxidized, while the other acts as hydrogen or electron acceptor and becomes reduced.

Oxygen radical absorbance capacity (ORAC) a method of measuring antioxidant capacities in biological samples.

Oxytocic *adj.* hastening or facilitating childbirth, especially by stimulating contractions of the uterus.

Oxytocin is a mammalian hormone that also acts as a neurotransmitter in the brain. It is best known for its roles in female reproduction: it is released in large amounts after distension of the cervix and vagina during labor, and after stimulation of the nipples, facilitating birth and breastfeeding, respectively.

Oxyuriasis infestation by pinworms.

Ozoena discharge of the nostrils caused by chronic inflammation of the nostrils.

p.o. per os, oral administration.

P-glycoprotein (P-gp, ABCB1, MDR1) a cell membrane-associated drug-exporting protein that transports a variety of drug substrates from cancer cells.

P- Selectin also known as CD62P, GMP-140, LLECAM-3, PADGEM, a member of the selectin family. It is expressed by activated platelets and endothelial cells.

p21waf1/cip1 encodes a cyclin-dependent kinase inhibitor that is transcriptionally activated by the p53 tumor suppressor gene, transforming growth factor beta 1 (TGF-beta 1), AP2, and other pathways, all regulating apoptosis and the cell cycle.

Palliative relieving pain without alleviating the underlying problem.

Palpebral ptosis the abnormal drooping of the upper lid, caused by partial or total reduction in levator muscle function.

Palpitation rapid pulsation or throbbing of the heart.

Paludism state of having symptoms of malaria characterized by high fever and chills.

Pancreatectomized having undergone a pancreatectomy.

Pancreatectomy surgical removal of all or part of the pancreas.

Pancreatitis inflammation of the pancreas.

Pancytopenia a hematological condition in which there is a reduction in the number of red and white blood cells, as well as platelets.

Pantothenic acid vitamin B5. See vitamin B5.

Papain a protein degrading enzyme used medicinally and to tenderize meat.

Papilloma a benign epithelial tumour growing outwardly like in finger-like fronds.

Papule a small, solid, usually inflammatory elevation of the skin that does not contain pus.

Paradontosis is the inflammation of gums and other deeper structures, including the bone.

Paralytic person affected with paralysis, pertaining to paralysis.

Paraoxonase an enzyme that protects against oxidation of low density lipoprotein and affects the risk of coronary artery disease.

Parasitemia presence of parasites in blood. *adj.* parasitemic.

Parasympathetic nervous system subsystem of the nervous systems that slows the heart rate and increases intestinal and gland activity and relaxes the sphincter muscles.

Parasympathomimetic having an action resembling that caused by stimulation of the parasympathetic nervous system.

Paresthesia a sensation of tingling, burning, pricking, or numbness of a person's skin with no apparent long-term physical effect. Also known as "pains and needles".

Parenteral administration administration by intravenous, subcutaneous or intramuscular routes.

Paresis a condition characterised by partial loss of movement, or impaired movement.

Paresthesia is an abnormal sensation of the skin, such as burning, numbness, itching, hyperesthesia (increased sensitivity) or tingling, with no apparent physical cause.

Parotitis inflammation of salivary glands.

Paroxysm a sudden outburst of emotion or action, a sudden attack, recurrence or intensification of a disease.

Paroxystic relating to an abnormal event of the body with an abrupt onset and an equally sudden return to normal.

PARP see poly (ADP-ribose) polymerase.

Pars compacta is a portion of the substantia nigra (a brain structure located in the mid-brain).

Parturition act of child birth.

PCAF (P300/CBP-associated factor) - a histone acetyl transferase (HAT) that plays a role in

regulation of transcriton, cell cycle progression and differentiation.

PCE/PCN ratio polychromatic erythrocyte/normochromatic erythrocyte ratio use as a measure of cytotoxic effects.

PCNA proliferating cell nuclear antigen, an auxiliary protein of DNA polymerase delata involve in modulating eukaryotic DNA replication.

pCREB phosphorylated cAMP (adenosine 3'5' cyclic monophosphate)-response element binding protein.

PDEF acronym for prostate-derived ETS factor, an ETS (epithelial-specific E26 transforming sequence) family member that has been identified as a potential tumour suppressor.

PDGR receptor (platelet-derived growth factor receptor) are cell surface tyrosine kinase receptors for members of the platelet-derived growth factor (PDGF) family.

PDGFs platelet-derived growth factors constitute a group of growth factors that play a significant role in blood vessel formation, and the growth of blood vessels.

Pectoral pertaining to or used for the chest and respiratory tract.

pERK phosphorylated extracellular signal-regulated kinase, protein kinases involved in many cell functions.

P53 also known as protein 53 or tumour protein 53, is a tumour suppressor protein that in humans is encoded by the TP53 gene.

Peliosis see purpura.

Pellagra is a systemic nutritional wasting disease caused by a deficiency of vitamin B3 (niacin).

Pemphigus neonatorum Staphylococcal scalded skin syndrome, a bacterial disease of infants, characterized by elevated vesicles or blebs on a normal or reddened skin.

Peptic ulcer a sore in the lining of the stomach or duodenum, the first part of the small intestine.

Peptide Y a short (36 amino acid) pancreatic protein released by cells in the ileum and colon in response to feeding.

Percutaneous pertains to a medical procedure where access to inner organs or tissues is done via needle puncture of the skin.

Perfusion to force fluid through the lymphatic system or blood vessels to an organ or tissue.

Periapical periodontitis is the inflammation of the tissue adjacent to the tip of the tooth's root.

Perifuse to flush a fresh supply of bathing fluid around all of the outside surfaces of a small piece of tissue immersed in it.

Perilipins highly phosphorylated adipocyte proteins that are localized at the surface of the lipid droplet.

Perimenopause is the phase before menopause actually takes place, when ovarian hormone production is declining and fluctuating. *adj.* perimenopausal.

Periodontal ligament (PDL) is a group of specialized connective tissue fibres that essentially attach a tooth to the bony socket.

Periodontitis is a severe form of gingivitis in which the inflammation of the gums extends to the supporting structures of the tooth. Also called pyorrhea.

Peripheral arterial disease (PAD) is a disease in which plaque builds up in the arteries that carry blood to your head, organs, and limbs.

Peripheral neuropathy refers to damage to nerves of the peripheral nervous system.

Peripheral neuropathic pain (PNP) refers to situations where nerve roots or peripheral nerve trunks have been damaged by mechanical and/or chemical stimuli that exceeded the physical capabilities of the nervous system. Symptoms may include pain, paresthesia, dysesthesia, spasm, weakness, hypoesthesia or anesthesia.

Peripheral vascular disease (PVD) see peripheral artery occlusive disease.

Peristalsis a series of organized, wave-like muscle contractions that occur throughout the digestive tract.

PERK a transmembrane protein kinase of the PEK family resident in the endoplasmic reticulum (ER) membrane and is linked to insulin processing.

Perlingual through or by way of the tongue.

Perniosis an abnormal reaction to cold that occurs most frequently in women, children, and the elderly. Also called chilblains.

Per os (P.O.) oral administration.

Peroxisome proliferator-activated receptors (PPARs) a family of nuclear receptors that are involved in lipid metabolism, differentiation, proliferation, cell death, and inflammation.

Peroxisome proliferator-activated receptor alpha (PPAR-alpha) a nuclear receptor

protein, transcription factor and a major regulator of lipid metabolism in the liver.

Peroxisome proliferator-activated receptor gamma (PPAR- γ) a type II nuclear receptor protein that regulates fatty acid storage and glucose metabolism.

Pertussis whooping cough, sever cough.

Peyers Patches patches of lymphoid tissue or lymphoid nodules on the walls of the ileal-small intestine.

PGE-2 Prostaglandin E2, a hormone-like substance that is released by blood vessel walls in response to infection or inflammation that acts on the brain to induce fever.

Phagocytes are the white blood cells that protect the body by ingesting (phagocytosing) harmful foreign particles, bacteria and dead or dying cells. *adj.* phagocytic.

Phagocytosis is process the human body uses to destroy dead or foreign cells.

Pharmacognosis the branch of pharmacology that studies the composition, use, and history of drugs.

Pharmacodynamics branch of pharmacology dealing with the effects of drugs and the mechanism of their action.

Pharmacokinetics branch of pharmacology concerned with the movement of drugs within the body including processes of absorption, distribution, metabolism and excretion in the body.

Pharmacopoeia authoritative treatise containing directions for the identification of drug samples and the preparation of compound medicines, and published by the authority of a government or a medical or pharmaceutical society and in a broader sense is a general reference work for pharmaceutical drug specifications.

Pharyngitis, Pharyngolaryngitis inflammation of the pharynx and the larynx.

Pharyngolaryngeal pertaining to the pharynx and larynx.

Phenolics class of chemical compounds consisting of a hydroxyl group (-OH) bonded directly to an aromatic hydrocarbon group.

Pheochromocytoma is a rare neuroendocrine tumour that usually originates from the adrenal glands' chromaffin cells, causing overproduction of catecholamines, powerful hormones that induce high blood pressure and other symptoms.

Phlebitis is an inflammation of a vein, usually in the legs.

Phlegm abnormally viscid mucus secreted by the mucosa of the respiratory passages during certain infectious processes.

Phlegmon a spreading, diffuse inflammation of the soft or connective tissue due to infection by Streptococci bacteria.

Phoroglucinol a white, crystalline compound used as an antispasmodic, analytical reagent, and decalcifier of bone specimens for microscopic examination.

Phosphatidylglycerol is a glycerophospholipid found in pulmonary active surface lipoprotein and consists of a L-glycerol 3-phosphate backbone ester-bonded to either saturated or unsaturated fatty acids on carbons 1 and 2.

Phosphatidylinositol 3-kinases (PI 3-kinases or PI3Ks) a group of enzymes involved in cellular functions such as cell growth, proliferation, differentiation, motility, survival and intracellular trafficking, which in turn are involved in cancer.

Phosphatidylserine a phosphoglyceride phospholipid that is one of the key building blocks of cellular membranes, particularly in the nervous system. It is derived from soy lecithin.

Phosphaturia a urinary tract condition of excessive urine phosphorus, causing urine to appear cloudy or murky color; also called hypophosphatemia.

Phosphodiesterases a diverse family of enzymes that hydrolyse cyclic nucleotides and thus play a key role in regulating intracellular levels of the second messengers cAMP and cGMP, and hence cell function.

Phosphoenolpyruvate C kinase (PEPCK) an enzyme in the lyase family used in the metabolic pathway of gluconeogenesis.

Phospholipase an enzyme that hydrolyzes phospholipids into fatty acids and other lipophilic substances.

Phospholipase A2 (PLA2) a small lipolytic enzyme that releases fatty acids from the second carbon group of glycerol. Plays an essential role in the synthesis of prostaglandins and leukotrienes.

Phospholipase C enzymes that cleaves phospholipase.

Phospholipase C gamma (PLC gamma) enzymes that cleaves phospholipase in cellular proliferation and differentiation, and its enzymatic activity is upregulated by a variety of growth factors and hormones.

Phosphorus (P) is an essential mineral that makes up 1% of a person's total body weight and is found in the bones and teeth. It plays an important role in the body's utilization of carbohydrates and fats; in the synthesis of protein for the growth, maintenance, and repair of cells and tissues. It is also crucial for the production of ATP, a molecule the body uses to store energy. Main sources are meat and milk; fruits and vegetables provides small amounts.

Photoaging is the term that describes damage to the skin caused by intense and chronic exposure to sunlight resulting in premature aging of the skin.

Photocarcinogenesis represents the sum of a complex of simultaneous and sequential biochemical events that ultimately lead to the occurrence of skin cancer caused by exposure to the sun.

Photodermatoses skin disorders caused by exposure to sunlight.

Photophobia abnormal visual intolerance to light.

Photopsia an affection of the eye, in which the patient perceives luminous rays, flashes, coruscations, etc.

Photosensitivity sensitivity toward light.

Phthisis an archaic name for tuberculosis.

Phytohemagglutinin a lectin found in plant that is involved in the stimulation of lymphocyte proliferation.

Phytonutrients certain organic components of plants, that are thought to promote human health. Fruits, vegetables, grains, legumes, nuts and teas are rich sources of phytonutrients. Phytonutrients are not 'essential' for life. Also called phytochemicals.

Phytosterols a group of steroid alcohols, cholesterol-like phytochemicals naturally occurring in plants like vegetable oils, nuts and legumes.

Piebaldism rare autosomal dominant disorder of melanocyte development characterized by distinct patches of skin and hair that contain no pigment.

Piles see haemorrhoids.

PI3K phosphoinositide 3-kinase.

PI13K/AKT signaling pathways are involved in the modulation of cell survival, cell cycle progression and cellular growth in cancer.

Pityriasis lichenoides is a rare skin disorder of unknown aetiology characterised by multiple papules and plaques.

PKC protein kinase C, a membrane bound enzyme that phosphorylates different intracellular proteins and raised intracellular Ca levels.

PKC Delta inhibitors Protein Kinase C delta inhibitors that induce apoptosis of haematopoietic cell lines.

Placebo a sham or simulated medical intervention.

Placode a platelike epithelial thickening in the embryo where some organ or structure later develops.

Plasma the yellow-colored liquid component of blood, in which blood cells are suspended.

Plasma kallikrien a serine protease, synthesized in the liver and circulates in the plasma.

Plasmalemma plasma membrane.

Plasmin a proteinase enzyme that is responsible for digesting fibrin in blood clots.

Plasminogen the proenzyme of plasmin, whose primary role is the degradation of fibrin in the vasculature.

Plasminogen activator inhibitor-1 (PAI-1) also known as endothelial plasminogen activator inhibitor or serpin E1 is a serine protease inhibitor (serpin) that functions as the principal inhibitor of tissue plasminogen activator (tPA) and urokinase (uPA), the activators of plasminogen and hence fibrinolysis (the physiological breakdown of blood clots).

Plaster poultice.

Platelet activating factor (PAF) is an acetylated derivative of glycerophosphorylcholine, released by basophils and mast cells in immediate hypersensitive reactions and macrophages and neutrophils in other inflammatory reactions. One of its main effects is to induce platelet aggregation.

PLC gamma phospholipase C gamma plays a central role in signal transduction.

Pleurisy is an inflammation of the pleura, the lining of the pleural cavity surrounding the

lungs, which can cause painful respiration and other symptoms. Also known as pleuritis.

Pneumonia an inflammatory illness of the lung caused by bacteria or viruses.

Pneumotoxicity damage to lung tissues.

Poliomyelitis is a highly infectious viral disease that may attack the central nervous system and is characterized by symptoms that range from a mild non-paralytic infection to total paralysis in a matter of hours; also called polio or infantile paralysis.

Poly (ADP-ribose) polymerase (PARP) a protein involved in a number of cellular processes especially DNA repair and programmed cell death.

Polyarthritis is any type of arthritis which involves five or more joints.

Polychromatic erythrocyte (PCE) an immature red blood cell containing RNA, that can be differentiated by appropriate staining techniques from a normochromatic erythrocyte (NCE), which lacks RNA.

Polycystic kidney disease is a kidney disorder passed down through families in which multiple cysts form on the kidneys, causing them to become enlarged.

Polycystic ovary syndrome imbalance of woman's sex hormone, this imbalance may cause changes in menstrual cycle, skin changes, small cysts in the ovary and problem in getting pregnant.

Polycythaemia a type of blood disorder characterised by the production of too many red blood cells.

Polymorphnuclear having a lobed nucleus. Used especially of neutrophilic white blood cells.

Polyneuritis widespread inflammation of the nerves.

Polyneuritis gallinarum a nervous disorder in birds and poultry.

Polyneuropathy simultaneous malfunction of many peripheral nerves throughout the body.

Polyp a growth that protrudes from a mucous membrane.

Polyphagia medical term for excessive hunger or eating.

Polyuria a condition characterized by the passage of large volumes of urine with an increase in urinary frequency.

Pomade a thick oily dressing.

Porphyrin any of a class of water-soluble, nitrogenous biological pigments.

Postherpetic neuralgia (PHN) is neuralgia (pain in the nerves) caused by the varicella Herpes Zoster virus. The pain may last for more than a month or more after a shingles infection occurred.

Postpartum Depression depression after pregnancy; also called postnatal depression.

Postprandial after mealtime.

Potassium (K) is an element that's essential for the body's growth and maintenance. It's necessary to keep a normal water balance between the cells and body fluids, for cellular enzyme activities and plays an essential role in the response of nerves to stimulation and in the contraction of muscles. Potassium is found in many plant foods and fish (tuna, halibut): chard, mushrooms, spinach, fennel, kale, mustard greens, Brussels sprouts, broccoli, cauliflower, cabbage winter squash, eggplant, cantaloupe, tomatoes, parsley, cucumber, bell pepper, turmeric, ginger root, apricots, strawberries, avocado and banana.

Poultice is a soft moist mass, often heated and medicated, that is spread on cloth over the skin to treat an aching, inflamed, or painful part of the body. Also called cataplasm.

PPARs peroxisome proliferator-activated receptors - a group of nuclear receptor proteins that function as transcription factors regulating the expression of genes.

Prebiotics a category of functional food, defined as non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, and thus improve host health. *cf.* probiotics.

Pre-ecampiasia toxic condition of pregnancy characterized by high blood pressure, abnormal weight gain, proteinuria and edema.

Prepubertal before puberty; pertaining to the period of accelerated growth preceding gonadal maturity.

Pregnane X receptor (PXR NR1I2) is a ligand-activated transcription factor that plays a role not only in drug metabolism and transport but also in various other biological processes.

- Pregnenolone** a steroid hormone produced by the adrenal glands, involved in the steroidogenesis of other steroid hormones like progesterone, mineralocorticoids, glucocorticoids, androgens, and estrogens.
- Prenidatory** referring to the time period between fertilization and implantation.
- Prenylated flavones** flavones with an isoprenyl group in the 8-position, has been reported to have good anti-inflammatory properties.
- Proangiogenic** promote angiogenesis (formation and development of new blood vessels).
- Probiotication** enhancement with beneficial probiotic bacteria such as *Lactobacillus* species that can prevent the growth of intestinal pathogenic microflora.
- Probiotics** are dietary supplements and live microorganisms containing potentially beneficial bacteria or yeasts that are taken into the alimentary system for healthy intestinal functions. *cf.* prebiotics.
- Proctitis** an inflammation of the rectum that causes discomfort, bleeding, and occasionally, a discharge of mucus or pus.
- Procyanidin** also known as proanthocyanidin, oligomeric proanthocyanidin, leukocyanidin, leucoanthocyanin, is a class of flavanols found in many plants. It has antioxidant activity and plays a role in the stabilization of collagen and maintenance of elastin.
- Progestational** of or relating to the phase of the menstrual cycle immediately following ovulation, characterized by secretion of progesterone.
- Proglottid** one of the segments of a tapeworm.
- Prognosis** medical term to describe the likely outcome of an illness.
- Prolactin** a hormone produced by the pituitary gland, it stimulates the breasts to produce milk in pregnant women. It is also present in males but its role is not well understood.
- Prolapse** a common condition where the bladder, uterus and or bowel protrudes into the vagina.
- Prolapsus** to fall or slip out of place.
- Prolapsus ani** eversion of the lower portion of the rectum, and protruding through the anus, common in infancy and old age.
- Proliferating cell nuclear antigen (PCNA)** a new marker to study human colonic cell proliferation.
- Proliferative vitreoretinopathy (PVR)** a most common cause of failure in retinal reattachment surgery, characterised by the formation of cellular membrane on both surfaces of the retina and in the vitreous.
- Promastigote** the flagellate stage in the development of trypanosomatid protozoa, characterized by a free anterior flagellum.
- Promyelocytic leukemia** a subtype of acute myelogenous leukemia (AML), a cancer of the blood and bone marrow.
- Pro-oxidants** chemicals that induce oxidative stress, either through creating reactive oxygen species or inhibiting antioxidant systems.
- Prophylaxis** prevention or protection against disease.
- Proptosis** see exophthalmos.
- Prostacyclin** a prostaglandin that is a metabolite of arachidonic acid, inhibits platelet aggregation, and dilates blood vessels.
- Prostaglandins** a family of C 20 lipid compounds found in various tissues, associated with muscular contraction and the inflammation response such as swelling, pain, stiffness, redness and warmth.
- Prostaglandin E2 (PEG -2)** one of the prostaglandins, a group of hormone-like substances that participate in a wide range of body functions such as the contraction and relaxation of smooth muscle, the dilation and constriction of blood vessels, control of blood pressure, and modulation of inflammation.
- Prostaglandin E synthase** an enzyme that in humans is encoded by the glutathione-dependent PTGES gene.
- Prostanoids** term used to describe a subclass of eicosanoids (products of COX pathway) consisting of: the prostaglandins (mediators of inflammatory and anaphylactic reactions), the thromboxanes (mediators of vasoconstriction) and the prostacyclins (active in the resolution phase of inflammation).
- Prostate** a gland that surround the urethra at the bladder in the male.
- Prostate cancer** a disease in which cancer develops in the prostate, a gland in the male reproductive system. Symptoms include pain, difficulty in urinating, erectile dysfunction and other symptoms.

- Prostate –specific antigen (PSA)** a protein produced by the cells of the prostate gland.
- Protein kinase C (PKC)** a family of enzymes involved in controlling the function of other proteins through the phosphorylation of hydroxyl groups of serine and threonine amino acid residues on these proteins. PKC enzymes play important roles in several signal transduction cascades.
- Protein tyrosine phosphatase (PTP)** a group of enzymes that remove phosphate groups from phosphorylated tyrosine residues on proteins.
- Proteinase** a protease (enzyme) involved in the hydrolytic breakdown of proteins, usually by splitting them into polypeptide chains.
- Proteinuria** means the presence of an excess of serum proteins in the urine.
- Proteolysis** cleavage of the peptide bonds in protein forming smaller polypeptides. *adj.* proteolytic.
- Proteomics** the large-scale study of proteins, particularly their structures and functions.
- Prothrombin** blood-clotting protein that is converted to the active form, factor IIa, or thrombin, by cleavage.
- Prothyroid** good for thyroid function.
- Protheolithic** proteolytic see proteolysis.
- Proto-oncogene** A normal gene which, when altered by mutation, becomes an oncogene that can contribute to cancer.
- Prurigo** a general term used to describe itchy eruptions of the skin.
- Pruritis** defined as an unpleasant sensation on the skin that provokes the desire to rub or scratch the area to obtain relief; itch, itching. *adj.* pruritic.
- PSA** Prostate Specific Antigen, a protein which is secreted into ejaculate fluid by the healthy prostate. One of its functions is to aid sperm movement.
- Psoriasis** a common chronic, non-contagious autoimmune dermatosis that affects the skin and joints.
- Psychoactive** having effects on the mind or behavior.
- Psychonautics** exploration of the psyche by means of approaches such as meditation, prayer, lucid dreaming, brain wave entrainment etc.
- Psychotomimetic** hallucinogenic.
- Psychotropic** capable of affecting the mind, emotions, and behavior.
- PTEN** phosphatase and tensin homolog, a tumour suppressor gene.
- Ptoxis** also known as drooping eyelid; caused by weakness of the eyelid muscle and damage to the nerves that control the muscles or looseness of the skin of the upper eyelid.
- P13-K** is a lipid kinase enzyme involved in the regulation of a number of cellular functions such as cell growth, proliferation, differentiation, motility, survival and intracellular trafficking, which in turn are involved in cancer.
- P13-K/AKT signaling pathway** shown to be important for an extremely diverse array of cellular activities - most notably cellular proliferation and survival.
- Pthysis** silicosis with tuberculosis.
- Ptosis** drooping of the upper eye lid.
- PTP** protein tyrosine phosphatase.
- PTPIB** protein tyrosine phosphatase 1B.
- P21** also known as cyclin-dependent kinase inhibitor 1 or CDK-interacting protein 1, is a potent cyclin-dependent kinase inhibitor.
- Puerperal** pertaining to child birth.
- Puerperium** post-partum period.
- Pulmonary embolism** a blockage (blood clot) of the main artery of the lung.
- Purgative** a substance used to cleanse or purge, especially causing the immediate evacuation of the bowel.
- Purpura** is the appearance of red or purple discolorations on the skin that do not blanch on applying pressure. Also called peliosis.
- Purulent** containing pus discharge.
- Purulent sputum** sputum containing, or consisting of, pus.
- Pustule** small, inflamed, pus-filled lesions.
- Pyelonephritis** an ascending urinary tract infection that has reached the pyelum (pelvis) of the kidney.
- Pyodermatitis** refers to inflammation of the skin.
- Pyorrhoea** see periodontitis.
- Pyretic** referring to fever.
- Pyrexia** fever of unknown origin.
- Pyridoxal** a chemical form of vitamin B6. See vitamin B6.
- Pyridoxamine** a chemical form of vitamin B6. See vitamin B6.

- Pyridoxine** a chemical form of vitamin B6. See vitamin B6.
- Pyrolysis** decomposition or transformation of a compound caused by heat. *adj.* pyrolytic.
- PYY Peptide** a 36 amino acid peptide secreted by L cells of the distal small intestine and colon that inhibits gastric and pancreatic secretion.
- QT interval** is a measure of the time between the start of the Q wave and the end of the T wave in the heart's electrical cycle. A prolonged QT interval is a biomarker for ventricular tachyarrhythmias and a risk factor for sudden death.
- Quorum sensing (QS)** the control of gene expression in response to cell density, is used by both gram-negative and gram-positive bacteria to regulate a variety of physiological functions.
- Radiolysis** the dissociation of molecules by radiation.
- Radioprotective** serving to protect or aiding in protecting against the injurious effect of radiations.
- RAGE** is the receptor for advanced glycation end products, a multiligand receptor that propagates cellular dysfunction in several inflammatory disorders, in tumours and in diabetes.
- RAS** see renin-angiotensin system or recurrent aphthous stomatitis.
- Rash** a temporary eruption on the skin, see urticaria.
- Reactive oxygen species** species such as superoxide, hydrogen peroxide, and hydroxyl radical. At low levels, these species may function in cell signaling processes. At higher levels, these species may damage cellular macromolecules (such as DNA and RNA) and participate in apoptosis (programmed cell death).
- Rec A** is a 38 kilodalton *Escherichia coli* protein essential for the repair and maintenance of DNA.
- Receptor for advanced glycation end products (RAGE)** is a member of the immunoglobulin superfamily of cell surface molecules; mediates neurite outgrowth and cell migration upon stimulation with its ligand, amphoterin.
- Reticulocyte** non-nucleated stage in the development of the red blood cell.
- Reticulocyte lysate** cell lysate produced from reticulocytes, used as an in-vitro translation system.
- Reticuloendothelial system** part of the immune system, consists of the phagocytic cells located in reticular connective tissue, primarily monocytes and macrophages.
- Recurrent aphthous stomatitis, or RAS** is a common, painful condition in which recurring ovoid or round ulcers affect the oral mucosa.
- Redox homeostasis** is considered as the cumulative action of all free radical reactions and antioxidant defenses in different tissues.
- Refrigerant** a medicine or an application for allaying heat, fever or its symptoms.
- Renal calculi** kidney stones.
- Renal interstitial fibrosis** damage sustained by the kidneys' renal tubules and interstitial capillaries due to accumulation of extracellular waste in the wall of the small arteries and arterioles.
- Renal resistive index (RRI)** measures the resistance of renal arterial flow to the kidney.
- Renin** also known as an angiotensinogenase, is an enzyme that participates in the body's renin-angiotensin system (RAS).
- Renin-angiotensin system (RAS)** also called the renin-angiotensin-aldosterone system (RAAS) is a hormone system that regulates blood pressure and water (fluid) balance.
- Reperfusion** the restoration of blood flow to an organ or tissue that has had its blood supply cut off, as after a heart attack.
- Reporter gene** a transfected gene that produces a signal, such as green fluorescence, when it is expressed.
- Resistin** a cysteine-rich protein secreted by adipose tissue of mice and rats.
- Resolutive** a substance that induces subsidence of inflammation.
- Resolvent** reduce inflammation or swelling.
- Resorb** to absorb or assimilate a product of the body such as an exudates or cellular growth.
- Restenosis** is the reoccurrence of stenosis, a narrowing of a blood vessel, leading to restricted blood flow.
- Resveratrol** is a phytoalexin produced naturally by several plants when under attack by pathogens such as bacteria or fungi. It is a potent antioxidant found in red grapes and other plants.
- Retinol** a form of vitamin A, see vitamin A.

- Retinopathy** a general term that refers to some form of non-inflammatory damage to the retina of the eye.
- Revulsive** counterirritant, used for swellings.
- Rhabdomyolysis** breakdown of muscle fibres leading to the release of muscle fibre content (myoglobin) into the bloodstream.
- Rheumatic** pertaining to rheumatism or to abnormalities of the musculoskeletal system.
- Rheumatism, Rheumatic disorder, Rheumatic diseases** refers to various painful medical conditions which affect bones, joints, muscles, tendons. Rheumatic diseases are characterized by the signs of inflammation – redness, heat, swelling, and pain.
- Rheumatoid arthritis (RA)** is a chronic, systemic autoimmune disorder that most commonly causes inflammation and tissue damage in joints (arthritis) and tendon sheaths, together with anemia.
- Rhinitis** irritation and inflammation of some internal areas of the nose and the primary symptom of rhinitis is a runny nose.
- Rhinopathy** disease or malformation of the nose.
- Rhinoplasty** is surgery to repair or reshape the nose.
- Rhinorrhea** commonly known as a runny nose, characterized by an unusually significant amount of nasal discharge.
- Rhinosinusitis** inflammation of the nasal cavity and sinuses.
- Rho GTPases** Rho-guanosine triphosphate hydrolase enzymes are molecular switches that regulate many essential cellular processes, including actin dynamics, gene transcription, cell-cycle progression and cell adhesion.
- Ribosome inactivating proteins** protein that are capable of inactivating ribosomes.
- Rickets** is a softening of the bones in children potentially leading to fractures and deformity.
- Ringworm** dermatophytosis, a skin infection caused by fungus.
- Roborant** restoring strength or vigour, a tonic.
- Rotavirus** the most common cause of infectious diarrhea (gastroenteritis) in young children and infants, one of several viruses that causes infections called stomach flu.
- Rubefacient** a substance for external application that produces redness of the skin e.g. by causing dilation of the capillaries and an increase in blood.
- Ryanodine receptor** intracellular Ca^{++} channels in animal tissues like muscles and neurons.
- S.C.** abbreviation for sub-cutaneous, beneath the layer of skin.
- S-T segment** the portion of an electrocardiogram between the end of the QRS complex and the beginning of the T wave. Elevation or depression of the S-T segment is the characteristics of myocardial ischemia or injury and coronary artery disease.
- Sapraemia** see septicaemia.
- Sarcoma** cancer of the connective or supportive tissue (bone, cartilage, fat, muscle, blood vessels) and soft tissues.
- Sarcopenia** degenerative loss of skeletal muscle mass and strength associated with aging.
- Sarcoplasmic reticulum** a special type of smooth endoplasmic reticulum found in smooth and striated muscle.
- SARS** Severe acute respiratory syndrome, the name of a potentially fatal new respiratory disease in humans which is caused by the SARS coronavirus (SARS-CoV).
- Satiety** state of feeling satiated, fully satisfied (appetite or desire).
- Scabies** a transmissible ectoparasite skin infection characterized by superficial burrows, intense pruritus (itching) and secondary infection.
- Scarlatina** scarlet fever, an acute, contagious disease caused by infection with group A streptococcal bacteria.
- Schwann cells** or neurolemmocytes, are the principal supporting cells of the peripheral nervous system, they form the myelin sheath of a nerve fibre.
- Schistosomiasis** is a parasitic disease caused by several species of fluke of the genus *Schistosoma*. Also known as bilharzia, bilharziosis or snail fever.
- Schizophrenia** a psychotic disorder (or a group of disorders) marked by severely impaired thinking, emotions, and behaviors.
- Sciatica** a condition characterised by pain deep in the buttock often radiating down the back of the leg along the sciatic nerve.
- Scleroderma** a disease of the body's connective tissue. The most common symptom is a thick-

ening and hardening of the skin, particularly of the hands and face.

Scrofula a tuberculous infection of the skin on the neck caused by the bacterium *Mycobacterium tuberculosis*.

Scrophulosis see scrofula.

Scurf abnormal skin condition in which small flakes or scales become detached.

Scurvy a state of dietary deficiency of vitamin C (ascorbic acid) which is required for the synthesis of collagen in humans.

Secretagogue a substance that causes another substance to be secreted.

Sedative having a soothing, calming, or tranquilizing effect; reducing or relieving stress, irritability, or excitement.

Seizure the physical findings or changes in behavior that occur after an episode of abnormal electrical activity in the brain.

Selectins are a family of cell adhesion molecules; e.g. selectin-E, selectin -L, selectin P.

Selenium (Se) a trace mineral that is essential to good health but required only in tiny amounts; it is incorporated into proteins to make selenoproteins, which are important antioxidant enzymes. It is found in avocado, brazil nut, lentils, sunflower seeds, tomato, whole grain cereals, seaweed, seafood and meat.

Sensorineural bradyacusia hearing impairment of the inner ear resulting from damage to the sensory hair cells or to the nerves that supply the inner ear.

Sepsis a condition in which the body is fighting a severe infection that has spread via the bloodstream.

Sequela an abnormal pathological condition resulting from a disease, injury or trauma.

Serine proteinase peptide hydrolases which have an active centre histidine and serine involved in the catalytic process.

Serotonergic liberating, activated by, or involving serotonin in the transmission of nerve impulses.

Serotonin a monoamine neurotransmitter synthesized in serotonergic neurons in the central nervous system.

Sepsis is a potentially fatal medical condition characterized by a whole-body inflammatory response (called a systemic inflammatory response syndrome or SIRS) that is triggered by an infection.

Septicaemia a systemic disease associated with the presence and persistence of pathogenic microorganisms or their toxins in the blood.

Sequelae a pathological condition resulting from a prior disease, injury, or attack.

Sexual potentiator increases sexual activity and potency, enhances sexual performance due to increased blood flow and efficient metabolism.

Sexually transmitted diseases (STD) infections that are transmitted through sexual activity.

SGOT, Serum glutamic oxaloacetic transaminase an enzyme that is normally present in liver and heart cells. SGOT is released into blood when the liver or heart is damaged. Also called aspartate transaminase (AST).

SGPT, Serum glutamic pyruvic transaminase an enzyme normally present in serum and body tissues, especially in the liver; it is released into the serum as a result of tissue injury, also called Alanine transaminase (ALT).

Shiga-like toxin a toxin produced by the bacterium *Escherichia coli* which disrupts the function of ribosomes, also known as verotoxin.

Shiga toxigenic *Escherichia coli* (STEC) comprises a diverse group of organisms capable of causing severe gastrointestinal disease in humans.

Shiga toxin a toxin produced by the bacterium *Shigella dysenteriae*, which disrupts the function of ribosomes.

Shingles skin rash caused by the Zoster virus (same virus that causes chicken pox) and is medically termed Herpes zoster.

Sialogogue salivation-promoter, a substance used to increase or promote the excretion of saliva.

Sialoproteins glycoproteins that contain sialic acid as one of their carbohydrates.

Sialylation reaction with sialic acid or its derivatives; used especially with oligosaccharides.

Sialyltransferases enzymes that transfer sialic acid to nascent oligosaccharide.

Sickle cell disease is an inherited blood disorder that affects red blood cells. People with sickle cell disease have red blood cells that contain mostly hemoglobin S, an abnormal type of hemoglobin. Sometimes these red blood cells become sickle-shaped (crescent shaped) and

have difficulty passing through small blood vessels.

Side stitch is an intense stabbing pain under the lower edge of the ribcage that occurs while exercising.

Signal transduction cascade refers to a series of sequential events that transfer a signal through a series of intermediate molecules until final regulatory molecules, such as transcription factors, are modified in response to the signal.

Silicon (Si) is required in minute amounts by the body and is important for the development of healthy hair and the prevention of nervous disorders. Lettuce is the best natural source of Silicon.

Sinapism signifies an external application, in the form of a soft plaster, or poultice.

Sinusitis inflammation of the nasal sinuses.

SIRC cells Statens Seruminstitut Rabbit Cornea (SIRC) cell line.

SIRT 1 stands for sirtuin (silent mating type information regulation 2 homolog) 1. It is an enzyme that deacetylates proteins that contribute to cellular regulation.

6-Keto-PGF1 alpha a physiologically active and stable hydrolysis product of Epoprostenol, found in nearly all mammalian tissues.

Skp1 (S-phase kinase-associated protein 1) is a core component of SCF ubiquitin ligases and mediates protein degradation.

Smads a family of intracellular proteins that mediate signaling by members of the TGF-beta (transforming growth factor beta) superfamily.

Smad2/3 a key signaling molecule for TGF-beta.

Smad7 a TGFβ type 1 receptor antagonist.

Smallpox is an acute, contagious and devastating disease in humans caused by *Variola* virus and have resulted in high mortality over the centuries.

Snuff powder inhaled through the nose.

SOD superoxide dismutase, is an enzyme that repairs cells and reduces the damage done to them by superoxide, the most common free radical in the body.

Sodium (Na) is an essential nutrient required for health. Sodium cations are important in neuron (brain and nerve) function, and in influencing

osmotic balance between cells and the interstitial fluid and in maintenance of total body fluid homeostasis. Extra intake may cause a harmful effect on health. Sodium is naturally supplied by salt intake with food.

Soleus muscle smaller calf muscle lower down the leg and under the gastrocnemius muscle.

Somites mesodermal structures formed during embryonic development that give rise to segmented body parts such as the muscles of the body wall.

Soporific a sleep inducing drug.

SOS response a global response to DNA damage in which the cell cycle is arrested and DNA repair and mutagenesis are induced.

Soyasapogenins triterpenoid products obtained from the acid hydrolysis of soyasaponins, designated soyasapogenols A,B, C, D and E.

Soyasaponins bioactive saponin compounds found in many legumes.

Spasmogenic inducing spasm.

Spasmolytic checking spasms, see antispasmodic.

Spermatorrhoea medically an involuntary ejaculation/drooling of semen usually nocturnal emissions.

Spermidine an important polyamine in DNA synthesis and gene expression.

Spina bifida a congenital birth defect caused by the incomplete closing of the embryonic neural tube.

Sphingolipid a member of a class of lipids derived from the aliphatic amino alcohol, sphingosine.

Spleen organ that filters blood and prevents infection.

Spleen tyrosine kinase (SYK) is an enigmatic protein tyrosine kinase functional in a number of diverse cellular processes such as the regulation of immune and inflammatory responses.

Splenitis inflammation of the spleen.

Splenocyte is a monocyte, one of the five major types of white blood cell, and is characteristically found in the splenic tissue.

Splenomegaly is an enlargement of the spleen.

Sprain to twist a ligament or muscle of a joint without dislocating the bone.

Sprue is a chronic disorder of the small intestine caused by sensitivity to gluten, a protein found in wheat and rye and to a lesser extent oats and

barley. It causes poor absorption by the intestine of fat, protein, carbohydrates, iron, water, and vitamins A, D, E, and K.

Sputum matter coughed up and usually ejected from the mouth, including saliva, foreign material, and substances such as mucus or phlegm, from the respiratory tract.

SREBP-1 see sterol regulatory element-binding protein-1.

Stanch to stop or check the flow of a bodily fluid like blood from a wound.

Statin a type of lipid-lowering drug.

STAT3 signal transducer and activator of transcription 3, plays a key role in many cellular processes such as cell growth and apoptosis.

Status epilepticus refers to a life-threatening condition in which the brain is in a state of persistent seizure.

STD sexually transmitted disease.

Steatorrhea is the presence of excess fat in feces which appear frothy, foul smelling and floats because of the high fat content.

Steatohepatitis liver disease, characterized by inflammation of the liver with fat accumulation in the liver.

Steatosis refer to the deposition of fat in the interstitial spaces of an organ like the liver, fatty liver disease.

Sterility inability to produce offspring, also called asepsis.

Steroidogenic relating to steroidogenesis.

Steroidogenesis the production of steroids.

Sterol regulatory element-binding protein-1 (SREBP1) is a key regulator of the transcription of numerous genes that function in the metabolism of cholesterol and fatty acids.

Stimulant a substance that promotes the activity of a body system or function.

Stomachic (digestive stimulant), an agent that stimulates or strengthens the activity of the stomach; used as a tonic to improve the appetite and digestive processes.

Stomatitis oral inflammation and ulcers, may be mild and localized or severe, widespread, and painful.

Stomatology medical study of the mouth and its diseases.

Stool faeces.

Strangury is the painful passage of small quantities of urine which are expelled slowly by straining with severe urgency; it is usually accompanied with the unsatisfying feeling of a remaining volume inside and a desire to pass something that will not pass.

Straub tail condition in which an animal carries its tail in an erect (vertical or nearly vertical) position.

STREPs sterol regulatory element binding proteins, a family of transcription factors that regulate lipid homeostasis by controlling the expression of a range of enzymes required for endogenous cholesterol, fatty acid, triacylglycerol and phospholipid synthesis.

Stria terminalis a structure in the brain consisting of a band of fibres running along the lateral margin of the ventricular surface of the thalamus.

Striae gravidarum a cutaneous condition characterized by stretch marks on the abdomen during and following pregnancy.

Stricture an abnormal constriction of the internal passageway within a tubular structure such as a vessel or duct.

Strongyloidiasis an intestinal parasitic infection in humans caused by two species of the parasitic nematode *Strongyloides*. The nematode or round worms are also called thread worms.

Styptic a short stick of medication, usually anhydrous aluminum sulfate (a type of alum) or titanium dioxide, which is used for stanching blood by causing blood vessels to contract at the site of the wound. Also called hemostatic pencil. see antihemorrhagic.

Subarachnoid hemorrhage is bleeding in the area between the brain and the thin tissues that cover the brain.

Substance P a neuropeptide that functions as a neurotransmitter, neuromodulator and is associated with the sensation of pain.

Substantia nigra is a dark coloured brain structure located in the midbrain that play an important role in reward, addiction and movement.

Sudatory medicine that causes or increases sweating. Also see sudorific.

Sudorific a substance that causes sweating.

Sulfur Sulfur is an essential component of all living cells. Sulfur is important for the syn-

thesis of sulfur-containing amino acids, all polypeptides, proteins, and enzymes such as glutathione an important sulfur-containing tripeptide which plays a role in cells as a source of chemical reduction potential. Sulfur is also important for hair formation. Good plant sources are garlic, onion, leeks and other Alliaceous vegetables, Brassicaceous vegetables like cauliflower, cabbages, Brussels sprout, Kale; legumes – beans, green and red gram, soybeans; horse radish, water cress, wheat germ.

Superior mesenteric artery (SMA) arises from the anterior surface of the abdominal aorta, just inferior to the origin of the celiac trunk, and supplies the intestine from the lower part of the duodenum to the left colic flexure and the pancreas.

Superoxidase mutase (SOD) antioxidant enzyme.

Suppuration the formation of pus, the act of becoming converted into and discharging pus.

Supraorbital located above the orbit of the eye.

Sural nerve sensory nerve comprising collateral branches off of the common tibial, and common fibular nerve.

SYK, Spleen tyrosine kinase is a human protein and gene. Syk plays a similar role in transmitting signals from a variety of cell surface receptors including CD74, Fc Receptor, and integrins.

Sympathetic nervous system the part of the autonomic nervous system originating in the thoracic and lumbar regions of the spinal cord that in general inhibits or opposes the physiological effects of the parasympathetic nervous system, as in tending to reduce digestive secretions or speed up the heart.

Synaptic plasticity the ability of neurons to change the number and strength of their synapses.

Synaptogenesis the formation of synapses.

Synaptoneuroosomes purified synapses containing the pre- and postsynaptic termini.

Synaptosomes isolated terminal of a neuron.

Syncope fainting, sudden loss of consciousness followed by the return of wakefulness.

Syndactyly webbed toes, a condition where two or more digits are fused together.

Syneresis expulsion of liquid from a gel, as contraction of a blood clot and expulsion of liquid.

Syngeneic genetically identical or closely related, so as to allow tissue transplant; immunologically compatible.

Synovial lubricating fluid secreted by synovial membranes, as those of the joints.

Synoviocyte located in the synovial membrane, there are two types. Type A cells are more numerous, have phagocytic characteristics and produce degradative enzymes. Type B cells produce synovial fluid, which lubricates the joint and nurtures nourishes the articular cartilage.

Syphilis is perhaps the best known of all the STD's. Syphilis is transmitted by direct contact with infection sores, called chancres, syphitic skin rashes, or mucous patches on the tongue and mouth during kissing, necking, petting, or sexual intercourse. It can also be transmitted from a pregnant woman to a fetus after the fourth month of pregnancy.

System lupus erythematosus a long-term autoimmune disorder that may affect the skin, joints, kidneys, brain, and other organs. Symptoms may include chest pain, fatigue, fever, hair loss, mailasie, mouth sores, sensitivity to sunlight, skin rash (butterfly-rash).

Systolic the blood pressure when the heart is contracting. It is specifically the maximum arterial pressure during contraction of the left ventricle of the heart.

T cells or T lymphocytes a type of white blood cell that play a key role in the immune system.

Tachyarrhythmia any disturbance of the heart rhythm in which the heart rate is abnormally increased.

Tachycardia a false heart rate applied to adults to rates over 100 beats per minute.

Tachykinins neuropeptide transmitters that are widely distributed and active in the central nervous system and periphery, evoking a variety of responses in a variety of tissues.

Tachyphylaxia a decreased response to a medicine given over a period of time so that larger doses are required to produce the same response.

Tachypnea abnormally fast breathing.

Taenia a parasitic tapeworm or flatworm of the genus, *Taenia*.

Taeniocide an agent that kills tapeworms.

Tau is a class of microtubule-associated protein (MAP) in neuronal and glial cells.

Tau-1 (Ser198/199/202), pS396 (Ser396), and pS214 (Ser214) epitopes serine phosphorylation sites of tau-1.

Tau phosphorylation plays an important role in neurodegenerative diseases and regulated by protein kinases and phosphatases.

TBARS see thiobarbituric acid reactive substances.

T-cell a type of white blood cell that attacks virus-infected cells, foreign cells and cancer cells.

TCA cycle see Tricarboxylic acid cycle.

TCID₅₀ median tissue culture infective dose; that amount of a pathogenic agent that will produce pathological change in 50% of cell cultures.

Telencephalon the cerebral hemispheres, the largest divisions of the human brain.

Telomerase enzyme that acts on parts of chromosomes known as telomeres.

Temporomandibular joint disorder (TMJD or TMD syndrome) a disorder characterized by acute or chronic inflammation of the temporomandibular joint, that connects the mandible to the skull.

Tendonitis is inflammation of a tendon.

Tenesmus a strong desire to defaecate.

Teratogen is an agent that can cause malformations of an embryo or fetus. *adj.* teratogenic.

Testicular torsion twisting of the spermatic cord, which cuts off the blood supply to the testicle and surrounding structures within the scrotum.

Tetanus an acute, potentially fatal disease caused by tetanus bacilli multiplying at the site of an injury and producing an exotoxin that reaches the central nervous system producing prolonged contraction of skeletal muscle fibres. Also called lockjaw.

Tete acute dermatitis caused by both bacterial and fungal infection.

Tetter any of a number of skin diseases.

TGF- β transforming growth factor beta is a protein that controls proliferation, cellular differentiation, and other functions in most cells.

Th cells or T helper cells a subgroup of lymphocytes that helps other white blood cells in immunologic processes.

Thalassemia major is a genetic blood disorder that causes the body to manufacture an abnormal form of haemoglobin.

Thelarche the beginning of secondary (postnatal) breast development, usually occurring at the beginning of puberty in girls.

Thermogenic tending to produce heat, applied to drugs or food (fat burning food).

Thermogenesis is the process of heat production in organisms.

Thermnociceptors or thermal nociceptors, sensory receptors that are stimulated by noxious heat or cold at various temperature.

Thiobarbituric acid reactive substances (TBARS) a well-established method for screening and monitoring lipid peroxidation.

Thixotropy the property exhibited by certain gels of becoming fluid when stirred or shaken and returning to the semisolid state upon standing.

Thrombocythaemia a blood condition characterize by a high number of platelets in the blood.

Thrombocytopenia a condition when the bone marrow does not produce enough platelets (thrombocytes) like in leukaemia.

Thromboembolism formation in a blood vessel of a clot (thrombus) that breaks loose and is carried by the blood stream to plug another vessel.cf. deep vein thrombosis.

Thrombogenesis formation of a thrombus or blood clot.

Thrombophlebitis occurs when there is inflammation and clot in a surface vein.

Thromboplastin an enzyme liberated from blood platelets that converts prothrombin into thrombin as blood starts to clot, also called thrombokinase.

Thrombosis the formation or presence of a thrombus (clot).

Thromboxanes any of several compounds, originally derived from prostaglandin precursors in platelets that stimulate aggregation of platelets and constriction of blood vessels.

Thromboxane B₂ the inactive product of thromboxane.

Thrombus a fibrinous clot formed in a blood vessel or in a chamber of the heart.

Thrush a common mycotic infection caused by yeast, *Candida albicans*, in the digestive tract or vagina. In children it is characterized by white spots on the tongue.

Thymocytes are T cell precursors which develop in the thymus.

Thyrototoxicosis or hyperthyroidism - an overactive thyroid gland, producing excessive circu-

- lating free thyroxine and free triiodothyronine, or both.
- Tight junction** associated areas of two cells whose membranes join together forming a virtually impermeable barrier to fluid.
- TIMP-3** a human gene belongs to the tissue inhibitor of matrix metalloproteinases (MMP) gene family. see MMP.
- Tincture** solution of a drug in alcohol.
- Tinea** ringworm, fungal infection on the skin.
- Tinea favosa** See favus.
- Tinea cruris** ringworm of the groin.
- Tinea pedis** fungal infection of the foot, also called athlete's foot.
- Tinnitus** a noise in the ears, as ringing, buzzing, roaring, clicking, etc.
- Tisane** a herbal infusion used as tea or for medicinal purposes.
- Tissue plasminogen activator (t-PA)** a serine protease involved in the breakdown of blood clots.
- TNF alpha** cachexin or cachectin and formally known as tumour necrosis factor-alpha, a cytokine involved in systemic inflammation. primary role of TNF is in the regulation of immune cells. TNF is also able to induce apoptotic cell death, to induce inflammation, and to inhibit tumorigenesis and viral replication.
- Tocolytics** medications used to suppress premature labor.
- Tocopherol** fat soluble organic compounds belonging to vitamin E group. See vitamin E.
- Tocotrienol** fat soluble organic compounds belonging to vitamin E group. See vitamin E.
- Tolerogenic** producing immunological tolerance.
- Toll-like receptors (TLRs)** a class of proteins that play a key role in the innate immune system.
- Tonic** substance that acts to restore, balance, tone, strengthen, or invigorate a body system without overt stimulation or depression.
- Tonic clonic seizure** a type of generalized seizure that affects the entire brain.
- Tonsillitis** an inflammatory condition of the tonsils due to bacteria, allergies or respiratory problems.
- TOP2A** topoisomerase II alpha enzyme.
- Topoisomerases** a class of enzymes involved in the regulation of DNA supercoiling.
- Topoisomerase inhibitors** a new class of anticancer agents with a mechanism of action aimed at interrupting DNA replication in cancer cells.
- Total parenteral nutrition (TPN)** is a method of feeding that bypasses the gastrointestinal tract.
- Toxemia** is the presence of abnormal substances in the blood, but the term is also used for a serious condition in pregnancy that involves hypertension and proteinuria. Also called pre-eclampsia.
- Tracheitis** is a bacterial infection of the trachea; also known as bacterial tracheitis or acute bacterial tracheitis.
- Trachoma** a contagious disease of the conjunctiva and cornea of the eye, producing painful sensitivity to strong light and excessive tearing.
- TRAIL** acronym for tumour necrosis factor-related apoptosis-inducing ligand, is a cytokine that preferentially induces apoptosis in tumour cells.
- Tranquilizer** a substance drug used in calming person suffering from nervous tension or anxiety.
- Transaminase** also called aminotransferase is an enzyme that catalyzes a type of reaction between an amino acid and an α -keto acid.
- Transaminitis** increase in alanine aminotransferase (ALT) and/or aspartate aminotransferase (AST) to > 5 times the upper limit of normal.
- Transcatheter arterial chemoembolization (TACE)** is an interventional radiology procedure involving percutaneous access of to the hepatic artery and passing a catheter through the abdominal artery aorta followed by radiology. It is used extensively in the palliative treatment of unresectable hepatocellular carcinoma (HCC).
- Transcriptional activators** are proteins that bind to DNA and stimulate transcription of nearby genes.
- Transcriptional coactivator PGC-1** a potent transcriptional coactivator that regulates oxidative metabolism in a variety of tissues.
- Transcriptome profiling** to identify genes involved in peroxisome assembly and function.
- Transforming growth factor beta (TGF- β)** a protein that controls proliferation, cellular differentiation, and other functions in most cells.
- Transient receptor potential vanilloid 1 (TRPV1)** receptor also known as capsaicin receptor and vanilloid receptor, is a Ca²⁺-permeable nonselective cation channel localized on a subset of primary sensory neurons

and can be activated by physical and chemical stimuli.

TRAP 6 thrombin receptor activating peptide with 6 amino acids.

Tremorine a chemical that produces a tremor resembling Parkinsonian tremor.

Tremulous marked by trembling, quivering or shaking.

Triacylglycerols or triacylglyceride, is a glyceride in which the glycerol is esterified with three fatty acids.

Tricarboxylic acid cycle (TCA cycle) a series of enzymatic reactions in aerobic organisms involving oxidative metabolism of acetyl units and producing high-energy phosphate compounds, which serve as the main source of cellular energy. Also called citric acid cycle, Krebs cycle.

Trichophytosis infection by fungi of the genus *Trichophyton*.

Trigeminal neuralgia (TN) is a neuropathic disorder of one or both of the facial trigeminal nerves, also known as prosopalgia.

Triglycerides a type of fat (lipids) found in the blood stream.

Trismus continuous contraction of the muscles of the jaw, specifically as a symptom of tetanus, or lockjaw; inability to open mouth fully.

TrKB receptor also known as TrKB tyrosine kinase, a protein in humans that acts as a catalytic receptor for several neutrophins.

Trolox Equivalent measures the antioxidant capacity of a given substance, as compared to the standard, Trolox also referred to as TEAC (Trolox equivalent antioxidant capacity).

Trypanocidal destructive to trypanosomes.

Trypanosomes protozoan of the genus *Trypanosoma*.

Trypanosomiasis human disease or an infection caused by a trypanosome.

Trypsin an enzyme of pancreatic juice that hydrolyzes proteins into smaller polypeptide units.

Trypsin inhibitor small protein synthesized in the exocrine pancreas which prevents conversion of trypsinogen to trypsin, so protecting itself against trypsin digestion.

TRPV1 see transient receptor potential vanilloid 1.

Tuberculosis (TB) is a bacterial infection of the lungs caused by a bacterium called *Mycobacterium tuberculosis*, characterized by the for-

mation of lesions (tubercles) and necrosis in the lung tissues and other organs.

Tumorigenesis formation or production of tumours.

Tumour an abnormal swelling of the body other than those caused by direct injury.

Tussis a cough.

Tympanic membrane ear drum.

Tympanitis infection or inflammation of the inner ear.

Tympanophonia increased resonance of one's own voice, breath sounds, arterial murmurs, etc., noted especially in disease of the middle ear.

Tympanosclerosis see myringosclerosis.

Tyrosinase a copper containing enzyme found in animals and plants that catalyses the oxidation of phenols (such as tyrosine) and the production of melanin and other pigments from tyrosine by oxidation.

Ubiquitin ligase also called an E3 ubiquitin ligase, is a protein that targets other proteins to be broken down (degraded) within cells.

UCP1 an uncoupling protein found in the mitochondria of brown adipose tissue used to generate heat by non-shivering thermogenesis.

UCP – 2 enzyme uncoupling protein 2 enzyme, a mitochondrial protein expressed in adipocytes.

Ulcer an open sore on an external or internal body surface usually accompanied by disintegration of tissue and pus.

Ulcerative colitis is one of 2 types of inflammatory bowel disease - a condition that causes the bowel to become inflamed and red.

Ulemorrhagia bleeding of the gums.

Ulitis inflammation of the gums.

Unguent ointment.

Unilateral ureteral obstruction unilateral blockage of urine flow through the ureter of 1 kidney, resulting in a backup of urine, distension of the renal pelvis and calyces, and hydronephrosis.

Uraemia an excess in the blood of urea, creatinine and other nitrogenous end products of protein and amino acids metabolism, more correctly referred to as azotaemia.

Urethra tube conveying urine from the bladder to the external urethral orifice.

Urethritis is an inflammation of the urethra caused by infection.

- Uricemia** an excess of uric acid or urates in the blood.
- Uricosuric** promoting the excretion of uric acid in the urine.
- Urinary** pertaining to the passage of urine.
- Urinogenital** relating to the genital and urinary organs or functions.
- Urodynia** pain on urination.
- Urokinase** also called urokinase-type plasminogen (u-PA), is a serine protease enzyme in human urine that catalyzes the conversion of plasminogen to plasmin. It is used clinically as a thrombolytic agent.
- Urokinase-type plasminogen (u-PA)** plays a key role in tumour invasion and metastasis, also see Urokinase.
- Urolithiasis** formation of stone in the urinary tract (kidney bladder or urethra).
- Urticant** a substance that causes wheals to form.
- Urticaria** (or hives) is a skin condition, commonly caused by an allergic reaction, that is characterized by raised red skin welts.
- Uterine** relating to the uterus.
- Uterine relaxant** an agent that relaxes the muscles in the uterus.
- Uterine stimulant** an agent that stimulates the uterus (and often employed during active childbirth).
- Uterotonic** giving muscular tone to the uterus.
- Uterotrophic** causing an effect on the uterus.
- Uterus** womb.
- Vagotomy** the surgical cutting of the vagus nerve to reduce acid secretion in the stomach.
- Vagus nerve** a cranial nerve, that is, a nerve connected to the brain. The vagus nerve has branches to most of the major organs in the body, including the larynx, throat, windpipe, lungs, heart, and most of the digestive system.
- Variola** or smallpox, a contagious disease unique to humans, caused by either of two virus variants, *Variola major* and *Variola minor*. The disease is characterised by fever, weakness and skin eruption with pustules that form scabs that leave scars.
- Varicose veins** are veins that have become enlarged and twisted.
- Vasa vasorum** is a network of small blood vessels that supply large blood vessels. *plur.* vasa vasori.
- Vascular endothelial growth factor (VEGF)** a polypeptide chemical produced by cells that stimulates the growth of new blood vessels.
- Vasculogenesis** the process of blood vessel formation occurring by a de novo production of endothelial cells.
- Vasoconstrictor** drug that causes constriction of blood vessels.
- Vasodilator** drug that causes dilation or relaxation of blood vessels.
- Vasodilatory** causing the widening of the lumen of blood vessels.
- Vasomotor symptoms** menopausal symptoms characterised by hot flushes and night sweats.
- Vasospasm** refers to a condition in which blood vessels spasm, leading to vasoconstriction and subsequently to tissue ischemia and death (necrosis).
- VCAM-1 (vascular cell adhesion molecule-1)** also known as CD106, contains six or seven immunoglobulin domains and is expressed on both large and small vessels only after the endothelial cells are stimulated by cytokines.
- VEGF** Vascular endothelial growth factor.
- Venereal disease (VD)** term given to the diseases syphilis and gonorrhoea.
- Venule** a small vein, especially one joining capillaries to larger veins.
- Vermifuge** a substance used to expel worms from the intestines.
- Verotoxin** a Shiga-like toxin produced by *Escherichia coli*, which disrupts the function of ribosomes, causing acute renal failure.
- Verruca plana** is a reddish-brown or flesh-colored, slightly raised, flat-surfaced, well-demarcated papule on the hand and face, also called flat wart.
- Verruca vulgaris** small painless warts on the skin caused by the human papillomavirus.
- Vertigo** an illusory, sensory perception that the surroundings or one's own body are revolving; dizziness.
- Very-low-density lipoprotein (VLDL)** a type of lipoprotein made by the liver. VLDL is one of the five major groups of lipoproteins (chylomicrons, VLDL, intermediate-density lipoprotein, low-density lipoprotein, high-density lipoprotein (HDL)) that enable fats and cholesterol to move within the water-

based solution of the bloodstream. VLDL is converted in the bloodstream to low-density lipoprotein (LDL).

Vesical calculus calculi (stones) in the urinary bladder.

Vesicant a substance that causes tissue blistering.

Vestibular relating to the sense of balance.

Vestibular disorders includes symptoms of dizziness, vertigo, and imbalance; it can be result from or worsened by genetic or environmental conditions.

Vestibular system includes parts of the inner ear and brain that process sensory information involved with controlling balance and eye movement.

Vibrissa stiff hairs that are located especially about the nostrils.

Viremia a medical condition where viruses enter the bloodstream and hence have access to the rest of the body.

Visceral fat intra-abdominal fat, is located inside the peritoneal cavity, packed in between internal organs and torso.

Vitamin any complex, organic compound, found in various food or sometimes synthesized in the body, required in tiny amounts and are essential for the regulation of metabolism, normal growth and function of the body.

Vitamin A retinol, fat-soluble vitamins that play an important role in vision, bone growth, reproduction, cell division, and cell differentiation, helps regulate the immune system in preventing or fighting off infections. Vitamin A that is found in colorful fruits and vegetables is called provitamin A carotenoid. They can be made into retinol in the body. Deficiency of vitamin A results in night blindness and keratomalacia.

Vitamin B1 also called thiamine, water-soluble vitamins, dissolve easily in water, and in general, are readily excreted from the body they are not readily stored, consistent daily intake is important. It functions as coenzyme in the metabolism of carbohydrates and branched chain amino acids, and other cellular processes. Deficiency results in beriberi disease.

Vitamin B2 also called riboflavin, an essential water-soluble vitamin that functions as coen-

zyme in redox reactions. Deficiency causes ariboflavinosis.

Vitamin B3 comprises niacin and niacinamide, water-soluble vitamin that function as coenzyme or co-substrate for many redox reactions and is required for energy metabolism. Deficiency causes pellagra.

Vitamin B5 also called pantothenic acid, a water-soluble vitamin that function as coenzyme in fatty acid metabolism. Deficiency causes paresthesia.

Vitamin B6 water-soluble vitamin, exists in three major chemical forms: pyridoxine, pyridoxal, and pyridoxamine. Vitamin B6 is needed in enzymes involved in protein metabolism, red blood cell metabolism, efficient functioning of nervous and immune systems and hemoglobin formation. Deficiency causes anaemia and peripheral neuropathy.

Vitamin B7 also called biotin or vitamin H, an essential water-soluble vitamin, is involved in the synthesis of fatty acids amino acids and glucose, in energy metabolism. Biotin promotes normal health of sweat glands, bone marrow, male gonads, blood cells, nerve tissue, skin and hair, Deficiency causes dermatitis and enteritis.

Vitamin B9 also called folic acid, an essential water-soluble vitamin. Folate is especially important during periods of rapid cell division and growth such as infancy and pregnancy. Deficiency during pregnancy is associated with birth defects such as neural tube defects. Folate is also important for production of red blood cells and prevent anemia. Folate is needed to make DNA and RNA, the building blocks of cells. It also helps prevent changes to DNA that may lead to cancer.

Vitamin B12 a water-soluble vitamin, also called cobalamin as it contains the metal cobalt. It helps maintain healthy nerve cells and red blood cells, and DNA production. Vitamin B12 is bound to the protein in food. Deficiency causes megaloblastic anaemia.

Vitamin C also known as ascorbic acid is an essential water-soluble vitamin. It functions as cofactor for reactions requiring reduced copper or iron metalloenzyme and as a protective antioxidant. Deficiency of vitamin C causes scurvy.

Vitamin D a group of fat-soluble, prohormone vitamin, the two major forms of which are vitamin D2 (or ergocalciferol) and vitamin D3 (or cholecalciferol). Vitamin D obtained from sun exposure, food, and supplements is biologically inert and must undergo two hydroxylations in the body for activation. Vitamin D is essential for promoting calcium absorption in the gut and maintaining adequate serum calcium and phosphate concentrations to enable normal growth and mineralization of bone and prevent hypocalcemic tetany. Deficiency causes rickets and osteomalacia. Vitamin D has other roles in human health, including modulation of neuromuscular and immune function, reduction of inflammation and modulation of many genes encoding proteins that regulate cell proliferation, differentiation, and apoptosis.

Vitamin E is the collective name for a group of fat-soluble compounds and exists in eight chemical forms (alpha-, beta-, gamma-, and delta-tocopherol and alpha-, beta-, gamma-, and delta-tocotrienol). It has pronounced antioxidant activities stopping the formation of Reactive Oxygen Species when fat undergoes oxidation and help prevent or delay the chronic diseases associated with free radicals. Besides its antioxidant activities, vitamin E is involved in immune function, cell signaling, regulation of gene expression, and other metabolic processes. Deficiency is very rare but can cause mild hemolytic anemia in newborn infants.

Vitamin K a group of fat soluble vitamin and consist of vitamin K₁ which is also known as phyloquinone or phytomenadione (also called phytonadione) and vitamin K₂ (menaquinone, menatetrenone). Vitamin K plays an important role in blood clotting. Deficiency is very rare but can cause bleeding diathesis.

Vitamin P a substance or mixture of substances obtained from various plant sources, identified as citrin or a mixture of bioflavonoids, thought to but not proven to be useful in reducing the extent of hemorrhage.

Vitiligo a chronic skin disease that causes loss of pigment, resulting in irregular pale patches of skin. It occurs when the melanocytes, cells responsible for skin pigmentation, die or are unable to function. Also called leucoderma.

Vitreoretinopathy see proliferative vitreoretinopathy.

VLA-4 very late antigen-4, expressed by most leucocytes but it is observed on neutrophils under special conditions.

VLDL see very low density lipoproteins.

Vomitive substance that causes vomiting.

Vulnerary (wound healer), a substance used to heal wounds and promote tissue formation.

Wart an infectious skin tumour caused by a viral infection.

Welt see wheal.

Wheal a firm, elevated swelling of the skin. Also called a weal or welt.

White fat white adipose tissue (WAT) in mammals, store of energy. cf. brown fat.

Whitlow painful infection of the hand involving 1 or more fingers that typically affects the terminal phalanx.

Whooping cough acute infectious disease usually in children caused by a *Bacillus* bacterium and accompanied by catarrh of the respiratory passages and repeated bouts of coughing.

Wnt signaling pathway is a network of proteins involved in embryogenesis and cancer, and also in normal physiological processes.

X-linked agammaglobulinemia also known as X-linked hypogammaglobulinemia, XLA, Bruton type agammaglobulinemia, Bruton syndrome, or sex-linked agammaglobulinemia; a rare x-linked genetic disorder that affects the body's ability to fight infection.

Xanthine oxidase a flavoprotein enzyme containing a molybdenum cofactor (Moco) and (Fe₂S₂) clusters, involved in purine metabolism. In humans, inhibition of xanthine oxidase reduces the production of uric acid, and prevent hyperuricemia and gout.

Xanthones unique class of biologically active phenol compounds with the molecular formula C₁₃H₈O₂ possessing antioxidant properties, discovered in the mangosteen fruit.

Xenobiotics a chemical (as a drug, pesticide, or carcinogen) that is foreign to a living organism.

Xenograft a surgical graft of tissue from one species to an unlike species.

Xerophthalmia a medical condition in which the eye fails to produce tears.

Yaws an infectious tropical infection of the skin, bones and joints caused by the spirochete bacterium *Treponema pertenue*, characterized by papules and pappiloma with subsequent deformation of the skins, bone and joints; also called framboesia.

yGCN5 a histone acetyl transferase (HAT) that plays a role in regulation of transcriton, cell cycle progression and differentiation.

Yellow fever is a viral disease that is transmitted to humans through the bite of infected mosquitoes. Illness ranges in severity from an influenza-like syndrome to severe hepatitis and hemorrhagic fever. Yellow fever virus (YFV) is maintained in nature by mosquito-borne transmission between nonhuman primates.

Zeaxanthin a common carotenoid, found naturally as coloured pigments in many fruit vegetables

and leafy vegetables. It is important for good vision and is one of the two carotenoids contained within the retina of the eye. Within the central macula, zeaxanthin predominates, whereas in the peripheral retina, lutein predominates.

Zinc (Zn) is an essential mineral for health. It is involved in numerous aspects of cellular metabolism: catalytic activity of enzymes, immune function, protein synthesis, wound healing, DNA synthesis, and cell division. It also supports normal growth and development during pregnancy, childhood, and adolescence and is required for proper sense of taste and smell. Dietary sources include beans, nuts, pumpkin seeds, sunflower seeds, whole wheat bread and animal sources.

ZO1 protein A high molecular weight tight junction-associated protein.

Scientific Glossary

- Abaxial** facing away from the axis, as of the surface of an organ.
- Abscission** shedding of leaves, flowers, or fruits following the formation of the abscission zone.
- Acaulescent** lacking a stem, or stem very much reduced.
- Accrescent** increasing in size after flowering or with age.
- Achene** a dry, small, one-seeded, indehiscent one-seeded fruit formed from a superior ovary of one carpel as in sunflower.
- Acid soil** soil that maintains a pH of less than 7.0.
- Acidulous** acid or sour in taste.
- Actinomorphic** having radial symmetry, capable of being divided into symmetrical halves by any plane, refers to a flower, calyx or corolla.
- Aculeate** having sharp prickles.
- Acuminate** tapering gradually to a sharp point.
- Acute** (Botany) tapering at an angle of less than 90° before terminating in a point as of leaf apex and base.
- Adaxial** side closest to the stem axis.
- Aldephous** having stamens united together by their filaments.
- Adherent** touching without organic fusion as of floral parts of different whorls.
- Adnate** united with another unlike part as of stamens attached to petals.
- Adpressed** lying close to another organ but not fused to it.
- Adventitious** arising in abnormal positions, e.g. roots arising from the stem, branches or leaves, buds arising elsewhere than in the axils of leaves.
- Adventive** Not native to and not fully established in a new habitat or environment; locally or temporarily naturalized. e.g. an adventive weed.
- Aestivation** refers to positional arrangement of the floral parts in the bud before it opens.
- Akinete** a thick-walled dormant cell derived from the enlargement of a vegetative cell. It serves as a survival structure.
- Alfisols** soil with a clay-enriched subsoil and relatively high native fertility, having undergone only moderate leaching, containing aluminium, iron and with at least 35% base saturation, meaning that calcium, magnesium, and potassium are relatively abundant.
- Alkaline soil** soil that maintains a pH above 7.0, usually containing large amounts of calcium, sodium, and magnesium, and is less soluble than acidic soils.
- Alkaloids** naturally occurring bitter, complex organic-chemical compounds containing basic nitrogen and oxygen atoms and having various pharmacological effects on humans and other animals.
- Alternate** leaves or buds that are spaced along opposite sides of stem at different levels.
- Allomorphic** with a shape or form different from the typical.
- Alluvial soil** a fine-grained fertile soil deposited by water flowing over flood plains or in river beds.
- Alluvium** soil or sediments deposited by a river or other running water.
- Amplexicaul** clasping the stem as base of certain leaves.

- Anatomizing** interconnecting network as applied to leaf veins.
- Andisols** are soils formed in volcanic ash and containing high proportions of glass and amorphous colloidal materials.
- Androdioecious** with male flowers and bisexual flowers on separate plants.
- Androecium** male parts of a flower; comprising the stamens of one flower.
- Androgynophore** a stalk bearing both the androecium and gynoecium above the perianth of the flower.
- Androgynous** with male and female flowers in distinct parts of the same inflorescence.
- Andromonoecious** having male flowers and bisexual flowers on the same plant.
- Angiosperm** a division of seed plants with the ovules borne in an ovary.
- Annual** a plant which completes its life cycle within a year.
- Annular** shaped like or forming a ring.
- Annulus** circle or ring-like structure or marking; the portion of the corolla which forms a fleshy, raised ring.
- Anthelate** an open, paniculate cyme.
- Anther** the part of the stamen containing pollen sac which produces the pollen.
- Antheriferous** containing anthers.
- Anthesis** the period between the opening of the bud and the onset of flower withering.
- Anthocarp** a false fruit consisting of the true fruit and the base of the perianth.
- Anthocyanidins** are common plant pigments. They are the sugar-free counterparts of anthocyanins.
- Anthocyanins** a subgroup of antioxidant flavonoids, are glucosides of anthocyanidins. They occur as water-soluble vacuolar pigments that may appear red, purple, or blue according to pH in plants.
- Antipetala** situated opposite petals.
- Antisepala** situated opposite sepals.
- Antrorse** directed forward upwards.
- Apetalous** lacking petals as of flowers with no corolla.
- Apical meristem** active growing point. A zone of cell division at the tip of the stem or the root.
- Apically** towards the apex or tip of a structure.
- Apiculate** ending abruptly in a short, sharp, small point.
- Apiculum** a short, pointed, flexible tip.
- Apocarpous** carpels separate in single individual pistils.
- Apopetalous** with separate petals, not united to other petals.
- Aposepalous** with separate sepals, not united to other sepals.
- Appressed** pressed closely to another structure but not fused or united.
- Aquatic** a plant living in or on water for all or a considerable part of its life span.
- Arachnoid** (Botany) formed of or covered with long, delicate hairs or fibers.
- Arborescent** resembling a tree; applied to non-woody plants attaining tree height and to shrubs tending to become tree-like in size.
- Arbuscular mycorrhiza (AM)** a type of mycorrhiza in which the fungus (of the phylum Glomeromycota) penetrates the cortical cells of the roots of a vascular plant and form unique structures such as arbuscules and vesicles. These fungi help plants to capture nutrients such as phosphorus and micronutrients from the soil.
- Archegonium** a flask-shaped female reproductive organ in mosses, ferns, and other related plants.
- Areolate** with areolea.
- Areole** (Botany) a small, specialized, cushion-like area on a cactus from which hairs, glochids, spines, branches, or flowers may arise; an irregular angular spaces marked out on a surface e.g fruit surface. *pl.* areolea.
- Aril** specialized outgrowth from the funiculus (attachment point of the seed) (or hilum) that encloses or is attached to the seed. *adj.* arillate.
- Arillode** a false aril; an aril originating from the micropyle instead of from the funicle or chalaza of the ovule, e.g. mace of nutmeg.
- Aristate** bristle-like part or appendage, e.g. awns of grains and grasses.
- Aristulate** having a small, stiff, bristle-like part or appendage; a diminutive of aristate.
- Articulate** jointed; usually breaking easily at the nodes or point of articulation into segments.
- Ascending** arched upwards in the lower part and becoming erect in the upper part.
- Ascospore** spore produced in the ascus in Ascomycete fungi.
- Ascus** is the sexual spore-bearing cell produced in Ascomycete fungi. *pl.* asci.

- Asperulous** refers to a rough surface with short, hard projections.
- Attenuate** tapered or tapering gradually to a point.
- Auricle** an ear-like appendage that occurs at the base of some leaves or corolla.
- Auriculate** having auricles.
- Awn** a hair-like or bristle-like appendage on a larger structure.
- Axil** upper angle between a lateral organ, such as a leaf petiole and the stem that bears it.
- Axile** situated along the central axis of an ovary having two or more locules, as in axile placentation.
- Axillary** arising or growing in an axil.
- Baccate** beery-like, pulpy or fleshy.
- Barbate** bearded, having tufts of hairs.
- Barbellae** short, stiff, hair-like bristles. *adj.* barbellate.
- Bark** is the outermost layers of stems and roots of woody plants.
- Basal** relating to, situated at, arising from or forming the base.
- Basaltic soil** soil derived from basalt, a common extrusive volcanic rock.
- Basidiospore** a reproductive spore produced by Basidiomycete fungi.
- Basidium** a microscopic, spore-producing structure found on the hymenophore of fruiting bodies of Basidiomycete fungi.
- Basifixed** attached by the base, as certain anthers are to their filaments.
- Basionym** the synonym of a scientific name that supplies the epithet for the correct name.
- Beak** a prominent apical projection, especially of a carpel or fruit. *adj.* beaked.
- Bearded** having a tuft of hairs.
- Berry** a fleshy or pulpy indehiscent fruit from a single ovary with the seed(s) embedded in the fleshy tissue of the pericarp.
- Biconvex** convex on both sides.
- Biennial** completing the full cycle from germination to fruiting in more than one, but not more than 2 years.
- Bifid** forked, divided into two parts.
- Bifoliolate** having two leaflets.
- Bilabiate** having two lips as of a corolla or calyx with segments fused into an upper and lower lip.
- Bipinnate** twice pinnate; the primary leaflets being again divided into secondary leaflets.
- Bipinnatisect** refers to a pinnately compound leaf, in which each leaflet is again divided into pinnae.
- Biserrate** doubly serrate; with smaller regular, asymmetric teeth on the margins of larger teeth.
- Bisexual** having both sexes, as in a flower bearing both stamens and pistil, hermaphrodite or perfect.
- Biternate** Twice ternate; with three pinnae each divided into three pinnules.
- Blade** lamina; part of the leaf above the sheath or petiole.
- Blotched** see variegated.
- Bole** main trunk of tree from the base to the first branch.
- Brachyblast** a short, axillary, densely crowded branchlet or shoot of limited growth, in which the internodes elongate little or not at all.
- Bracket fungus** shelf fungus.
- Bract** a leaf-like structure, different in form from the foliage leaves, associated with an inflorescence or flower. *adj.* bracteate.
- Bracteate** possessing bracts.
- Bracteolate** having bracteoles.
- Bracteole** a small, secondary, bract-like structure borne singly or in a pair on the pedicel or calyx of a flower. *adj.* bracteolate.
- Bran** hard outer layer of grain and comprises the aleurone and pericarp. It contains important antioxidant, vitamins and fibre.
- Bristle** a stiff hair.
- Bulb** a modified underground axis that is short and crowned by a mass of usually fleshy, imbricate scales. *adj.* bulbous.
- Bulbil** A small bulb or bulb-shaped body, especially one borne in the leaf axil or an inflorescence, and usually produced for asexual reproduction.
- Bullate** puckered, blistered.
- Burr** type of seed or fruit with short, stiff bristles or hooks or may refer to a deformed type of wood in which the grain has been misformed.
- Bush** low, dense shrub without a pronounced trunk.
- Buttress** supporting, projecting outgrowth from base of a tree trunk as in some Rhizophoraceae and Moraceae.
- Caducous** shedding or falling early before maturity refers to sepals and petals.

- Caespitose** growing densely in tufts or clumps; having short, closely packed stems.
- Calcareous** composed of or containing lime or limestone.
- Calcrete** a hardpan consisting gravel and sand cemented by calcium.
- Callus** a condition of thickened raised mass of hardened tissue on leaves or other plant parts often formed after an injury but sometimes a normal feature. A callus also can refer to an undifferentiated plant cell mass grown on a culture medium. *n.* callosity. *pl.* calli, callosities. *adj.* callose.
- Calyptra** the protective cap or hood covering the spore case of a moss or related plant.
- Calyptrate** operculate, having a calyptra.
- Calyx** outer floral whorl usually consisting of free sepals or fused sepals (calyx tube) and calyx lobes. It encloses the flower while it is still a bud. *adj.* calycine.
- Calyx lobe** one of the free upper parts of the calyx which may be present when the lower part is united into a tube.
- Calyx tube** the tubular fused part of the calyx, often cup shaped or bell shaped, when it is free from the corolla.
- Campanulate** shaped like a bell refers to calyx or corolla.
- Canaliculate** having groove or grooves.
- Candelabriform** having the shape of a tall branched candle-stick.
- Canescent** covered with short, fine whitish or grayish hairs or down.
- Canopy** uppermost leafy stratum of a tree.
- Cap** see pileus.
- Capitate** growing together in a head. Also means enlarged and globular at the tip.
- Capitulum** a flower head or inflorescence having a dense cluster of sessile, or almost sessile, flowers or florets.
- Capsule** a dry, dehiscent fruit formed from two or more united carpels and dehiscing at maturity by sections called valves to release the seeds. *adj.* capsular.
- Carinate** keeled.
- Carpel** a simple pistil consisting of ovary, ovules, style and stigma. *adj.* carpellary.
- Carpogonium** female reproductive organ in red algae. *pl.* carpogonia.
- Carpophore** part of the receptacle which is lengthened between the carpels as a central axis; any fruiting body or fruiting structure of a fungus.
- Cartilaginous** sinewy, having a firm, tough, flexible texture (in respect of leaf margins).
- Caryopsis** a simple dry, indehiscent fruit formed from a single ovary with the seed coat united with the ovary wall as in grasses and cereals.
- Cataphyll** a reduced or scarcely developed leaf at the start of a plant's life (i.e., cotyledons) or in the early stages of leaf development.
- Catkin** a slim, cylindrical, pendulous flower spike usually with unisexual flowers.
- Caudate** having a narrow, tail-like appendage.
- Caudex** thickened, usually underground base of the stem.
- Caulescent** having a well developed aerial stem.
- Cauliflory** botanical term referring to plants which flower and fruit from their main stems or woody trunks. *adj.* cauliflorous.
- Cauline** borne on the aerial part of a stem.
- Chaffy** having thin, membranous scales in the inflorescence as in the flower heads of the sunflower family.
- Chalaza** the basal region of the ovule where the stalk is attached.
- Chartaceous** papery, of paper-like texture.
- Chasmogamous** describing flowers in which pollination takes place while the flower is open.
- Chloroplast** a chlorophyll-containing organelle (plastid) that gives the green colour to leaves and stems. Plastids harness light energy that is used to fix carbon dioxide in the process called photosynthesis.
- Chromoplast** plastid containing colored pigments apart from chlorophyll.
- Chromosomes** thread-shaped structures that occur in pairs in the nucleus of a cell, containing the genetic information of living organisms.
- Cilia** hairs along the margin of a leaf or corolla lobe.
- Ciliate** with a fringe of hairs on the margin as of the corolla lobes or leaf.
- Ciliolate** minutely ciliate.
- Cilium** a straight, usually erect hair on a margin or ridge. *pl.* cilia.
- Cincinnus** a monochasial cyme in which the lateral branches arise alternately on opposite sides of the false axis.
- Circinnate** spirally coiled, with the tip innermost.

- Circumscissile** opening by a transverse line around the circumference as of a fruit.
- Cladode** the modified photosynthetic stem of a plant whose foliage leaves are much reduced or absent. *cf.* cladophyll, phyllode.
- Cladophyll** A photosynthetic branch or portion of a stem that resembles and functions as a leaf, like in asparagus. *cf.* cladode, phyllode.
- Clamp connection** In the Basidiomycetes fungi, a lateral connection or outgrowth formed between two adjoining cells of a hypha and arching over the septum between them.
- Clavate** club shaped thickened at one end refer to fruit or other organs.
- Claw** the conspicuously narrowed basal part of a flat structure.
- Clay** a naturally occurring material composed primarily of fine-grained minerals like kaolinite, montmorillonite-smectite or illite which exhibit plasticity through a variable range of water content, and which can be hardened when dried and/or fired.
- Clayey** resembling or containing a large proportion of clay.
- Cleft** incised halfway down.
- Cleistogamous** refers to a flower in which fertilization occurs within the bud i.e. without the flower opening. *cf.* chasmogamous.
- Climber** growing more or less upwards by leaning or twining around another structure.
- Clone** all the plants reproduced, vegetatively, from a single parent thus having the same genetic make-up as the parent.
- Coccus** one of the sections of a distinctly lobed fruit which becomes separate at maturity; sometimes called a mericarp. *pl.* cocci.
- Coenocarpium** a fleshy, multiple pseudocarp formed from an inflorescence rather than a single flower.
- Coherent** touching without organic fusion, referring to parts normally together, e.g. floral parts of the same whorl. *cf.* adherent, adnate, connate.
- Collar** boundary between the above- and below ground parts of the plant axis.
- Colliculate** having small elevations.
- Column** a structure formed by the united style, stigma and stamen(s) as in Asclepiadaceae and Orchidaceae.
- Comose** tufted with hairs at the ends as of seeds.
- Composite** having two types of florets as of the flowers in the sunflower family, Asteraceae.
- Compost** organic matter (like leaves, mulch, manure, etc) that breaks down in soil releasing its nutrients.
- Compound** describe a leaf that is further divided into leaflets or pinnae or flower with more than a single floret.
- Compressed** flattened in one plane.
- Conceptacles** specialised cavities of marine algae that contain the reproductive organs.
- Concolorous** uniformly coloured, as in upper and lower surfaces. *cf.* discolorous.
- Conduplicate** folded together lengthwise.
- Cone** a reproductive structure composed of an axis (branch) bearing sterile bract-like organs and seed or pollen bearing structures. Applied to Gymnospermae, Lycopodiaceae, Casuarinaceae and also in some members of Proteaceae.
- Conic** cone shaped, attached at the broader end.
- Conic-capitate** a cone-shaped head of flowers.
- Connate** fused to another structure of the same kind. *cf.* adherent, adnate, coherent.
- Connective** the tissue separating two lobes of an anther.
- Connivent** converging.
- Conspecific** within or belonging to the same species.
- Contorted** twisted.
- Convolute** refers to an arrangement of petals in a bud where each has one side overlapping the adjacent petal.
- Cordate** heart-shaped as of leaves.
- Core** central part.
- Coriaceous** leathery texture as of leaves.
- Corm** a short, swollen, fleshy, underground plant stem that serves as a food storage organ used by some plants to survive winter or other adverse conditions.
- Cormel** a miniature, new corm produced on a mature corm.
- Corn silk** the long, filamentous styles that grow as a silky tuft or tassel at the tip of an ear of corn.
- Corolla** the inner floral whorl of a flower, usually consisting of free petals or a petals fused forming a corolla tube and corolla lobes. *adj.* corolline.
- Corona** a crown-like section of the staminal column, usually with the inner and outer lobes as in the Stapelieae.

- Coroniform** crown shaped, as in the pappus of Asteraceae.
- Cortex** the outer of the stem or root of a plant, bounded on the outside by the epidermis and on the inside by the endodermis containing undifferentiated cells.
- Corymb** a flat-topped, short, broad inflorescence, in which the flowers, through unequal pedicels, are in one horizontal plane and the youngest in the centre. *adj.* corymbose.
- Costa** a thickened, linear ridge or the midrib of the pinna in ferns. *adj.* costate.
- Costapalmate** having definite costa (midrib) unlike the typical palmate leaf, but the leaflets are arranged radially like in a palmate leaf.
- Cotyledon** the primary seed leaf within the embryo of a seed.
- Cover crop** crop grown in between trees or in fields primarily to protect the soil from erosion, to improve soil fertility and to keep off weeds.
- Crenate** round-toothed or scalloped as of leaf margins.
- Crenulate** minutely crenate, very strongly scalloped.
- Crisped** with a curled or twisted edge.
- Cristate** having or forming a crest or crista.
- Crozier** shaped like a shepherd's crook.
- Crustaceous** like a crust; having a hard crust or shell.
- Cucullate** having the shape of a cowl or hood, hooded.
- Culm** the main aerial stem of the Graminae (grasses, sedges, rushes and other monocots).
- Culm sheath** the plant casing (similar to a leaf) that protects the young bamboo shoot during growth, attached at each node of culm.
- Cultigen** plant species or race known only in cultivation.
- Cultivar** cultivated variety; an assemblage of cultivated individuals distinguished by any characters significant for the purposes of agriculture, forestry or horticulture, and which, when reproduced, retains its distinguishing features.
- Cuneate** wedge-shaped, obtriangular.
- Cupular** cup-shaped, havin a cupule.
- Cupule** a small cup-shaped structure or organ, like the cup at the base of an acorn.
- Cusp** an elongated, usually rigid, acute point. *cf.* mucro.
- Cuspidate** terminating in or tipped with a sharp firm point or cusp. *cf.* mucronate.
- Cuspidulate** constricted into a minute cusp. *cf.* cuspidate.
- Cyathiform** in the form of a cup, a little widened at the top.
- Cyathium** a specialised type of inflorescence of plants in the genus Euphorbia and Chamaesyce in which the unisexual flowers are clustered together within a bract-like envelope. *pl.* cyathia.
- Cylindric** tubular or rod shaped.
- Cylindric-acuminate** elongated and tapering to a point.
- Cymbiform** boat shaped, elongated and having the upper surface decidedly concave.
- Cyme** an inflorescence in which the lateral axis grows more strongly than the main axis with the oldest flower in the centre or at the ends. *adj.* cymose.
- Cymule** a small cyme or one or a few flowers.
- Cystidium** a relatively large cell found on the hymenium of a Basidiomycete, for example, on the surface of a mushroom.
- Cystocarp** fruitlike structure (sporocarp) developed after fertilization in the red algae.
- Deciduous** falling off or shedding at maturity or a specific season or stage of growth.
- Decorticate** to remove the bark, rind or husk from an organ; to strip of its bark; to come off as a skin.
- Decompound** as of a compound leaf; consisting of divisions that are themselves compound.
- Decumbent** prostrate, laying or growing on the ground but with ascending tips. *cf.* ascending, procumbent.
- Decurrent** having the leaf base tapering down to a narrow wing that extends to the stem.
- Decussate** having paired organs with successive pairs at right angles to give four rows as of leaves.
- Deflexed** bent downwards.
- Degumming** removal of gum deposits (phosphatides, entrained oil and meal particles) from crude edible oils traditionally done with water. Water degumming process also remove hydrophilic substances such as sugars from the oil.
- Dehisce** to split open at maturity, as in a capsule.
- Dehiscent** splitting open at maturity to release the contents. *cf.* indehiscent.

- Deltate** triangular shape.
- Deltoid** shaped like an equilateral triangle.
- Dendritic** branching from a main stem or axis like the branches of a tree.
- Dentate** with sharp, rather coarse teeth perpendicular to the margin.
- Denticulate** finely toothed.
- Diageotropic** the tendency of growing parts, such as roots, to grow at right angle to the line of gravity.
- Diadelphous** having stamens in two bundles as in Papilionaceae flowers.
- Dichasium** a cymose inflorescence in which the branches are opposite and approximately equal. *pl.* dichasia. *adj.* dichasial.
- Dichotomous** divided into two parts.
- Dicotyledon** angiosperm with two cotyledons.
- Didymous** arranged or occurring in pairs as of anthers, having two lobes.
- Digitate** having digits or fingerlike projections.
- Dikaryophyses** or dendrophydia, irregularly, strongly branched terminal hyphae in the Hymenomycetes (class of Basidiomycetes) fungi.
- Dimorphic** having or occurring in two forms, as of stamens of two different lengths or a plant having two kinds of leaves.
- Diocious** with male and female unisexual flowers on separate plants. *cf.* monoecious.
- Diploid** a condition in which the chromosomes in the nucleus of a cell exist as pairs, one set being derived from the female parent and the other from the male.
- Diplobiontic life cycle** life cycle that exhibits alternation of generations, which features of spore-producing multicellular sporophytes and gamete-producing multicellular gametophytes. mitoses occur in both the diploid and haploid phases.
- Diplontic life cycle** or gametic meiosis, wherein instead of immediately dividing meiotically to produce haploid cells, the zygote divides mitotically to produce a multicellular diploid individual or a group of more diploid cells.
- Dipterocarpous** trees of the family Dipterocarpaceae, with two-winged fruit found mainly in tropical lowland rainforest.
- Disc** (Botany) refers to the usually disc shaped receptacle of the flower head in Asteraceae; also the fleshy nectariferous organ usually between the stamens and ovary; also used for the enlarged style-end in Proteaceae.
- Disc floret** the central, tubular 4 or 5-toothed or lobed floret on the disc of an inflorescence, as of flower head of Asteraceae.
- Disciform** flat and rounded in shaped. *cf.* discoid, radiate.
- Discoid** resembling a disc; having a flat, circular form; disk-shaped *cf.* disciform, radiate.
- Discolorous** having two colours, as of a leaf which has different colors on the two surfaces. *cf.* concolorous.
- Disomic** having one or more chromosomes present twice but without the entire genome doubled.
- Dispersal** dissemination of seeds.
- Distal** site of any structure farthest from the point of attachment. *cf.* proximal.
- Distichous** referring to two rows of upright leaves in the same plane.
- Dithecous** having two thecae.
- Divaricate** diverging at a wide angle.
- Domatium** a part of a plant (e.g., a leaf) that has been modified to provide protection for other organisms. *pl.* domatia.
- Dormancy** a resting period in the life of a plant during which growth slows or appears to stop.
- Dorsal** referring to the back surface.
- Dorsifixed** attached to the back as of anthers.
- Drupaceous** resembling a drupe.
- Drupe** a fleshy fruit with a single seed enclosed in a hard shell (endocarp) which is tissue embedded in succulent tissue (mesocarp) surrounded by a thin outer skin (epicarp). *adj.* drupaceous.
- Drupelet** a small drupe.
- Ebracteate** without bracts.
- Echinate** bearing stiff, stout, bristly, prickly hairs.
- Edaphic** refers to plant communities that are distinguished by soil conditions rather than by the climate.
- Eglandular** without glands. *cf.* glandular.
- Ellipsoid** a 3-dimensional shape; elliptic in outline.
- Elliptic** having a 2-dimensional shape of an ellipse or flattened circle.
- Eongate** extended, stretched out.
- Emarginate** refers to leaf with a broad, shallow notch at the apex. *cf.* retuse.
- Embryo** (Botany) a minute rudimentary plant contained within a seed or an archegonium,

- composed of the embryonic axis (shoot end and root end).
- Endemic** prevalent in or peculiar to a particular geographical locality or region.
- Endocarp** The hard innermost layer of the pericarp of many fruits.
- Endosperm** tissue that surrounds and nourishes the embryo in the angiosperm seed. It contains starchy carbohydrates, proteins and small amounts of vitamins and minerals.
- Endospermous** refers to seeds having an endosperm.
- Endotrophic** as of mycorrhiza obtaining nutrients from inside.
- Ensilage** the process of preserving green food for livestock in an undried condition in airtight conditions. Also called silaging.
- Entire** having a smooth, continuous margin without any incisions or teeth as of a leaf.
- Entisols** soils that do not show any profile development other than an A horizon.
- Ephemeral** transitory, short-lived.
- Epicalyx** a whorl of bracts, subtending and resembling a calyx.
- Epicarp** outermost layer of the pericarp of a fruit.
- Epicormic** attached to the corm.
- Epicotyl** the upper portion of the embryonic axis, above the cotyledons and below the first true leaves.
- Epigeal** above grounds with cotyledons raised above ground.
- Epiparasite** an organism parasitic on another that parasitizes a third.
- Epipetalous** borne on the petals, as of stamens.
- Epiphyte** a plant growing on, but not parasitic on, another plant, deriving its moisture and nutrients from the air and rain e.g. some Orchidaceae. *adj.* epiphytic.
- Erect** upright, vertical.
- Essential oils** volatile products obtained from a natural source; refers to volatile products obtained by steam or water distillation in a strict sense.
- Etiolation** to cause (a plant) to develop without chlorophyll by preventing exposure to sunlight.
- Eutrophic** having waters rich in mineral and organic nutrients that promote a proliferation of plant life, especially algae, which reduces the dissolved oxygen content and often causes the extinction of other organisms.
- Excentric** off the true centre.
- Excrescence** abnormal outgrowth.
- Excurrent** projecting beyond the tip, as the midrib of a leaf or bract.
- Exserted** sticking out, protruding beyond some enclosing organ, as of stamens which project beyond the corolla or perianth.
- Exstipulate** without stipules. *cf.* stipulate.
- Extra-floral** outside the flower.
- Extrose** turned outwards or away from the axis as of anthers. *cf.* introrse, latrorse.
- Falcate** sickle shaped, crescent-shaped.
- Fascicle** a cluster or bundle of stems, flowers, stamens. *adj.* fasciculate.
- Fasciclude** staminode bundles.
- Fastigiate** a tree in which the branches grow almost vertically.
- Ferrosols** soils with an iron oxide content of greater than 5%.
- Ferruginous** rust coloured, reddish-brown.
- Fertile** having functional sexual parts which are capable of fertilisation and seed production. *cf.* sterile.
- Filament** the stalk of a stamen supporting and subtending the anther.
- Filiform** Having the form of or resembling a thread or filament.
- Fimbriate** fringed.
- Fixed oils** non volatile oils, triglycerides of fatty acids.
- Flaccid** limp and weak.
- Flag leaf** the uppermost leaf on the stem.
- Flaky** in the shape of flakes or scales.
- Flexuous** zig-zagging, sinuous, bending, as of a stem.
- Floccose** covered with tufts of soft woolly hairs.
- Floral tube** a flower tube usually formed by the basal fusion of the perianth and stamens.
- Floret** one of the small individual flowers of sunflower family or the reduced flower of the grasses, including the lemma and palea.
- Flower** the sexual reproductive organ of flowering plants, typically consisting of gynoecium, androecium and perianth or calyx and/or corolla and the axis bearing these parts.
- Fluted** as of a trunk with grooves and folds.
- Fodder** plant material, fresh or dried fed to animals.
- Foliaceous** leaf-like.
- Foliar** pertaining to a leaf.

- Foliate** pertaining to leaflets, used with a number prefix to denote the number of leaflets.
- Foliose** leaf-like.
- Follicle** (Botany) a dry fruit, derived from a single carpel and dehiscing along one suture.
- Forb** any herb that is not grass or grass-like.
- Free central placentation** The arrangement of ovules on a central column that is not connected to the ovary wall by partitions, as in the ovaries of the carnation and primrose.
- Frond** the leaf of a fern or cycad.
- Fruit** ripened ovary with adnate parts.
- Fugacious** shedding off early.
- Fulvous** yellow, tawny.
- Funiculus** (Botany) short stalk which attaches the ovule to the ovary wall.
- Fusiform** a 3-dimensional shape; spindle shaped, i.e. broad in the centre and tapering at both ends thick, but tapering at both ends.
- Gall-flower** short styled flower that do not develop into a fruit but are adapted for the development of a specific wasp within the fruit e.g. in the fig.
- Gamete** a reproductive cell that fuses with another gamete to form a zygote. Gametes are haploid, (they contain half the normal (diploid) number of chromosomes); thus when two fuse, the diploid number is restored.
- Gametophyte** The gamete-producing phase in a plant characterized by alternation of generations.
- Gamosepalous** with sepals united or partially united.
- Genome** complete set of genetic material of an organism.
- Geniculate** bent like a knee, refer to awns and filaments.
- Geocarpic** where the fruit are pushed into the soil by the gynophore and mature.
- Geophyte** a plant that stores food in an underground storage organ e.g. a tuber, bulb or rhizome and has subterranean buds which form aerial growth.
- Geotextile** are permeable fabrics which, when used in association with soil, have the ability to separate, filter, reinforce, protect, or drain.
- Germ** of cereal is the embryo of the seed or kernel. It contains vitamins B, E, folic acid, some protein, minerals and polyunsaturated fats.
- Glabrescent** becoming glabrous.
- Glabrous** smooth, hairless without pubescence.
- Gland** a secretory organ, e.g. a nectary, extra-floral nectary or a gland tipped, hair-like or wart-like organ. *adj.* glandular. *cf.* eglandular.
- Glaucous** pale blue-green in colour, covered with a whitish bloom that rubs off readily.
- Gley soils** a hydric soil which exhibits a greenish-blue-grey soil color due to wetland conditions.
- Globose** spherical in shape.
- Globular** a three-dimensional shape; spherical or orbicular; circular in outline.
- Glochids** tiny, finely barbed hair-like spines found on the areoles of some cacti and other plants.
- Glochidiate** having glochids.
- Glochidote** plant having glochids.
- Glume** one of the two small, sterile bracts at the base of the grass spikelet, called the lower and upper glumes, due to their position on the rachilla. Also used in Apiaceae, Cyperaceae for the very small bracts on the spikelet in which each flower is subtended by one floral glume. *adj.* glumaceous.
- Grits** consist of coarsely ground corn, or sometimes alkali-treated corn.
- Groats** hulled, whole grains of various cereals, such as oats, wheat, barley or buckwheat, it includes the cereal germ, fibre-rich bran portion and endosperm of the grain.
- Guttation** the appearance of drops of xylem sap on the tips or edges of leaves of some vascular plants, such as grasses and bamboos.
- Guttule** small droplet.
- Gymnosperm** a group of spermatophyte seed-bearing plants with ovules on scales, which are usually arranged in cone-like structures and not borne in an ovary. *cf.* angiosperm.
- Gynoecium** the female organ of a flower; a collective term for the pistil, carpel or carpels.
- Gynomonoecious** having female flowers and bisexual flowers on the same plant. *cf.* andromonoecious.
- Gynophore** stalk that bears the pistil/carpel.
- Habit** the general growth form of a plant, comprising its size, shape, texture and stem orientation, the locality in which the plant grows.
- Halophyte** a plant adapted to living in highly saline habitats. Also a plant that accumulates high concentrations of salt in its tissues. *adj.* halophytic.

- Hapaxanthic** refer to palms which flowers only once and then dies. *c.f.* pleoanthic.
- Haploid** condition where nucleus or cell has a single set of unpaired chromosomes, the haploid number is designated as *n*.
- Haplontic life cycle** or zygotic meiosis wherein meiosis of a zygote immediately after karyogamy, produces haploid cells which produces more or larger haploid cells ending its diploid phase.
- Hastate** having the shape of an arrowhead but with the basal lobes pointing outward at right angles as of a leaf.
- Hastula** a piece of plant material at the junction of the petiole and the leaf blade; the hastula can be found on the top of the leaf, adaxial or the bottom, abaxial or both sides.
- Heartwood** wood from the inner portion of a tree.
- Heliophilous** sun-loving, tolerates high level of sunlight.
- Heliotropic** growing towards sunlight.
- Herb** a plant which is non-woody or woody at the base only, the above ground stems usually being ephemeral. *adj.* herbaceous.
- Herbaceous** resembling a herb, having a habit of a herb.
- Hermaphrodite** bisexual, bearing flowers with both androecium and gynoecium in the same flower. *adj.* hermaphroditic.
- Heterocyst** a differentiated cyanobacterial cell that carries out nitrogen fixation.
- Heterogamous** bearing separate male and female flowers, or bisexual and female flowers, or florets in an inflorescence or flower head, e.g. some Asteraceae in which the ray florets may be neuter or unisexual and the disk florets may be bisexual. *cf.* homogamous.
- Heteromorphous** having two or more distinct forms. *cf.* homomorphous.
- Heterophyllous** having leaves of different form.
- Heterosporous** producing spores of 2 sizes, the larger giving rise to megagametophytes (female), the smaller giving rise to microgametophytes (male). Refer to the ferns and fern allies. *cf.* homosporous.
- Heterostylous** having styles of two different lengths or forms.
- Heterostyly** the condition in which flowers on polymorphous plants have styles of different lengths, thereby facilitating cross-pollination.
- Hilar** of or relating to a hilum.
- Hilum** The scar on a seed, indicating the point of attachment to the funiculus.
- Hirsute** bearing long coarse hairs.
- Hispid** bearing stiff, short, rough hairs or bristles.
- Hispidulous** minutely hispid.
- Histosol** soil comprising primarily of organic materials, having 40 cm or more of organic soil material in the upper 80 cm.
- Hoary** covered with a greyish layer of very short, closely interwoven hairs.
- Holdfast** an organ or structure of attachment, especially the basal, root-like formation by which certain seaweeds or other algae are attached to a substrate.
- Holocarpic** having the entire thallus developed into a fruiting body or sporangium.
- Homochromous** having all the florets of the same colour in the same flower head *cf.* heterochromous.
- Homogamous** bearing flowers or florets that do not differ sexually *cf.* heterogamous.
- Homogenous endosperm** endosperm with even surface that lacks invaginations or infoldings of the surrounding tissue.
- Homogonium** a part of a filament of a cyanobacterium that detaches and grows by cell division into a new filament. *pl.* homogonia.
- Homomorphous** uniform, with only one form. *cf.* heteromorphous.
- Homosporous** producing one kind of spores. Refer to the ferns and fern allies. *cf.* heterosporous.
- Hurd fibre** long pith fibre of the stem.
- Hyaline** colourless, almost transparent.
- Hybrid** the first generation progeny of the sexual union of plants belonging to different taxa.
- Hybridisation** the crossing of individuals from different species or taxa.
- Hydathode** a type of secretory tissue in leaves, usually of Angiosperms, that secretes water through pores in the epidermis or margin of the leaf.
- Hydrophilous** water loving; requiring water in order to be fertilized, referring to many aquatic plants.
- Hygrochastic** applied to plants in which the opening of the fruits is caused by the absorption of water.
- Hygrophilous** living in water or moist places.

- Hymenial cystidia** the cells of the hymenium develop into basidia or asci, while in others some cells develop into sterile cells called cystidia.
- Hymenium** spore-bearing layer of cells in certain fungi containing asci (Ascomycetes) or basidia (Basidiomycetes).
- Hypanthium** cup-like receptacles of some dicotyledonous flowers formed by the fusion of the calyx, corolla, and androecium that surrounds the ovary which bears the sepals, petals and stamens.
- Hypha** is a long, branching filamentous cell of a fungus, and also of unrelated Actinobacteria. *pl.* hyphae.
- Hypocotyl** the portion of the stem below the cotyledons.
- Hypodermis** the cell layer beneath the epidermis of the pericarp.
- Hypogeal** below ground as of germination of seed.
- Hysteresis** refers to systems that may exhibit path dependence.
- Imbricate** closely packed and overlapping. *cf.* valvate.
- Imparipinnate** pinnately compound with a single terminal leaflet and hence with an odd number of leaflets. *cf.* paripinnate.
- Inceptisols** old soils that have no accumulation of clays, iron, aluminium or organic matter.
- Incised** cut jaggedly with very deep teeth.
- Included** referring to stamens which do not project beyond the corolla or to valves which do not extend beyond the rim of a capsular fruit. *cf.* exserted.
- Incurved** curved inwards; curved towards the base or apex.
- Indefinite** numerous and variable in number.
- Indehiscent** not opening or splitting to release the contents at maturity as of fruit. *cf.* dehiscent.
- Indumentum** covering of fine hairs or bristles commonly found on external parts of plants.
- Indurate** to become hard, often the hardening developed only at maturity.
- Indusium** an enclosing membrane, covering the sorus of a fern. Also used for the modified style end or pollen-cup of some Goodeniaceae (including *Brunoniaceae*). *adj.* indusiate.
- Inferior** said of an ovary or fruit that has sepals, petals and stamens above the ovary. *cf.* superior.
- Inflated** enlarged and hollow except in the case of a fruit which may contain a seed. *cf.* swollen.
- Inflexed** Bent or curved inward or downward, as petals or sepals.
- Inflorescence** a flower cluster or the arrangement of flowers in relation to the axis and to each other on a plant.
- Infracoliar** located below the leaves.
- Infraspecific** referring to any taxon below the species rank.
- Infructescence** the fruiting stage of an inflorescence.
- Inrolled** curved inwards.
- Integuments** two distinct tissue layers that surround the nucellus of the ovule, forming the testa or seed coat when mature.
- Intercalary** of growth, between the apex and the base; of cells, spores, etc., between two cells.
- Interfoliar** inter leaf.
- Internode** portion of the stem, culm, branch, or rhizome between two nodes or points of attachment of the leaves.
- Interpetiolar** as of stipules positioned between petioles of opposite leaves.
- Intrastaminal** within the stamens.
- Intricate** entangled, complex.
- Introduced** not indigenous; not native to the area in which it now occurs.
- Introrse** turned inwards or towards the axis or pistil as of anthers. *cf.* extrorse, latrorse.
- Involucre** a whorl of bracts or leaves that surround one to many flowers or an entire inflorescence.
- Involute** having the margins rolled inwards, referring to a leaf or other flat organ.
- Jugate** of a pinnate leaf; having leaflets in pairs.
- Juvenile** young or immature, used here for leaves formed on a young plant which are different in morphology from those formed on an older plant.
- Keel** a longitudinal ridge, at the back of the leaf. Also the two lower fused petals of a 'pea' flower in the Papilionaceae, which form a boat-like structure around the stamens and styles, also called carina. *adj.* keeled. *cf.* standard, wing.
- Labellum** the modified lowest of the three petals forming the corolla of an orchid, usually larger than the other two petals, and often spurred.

- Laciniate** fringed; having a fringe of slender, narrow, pointed lobes cut into narrow lobes.
- Lamella** a gill-shaped structure: fine sheets of material held adjacent to one another.
- Lamina** the blade of the leaf or frond.
- Lanate** wooly, covered with long hairs which are loosely curled together like wool.
- Lanceolate** lance-shaped in outline, tapering from a broad base to the apex.
- Landrace** plants adapted to the natural environment in which they grow, developing naturally with minimal assistance or guidance from humans and usually possess more diverse phenotypes and genotypes. They have not been improved by formal breeding programs.
- Laterite** reddish-coloured soils rich in iron oxide, formed by weathering of rocks under oxidizing and leaching conditions, commonly found in tropical and subtropical regions. *adj.* lateritic.
- Latex** a milky, clear or sometimes coloured sap of diverse composition exuded by some plants.
- Latrorse** turned sideways, i.e. not towards or away from the axis as of anthers dehiscing longitudinally on the side. *cf.* extrorse, introse.
- Lax** loose or limp, not densely arranged or crowded.
- Leaflet** one of the ultimate segments of a compound leaf.
- Lectotype** a specimen chosen after the original description to be the type.
- Lemma** the lower of two bracts (scales) of a grass floret, usually enclosing the palea, lodicules, stamens and ovary.
- Lenticel** is a lens shaped opening that allows gases to be exchanged between air and the inner tissues of a plant, commonly found on young bark, or the surface of the fruit.
- Lenticellate** dotted with lenticels.
- Lenticular** shaped like a biconvex lens. *cf.* lentiform.
- Lentiform** shaped like a biconvex lens, *cf.* lenticular.
- Leptomorphic** temperate, running bamboo rhizome; usually thinner than the culms they support and the internodes are long and hollow.
- Liane** a woody climbing or twining plant.
- Lignotuber** a woody, usually underground, tuberous rootstock often giving rise to numerous aerial stems.
- Ligulate** small and tongue shaped or with a little tongue shaped appendage or ligule, star shaped as of florets of Asteraceae.
- Ligule** a strap-shaped corolla in the flowers of Asteraceae; also a thin membranous outgrowth from the inner junction of the grass leaf sheath and blade. *cf.* ligulate.
- Limb** the expanded portion of the calyx tube or the corolla tube, or the large branch of a tree.
- Linear** a 2-dimensional shape, narrow with nearly parallel sides.
- Linguiform** tongue shaped *cf.* ligulate.
- Lithosol** a kind of shallow soils lacking well-defined horizons and composed of imperfectly weathered fragments of rock.
- Littoral** of or on a shore, especially seashore.
- Loam** a type of soil mad up of sand, silt, and clay in relative concentration of 40-40-20% respectively.
- Lobed** divided but not to the base.
- Loculicidal** opening into the cells, when a ripe capsule splits along the back.
- Locus** cavity or chamber of an ovary. *pl.* loculi.
- Lodicules** two small structures below the ovary which, at flowering, swell up and force open the enclosing bracts, exposing the stamens and carpel.
- Lyrate** pinnately lobed, with a large terminal lobe and smaller laterals ones which become progressively smaller towards the base.
- Macronutrients** chemical elements which are needed in large quantities for growth and development by plants and include nitrogen, phosphorus, potassium, and magnesium.
- Maculate** spotted.
- Mallee** a growth habit in which several to many woody stems arise separately from a lignotuber; usually applied to certain low-growing species of *Eucalyptus*.
- Mangrove** a distinctive vegetation type of trees and shrubs with modified roots, often viviparous, occupying the saline coastal habitats that are subject to periodic tidal inundation.
- Marcrescent** withering or to decay without falling off.
- Margin** the edge of the leaf blade.
- Medulla** the pith in the stems or roots of certain plants; or the central portion of a thallus in certain lichens.

- Megasporangium** the sporangium containing megaspores in fern and fern allies. *cf.* microsporangium.
- Megaspore** the large spore which may develop into the female gametophyte in heterosporous ferns and fern allies. *cf.* microspore.
- Megasporophyll** a leaflike structure that bears megasporangia.
- Megastrobilus** female cone, seed cone, or ovulate cone, contains ovules within which, when fertilized by pollen, become seeds. The female cone structure varies more markedly between the different conifer families.
- Meiosis** the process of cell division that results in the formation of haploid cells from diploid cells to produce gametes.
- Mericarp** a 1-seeded portion of an initially syncarpous fruit (schizocarp) which splits apart at maturity. *Cf.* coccus.
- Meristem** the region of active cell division in plants, from which permanent tissue is derived. *adj.* meristematic.
- merous** used with a number prefix to denote the basic number of the 3 outer floral whorls, e.g. a 5-merous flower may have 5 sepals, 10 petals and 15 stamens.
- Mesic** moderately wet.
- Mesocarp** the middle layer of the fruit wall derived from the middle layer of the carpel wall. *cf.* endocarp, exocarp, pericarp.
- Mesophytes** terrestrial plants which are adapted to neither a particularly dry nor particularly wet environment.
- Micropyle** the small opening in a plant ovule through which the pollen tube passes in order to effect fertilisation.
- Microsporangium** the sporangium containing microspores in petridophytes. *cf.* megasporangium.
- Microspore** a small spore which gives rise to the male gametophyte in heterosporous pteridophytes. Also for a pollen grain. *cf.* megaspore.
- Midvein** the main vascular supply of a simple leaf blade or lamina. Also called mid-rib.
- Mitosis** is a process of cell division which results in the production of two daughter cells from a single parent cell.
- Mollisols** soils with deep, high organic matter, nutrient-enriched surface soil (A horizon), typically between 60 and 80 cm thick.
- Monadelphous** applied to stamens united by their filaments into a single bundle.
- Monocarpic** refer to plants that flower, set seeds and then die.
- Monochasial** a cyme having a single flower on each axis.
- Monocotyledon** angiosperm having one cotyledon.
- Monoecious** having both male and female unisexual flowers on the same individual plant. *cf.* dioecious.
- Monoembryonic seed** the seed contains only one embryo, a true sexual (zygotic) embryo. polyembryonic seed.
- Monolete** a spore that has a simple linear scar.
- Monopodial** with a main terminal growing point producing many lateral branches progressively. *cf.* sympodial.
- Monotypic** of a genus with one species or a family with one genus; in general, applied to any taxon with only one immediately subordinate taxon.
- Montane** refers to highland areas located below the subalpine zone.
- Mucilage** a soft, moist, viscous, sticky secretion. *adj.* mucilaginous.
- Mucous** (Botany) slimy.
- Mucro** a sharp, pointed part or organ, especially a sharp terminal point, as of a leaf.
- Mucronate** ending with a short, sharp tip or mucro, resembling a spine. *cf.* cuspidate, muticous.
- Mucronulate** with a very small mucro; a diminutive of mucronate.
- Mulch** protective cover of plant (organic) or non-plant material placed over the soil, primarily to modify and improve the effects of the local microclimate and to control weeds.
- Multiple fruit** a fruit that is formed from a cluster of flowers.
- Muricate** covered with numerous short hard outgrowths. *cf.* papillose.
- Muriculate** with numerous minute hard outgrowths; a diminutive of muricate.
- Muticous** blunt, lacking a sharp point. *cf.* mucronate.
- MYB proteins** are a superfamily of transcription factors that play regulatory roles in developmental processes and defense responses in plants.

Mycorrhiza the mutualistic symbiosis (non-pathogenic association) between soil-borne fungi with the roots of higher plants.

Mycorrhiza (vesicular arbuscular) endomycorrhiza living in the roots of higher plants producing inter-and intracellular fungal growth in root cortex and forming specific fungal structures, referred to as vesicles and arbuscles. *abbrev.* VAM.

Native a plant indigenous to the locality or region.

Naviculate boat-shaped.

Necrotic applied to dead tissue.

Nectariferous having one or more nectaries.

Nectary a nectar secretory gland; commonly in a flower, sometimes on leaves, fronds or stems.

Nervation venation, a pattern of veins or nerves as of leaf.

Nixtamalization refers to a process for the preparation of maize (corn), or other grain, in which the grains are soaked and cooked in an alkaline solution, usually limewater, and hulled.

Node the joint between segments of a culm, stem, branch, or rhizome; the point of the stem that gives rise to the leaf and bud.

Nodule a small knoblike outgrowth, as those found on the roots of many leguminous, that containing *Rhizobium* bacteria which fixes nitrogen in the soil.

Nom. ambig. nomen ambiguum (Latin) ambiguous name used in different senses which has become a long-persistent source of error.

Nom. cons. nomen nonservandum (Latin) name conserved in International Code of Botanical Nomenclature.

Nom. dub. nomen dubium (Latin) an invalid proposed taxonomic name because it is not accompanied by a definition or description of the taxon to which it applies.

Nom. illeg. nomen illegitimum (Latin) illegitimate taxon deemed as superfluous at its time of publication either because the taxon to which it was applied already has a name, or because the name has already been applied to another plant.

Nom. invalid. nomen invalidum (Latin) invalid name according to International Code of Botanical Nomenclature.

Nom. nud. nomen nudum (Latin) the name of a taxon which has never been validated by a description.

Nom. rej. nomen rejiciendum (Latin) name rejected in International Code of Botanical Nomenclature.

Notho- (subsp. or var.) prefix to the rank of a hybrid taxon below the rank of species.

Nucellus central portion of an ovule in which the embryo sac develops.

Nucellar embryony a form of seed reproduction in which the nucellar tissue which surrounds the embryo sac can produce additional embryos (polyembryony) which are genetically identical to the parent plant. This is found in many citrus species and in mango.

Nut a dry indehiscent 1-celled fruit with a hard pericarp.

Nutlet a small, 1-seeded, indehiscent lobe of a divided fruit.

Ob- prefix meaning inversely or opposite to.

Obconic a 3-dimensional shape; inversely conic; cone shaped, conic with the vertex pointing downward.

Obcordate inversely cordate, broad and notched at the tip; heart shaped but attached at the pointed end.

Obdeltate inversely deltate; deltate with the broadest part at the apex.

Ob lanceolate inversely lanceolate, lance-shaped but broadest above the middle and tapering toward the base as of leaf.

Oblate having the shape of a spheroid with the equatorial diameter greater than the polar diameter; being flattened at the poles.

Oblong longer than broad with sides nearly parallel to each other.

Obovate inversely ovate, broadest above the middle.

Obpyramidal resembling a 4-sided pyramid attached at the apex with the square base facing away from the attachment.

Obpyriform inversely pyriform, resembling a pear which is attached at the narrower end. *cf.* pyriform.

Obspathulate inversely spathulate; resembling a spoon but attached at the broadest end. *cf.* spathulate.

Obtriangular inversely triangular; triangular but attached at the apex. *cf.* triangular.

- Obtrullate** inversely trullate; resembling a trowel blade with the broadest axis above the middle. *cf.* trullate.
- Obtuse** with a blunt or rounded tip, the converging edges separated by an angle greater than 90°.
- oid** suffix denoting a 3-dimensional shape, e.g. spheroid.
- Ochraceous** a dull yellow color.
- Ocreate** having a tube-like covering around some stems, formed of the united stipules; sheathed.
- Oleaginous** oily.
- Oligotrophic** lacking in plant nutrients and having a large amount of dissolved oxygen throughout.
- Operculum** a lid or cover that becomes detached at maturity by abscission, e.g. in *Eucalyptus*, also a cap or lid covering the bud and formed by fusion or cohesion of sepals and/or petals. *adj.* operculate.
- Opposite** describing leaves or other organs which are borne at the same level but on opposite sides of the stem. *cf.* alternate.
- Orbicular** of circular outline, disc-like.
- Order** a taxonomic rank between class and family used in the classification of organisms, i.e. a group of families believed to be closely related.
- Orifice** an opening or aperture.
- Organosols** soils not regularly inundated by marine waters and containing a specific thickness of organic materials within the upper part of the profile.
- Orth. Var.** orthographic variant, i.e., an incorrect alternate spelling of a name.
- Ovary** the female part of the pistil of a flower which contains the ovules (immature seeds).
- Ovate** egg-shaped, usually with reference to two dimensions.
- Ovoid** egg-shaped, usually with reference to three dimensions.
- Ovule** the young, immature seed in the ovary which becomes a seed after fertilisation. *adj.* ovular.
- Ovulode** a sterile reduced ovule borne on the placenta, commonly occurring in Myrtaceae.
- Oxisols** refer to ferralsols.
- Pachymorphic** describes the short, thick, rhizomes of clumping bamboos with short, thick and solid internode (except the bud-bearing internodes, which are more elongated). *cf.* sympodial.
- Palate** (Botany) a raised appendage on the lower lip of a corolla which partially or completely closes the throat.
- Palea** the upper of the two membranous bracts of a grass floret, usually enclosing the lodicules, stamens and ovary. *pl.* paleae. *adj.* pal-eal. *cf.* lemma.
- Paleate** having glumes.
- Palm heart** refers to soft, tender inner core and growing bud of certain palm trees which are eaten as vegetables. Also called heart of palm, palmito, burglar's thigh, chonta or swamp cabbage.
- Palmate** describing a leaf which is divided into several lobes or leaflets which arise from the same point. *adj.* palmately.
- Palmito** see palm heart.
- Palustrial** paludal, swampy, marshy.
- Palustrine** marshy, swampy.
- Palustrine herb** vegetation that is rooted below water but grows above the surface in wetland system.
- Panduriform** fiddle shaped, usually with reference to two dimensions.
- Panicle** a compound, indeterminate, racemose inflorescence in which the main axis bears lateral racemes or spikes. *adj.* paniculate.
- Pantropical** distributed through-out the tropics.
- Papilionaceous** butterfly-like, said of the pea flower or flowers of Papilionaceae, flowers which are zygomorphic with imbricate petals, one broad upper one, two narrower lateral ones and two narrower lower ones.
- Papilla** a small, superficial protuberance on the surface of an organ being an outgrowth of one epidermal cell. *pl.* papillae. *adj.* papillose.
- Papillate** having papillae.
- Papillose** covered with papillae.
- Pappus** a tuft (or ring) of hairs, bristles or scales borne above the ovary and outside the corolla as in Asteraceae often persisting as a tuft of hairs on a fruit. *adj.* pappose.
- Papyraceous** resembling parchment of paper.
- Parenchyma** undifferentiated plant tissue composed of more or less uniform cells.
- Parietal** describes the attachment of ovules to the outer walls of the ovaries.
- Paripinnate** pinnate with an even number of leaflets and without a terminal leaflet. *cf.* imparipinnate.

- partite** divided almost to the base into segments, the number of segments written as a prefix.
- Patelliform** shaped like a limpet shell; cap-shaped and without whorls.
- Patent** diverging from the axis almost at right angles.
- Peat** is an accumulation of partially decayed vegetation matter.
- Pectin** a group of water-soluble colloidal carbohydrates of high molecular weight found in certain ripe fruits.
- Pectinate** pinnatifid with narrow segments resembling the teeth of a comb.
- Pedicel** the stalk of the flower or stalk of a spikelet in Poaceae. *adj.* pedicellate.
- Pedicellate** having pedicel.
- Peduncle** a stalk supporting an inflorescence. *adj.* pedunculate.
- Pellucid** allowing the passage of light; transparent or translucent.
- Pellucid-dotted** copiously dotted with immersed, pellucid, resinous glands.
- Peltate** with the petiole attached to the lower surface of the leaf blade.
- Pendant** hanging down.
- Pendulous** drooping, as of ovules.
- Penniveined or penni-nerved** pinnately veined.
- Pentamerous** in five parts.
- Perennial** a plant that completes its life cycle or lives for more than 2 years. *cf.* annual, biennial.
- Perfoliate** a leaf with the basal lobes united around--and apparently pierced by--the stem.
- Pergamentaceous** parchment-like.
- Perianth** the two outer floral whorls of the Angiosperm flower; commonly used when the calyx and the corolla are not readily distinguishable (as in monocotyledons).
- Pericarp** (Botany). The wall of a ripened ovary; fruit wall composed of the exocarp, mesocarp and endocarp.
- Persistent** remaining attached; not falling off. *cf.* caduceus.
- Petal** free segment of the corolla. *adj.* petaline. *cf.* lobe.
- Petiole** relating to the petiole.
- Petiolate** having petiole.
- Petiole** leaf stalk. *adj.* petiolate.
- Petiolulate** supported by its own petiolule.
- Petiolule** the stalk of a leaflet in a compound leaf. *adj.* petiolulate.
- pH** is a measure of the acidity or basicity of a solution. It is defined as the cologarithm of the activity of dissolved hydrogen ions (H⁺).
- Phenology** the study of periodic plant life cycle events as influenced by seasonal and interannual variations in climate.
- Phyllary** a bract of the involucre of a composite plant, term for one of the scale-like bracts beneath the flower-head in Asteraceae.
- Phylloclade** a flattened, photosynthetic branch or stem that resembles or performs the function of a leaf, with the true leaves represented by scales.
- Phyllode** a petiole that function as a leaf. *adj.* phyllodineous. *cf.* cladode.
- Phyllopodia** refer to the reduced, scale-like leaves found on the outermost portion of the corm where they seem to persist longer than typical sporophylls as in the fern *Isoetes*.
- Phytoremediation** describes the treatment of environmental problems (bioremediation) through the use of plants which mitigate the environmental problem without the need to excavate the contaminant material and dispose of it elsewhere.
- Pileus** (Botany) cap of mushroom.
- Piliferous** (Botany) bearing or producing hairs, as of an organ with the apex having long, hair-like extensions.
- Pilose** covered with fine soft hairs.
- Pinna** a primary division of the blade of a compound leaf or frond. *pl.* pinnae.
- Pinnate** bearing leaflets on each side of a central axis of a compound leaf; divided into pinnae.
- Pinnatifid, pinnatilobed** a pinnate leaf parted approximately halfway to midrib; when divided to almost to the mid rib described as deeply pinnatifid or pinnatisect.
- Pinnatisect** lobed or divided almost to the midrib.
- Pinnule** a leaflet of a bipinnate compound leaf.
- Pistil** female part of the flower comprising the ovary, style, and stigma.
- Pistillate** having one or more pistils; having pistils but no stamens.
- Placenta** the region within the ovary to which ovules are attached. *pl.* placentae.
- Placentation** the arrangement of the placentae and ovules in the ovary.

Plano- a prefix meaning level or flat.

Pleonanthic refer to palms in which the stem does not die after flowering.

Plicate folded like a fan.

Plumose feather-like, with fine hairs arising laterally from a central axis; feathery.

Pneumatophore modified root which allows gaseous exchange in mud-dwelling shrubs, e.g. mangroves.

Pod a dry 1 to many-seeded dehiscent fruit, as applied to the fruit of Fabaceae ie. Caesalpiniaceae, Mimosaceae and Papilionaceae.

Podzol, Podsolic soil any of a group of acidic, zonal soils having a leached, light-coloured, gray and ashy appearance. Also called spodosol.

Pollen cone male cone or microstrobilus or pollen cone is structurally similar across all conifers, extending out from a central axis are microsporophylls (modified leaves). Under each microsporophyll is one or several microsporangia (pollen sacs).

Pollinia the paired, waxy pollen masses of flowers of orchids and milkweeds.

Polyandrous (Botany) having an indefinite number of stamens.

Polyembryonic seed seeds contain many embryos, most of which are asexual (nucellar) in origin and genetically identical to the maternal parent.

Polygamous with unisexual and bisexual flowers on the same or on different individuals of the same species.

Polymorphic with different morphological variants.

Polypetalous (Botany) having a corolla composed of distinct, separable petals.

Pome a fleshy fruit where the succulent tissues are developed from the receptacle.

Pore a tiny opening.

Premorse Abruptly truncated, as though bitten or broken off as of a leaf.

Procumbent trailing or spreading along the ground but not rooting at the nodes, referring to stems. *cf.* ascending, decumbent, erect.

Pro hyb. (Latin) as a hybrid.

Pro parte (Latin) in part.

Pro Parte majore (Latin) for the greater part.

Pro parte minore (Latin) for a small part.

Pro sp. (Latin) as a species.

Pro subsp. (Latin) as a subspecies.

Pro syn. (Latin) as a synonym.

Prophyll a plant structure that resembles a leaf.

Prostrate lying flat on the ground.

Protandous relating to a flower in which the anthers release their pollen before the stigma of the same flower becomes receptive.

Proximal end of any structure closest to the point of attachment. *cf.* distal.

Pruinose having a thick, waxy, powdery coating or bloom.

Pseudocarp a false fruit, largely made up of tissue that is not derived from the ovary but from floral parts such as the receptacle and calyx.

Pseudostem The false, herbaceous stem of a banana plant composed of overlapping leaf bases.

Pteridophyte a vascular plant which reproduces by spores; the ferns and fern allies.

Puberulent covered with minute hairs or very fine down; finely pubescent.

Puberulous covered with a minute down.

Pubescent covered with short, soft hairs.

Pulvinate having a swelling, pulvinus at the base as a leaf stalk.

Pulvinus swelling at the base of leaf stalk.

Pulviniform swelling or bulging.

Punctate marked with translucent dots or glands.

Punctiform marked by or composed of points or dots.

Punctulate marked with minute dots; a diminutive of punctate.

Pusticulate characterized by small pustules.

Pyrene the stone or pit of a drupe, consisting of the hardened endocarp and seed.

Pyriform pear-shaped, a 3-dimensional shape; attached at the broader end. *cf.* obpyriform.

Pyxidium seed capsule having a circular lid (operculum) which falls off to release the seed.

Raceme an indeterminate inflorescence with a simple, elongated axis and pedicellate flowers, youngest at the top. *adj.* racemose.

Rachilla the main axis of a grass spikelet.

Rachis the main axis of the spike or other inflorescence of grasses or a compound leaf.

Radiate arranged around a common centre; as of an inflorescence of Asteraceae with marginal, female or neuter, ligulate ray-florets and

- central, perfect or functionally male, tubular, disc florets. *cf.* disciform, discoid.
- Radical** arising from the root or its crown, or the part of a plant embryo that develops into a root.
- Ray** the marginal portion of the inflorescence of Asteraceae and Apiaceae when distinct from the disc. Also, the spreading branches of a compound umbel.
- Receptacle** the region at the end of a pedicel or on an axis which bears one or more flowers. *adj.* receptacular.
- Recurved** curved downwards or backwards.
- Reflexed** bent or turned downward.
- Regosol** soil that is young and undeveloped, characterized by medium to fine-textured unconsolidated parent material that maybe alluvial in origin and lacks a significant horizon layer formation.
- Reniform** kidney shaped in outline.
- Repand** with slightly undulate margin.
- Replicate** folded back, as in some corolla lobes.
- Resinous** producing sticky resin.
- Resupinate** twisted through 180°.
- Reticulate** having the appearance of a network.
- Retorse** bent or directed downwards or backwards. *cf.* antrorse.
- Retuse** with a very blunt and slightly notched apex. *cf.* emarginated.
- Revolute** with the margins inrolled on the lower (abaxial) surface.
- Rhizine** a root-like filament or hair growing from the stems of mosses or on lichens.
- Rhizoid** root-like filaments in a moss, fern, fungus, etc. that attach the plant to the substratum.
- Rhizome** a prostrate or underground stem consisting of a series of nodes and internodes with adventitious roots and which generally grows horizontally.
- Rhizophore** a stilt-like outgrowth of the stem which branches into roots on contact with the substrate.
- Rhombic** shaped like a rhombus.
- Rhomboid** shaped like a rhombus.
- Rib** a distinct vein or linear marking, often raised as a linear ridge.
- Riparian** along the river margins, interface between land and a stream.
- Rosette** a tuft of leaves or other organs arranged spirally like petals in a rose, ranging in form from a hemispherical tuft to a flat whorl. *adj.* rosetted, rosulate.
- Rostrate** beaked; the apex tapered into a slender, usually obtuse point.
- Rostrum** a beak-like extension.
- Rosulate** having a rosette.
- Rotate** wheel shaped; refers to a corolla with a very short tube and a broad upper part which is flared at right angles to the tube. *cf.* salverform.
- Rotundate** rounded; especially at the end or ends.
- Rugae** refers to a series of ridges produced by folding of the wall of an organ.
- Rugose** deeply wrinkled.
- Rugulose** finely wrinkled.
- Ruminate** (Animal) chew repeatedly over an extended period.
- Ruminate endosperm** uneven endosperm surface that is often highly enlarged by ingrowths or infoldings of the surrounding tissue. *cf.* homogenous endosperm.
- Rz value** is a numerical reference to the mesh/emulsion equalization on the screen.
- Saccate** pouched.
- Sagittate** shaped like an arrow head.
- Saline soils** soils that contain excessive levels of salts that reduce plant growth and vigor by altering water uptake and causing ion-specific toxicities or imbalances.
- Salinity** is characterised by high electrical conductivities and low sodium ion concentrations compared to calcium and magnesium.
- Salverform** applies to a gamopetalous corolla having a slender tube and an abruptly expanded limb.
- Samara** an indehiscent, winged, dry fruit.
- Sand** a naturally occurring granular material composed of finely divided rock and mineral particles range in diameter from 0.0625 to 2 mm. *adj.* sandy.
- Saponins** are plant glycosides with a distinctive foaming characteristic. They are found in many plants, but get their name from the soapwort plant (*Saponaria*).
- Saprophytic** living on and deriving nourishment from dead organic matter.
- Sapwood** outer woody layer of the tree just adjacent to and below the bark.
- Sarcotesta** outermost fleshy covering of Cycad seeds below which is the sclerotesta.

- Scabrid** scurfy, covered with surface abrasions, irregular projections or delicate scales.
- Scabrous** rough to the touch.
- Scale** dry bract or leaf.
- Scandent** refer to plants, climbing.
- Scape** erect flowering stem, usually leafless, rising from the crown or roots of a plant. *adj.* scapose.
- Scapigerous** with a scape.
- Scarious** dry, thin and membranous.
- Schizocarp** a dry fruit which splits into longitudinally multiple parts called mericarps or cocci. *adj.* schizocarpous.
- Sclerotesta** the innermost fleshy coating of cycad seeds, usually located directly below the sarcotesta.
- Scorpioid** refers to a cymose inflorescence in which the main axis appears to coil.
- Scutellum** (Botany) any of various parts shaped like a shield.
- Secondary venation** arrangement of the lateral veins arising from the midrib in the leaf lamina.
- Secund** with the flowers all turned in the same direction.
- Sedge** a plant of the family Apiaceae, Cyperaceae.
- Segmented** constricted into divisions.
- Seminal root** or seed root originate from the scutellar node located within the seed embryo and are composed of the radicle and lateral seminal roots.
- Senescence** refers to the biological changes which take place in plants as they age.
- Sepal** free segment of the calyx. *adj.* sepaline.
- Septum** a partition or cross wall. *pl.* septa. *adj.* septate.
- Seriate** arranged in rows.
- Sericeous** silky; covered with close-pressed, fine, straight silky hairs.
- Serrate** toothed like a saw; with regular, asymmetric teeth pointing forward.
- Serrated** toothed margin.
- Serratures** serrated margin.
- Serrulate** with minute teeth on the margin.
- Sessile** without a stalk.
- Seta** a bristle or stiff hair. *pl.* setae. *adj.* setose, setaceous.
- Setaceous** bristle-like.
- Setate** with bristles.
- Setiform** bristle shaped.
- Setulose** with minute bristles.
- Sheathing** clasping or enveloping the stem.
- Shrub** a woody plant usually less than 5 m high and many-branched without a distinct main stem except at ground level.
- Silicula** a broad, dry, usually dehiscent fruit derived from two or more carpels which usually dehisce along two sutures. *cf.* siliqua.
- Siliqua** a silicula which is at least twice as long as broad.
- Silt** is soil or rock derived granular material of a grain size between sand and clay, grain particles ranging from 0.004 to 0.06 mm in diameter. *adj.* silty.
- Simple** refer to a leaf or other structure that is not divided into parts. *cf.* compound.
- Sinuate** with deep wavy margin.
- Sinuuous** wavy.
- Sinus** an opening or groove, as occurs between the bases of two petals.
- Sodicity** is characterised by low electrical conductivities and high sodium ion; concentrations compared to calcium and magnesium.
- Sodic soils** contains high levels of sodium salts that affects soil structure, inhibits water movement and causes poor germination and crop establishment and plant toxicity.
- Soil pH** is a measure of the acidity or basicity of the soil. See pH.
- Solitary** usually refer to flowers which are borne singly, and not grouped into an inflorescence or clustered.
- Sorocarp** fruiting body formed by some cellular slime moulds, has both stalk and spore mass.
- Sorophore** stalk bearing the sorocarp.
- Sorosis** fleshy multiple fruit formed from flowers that are crowded together on a fleshy stem e.g. pineapple and mulberry.
- Sorus** a discrete aggregate of sporangia in ferns. *pl.* sori.
- Spadix** fleshy spike-like inflorescence with an unbranched, usually thickened axis and small embedded flowers often surrounded by a spathe. *pl.* spadices.
- Spathe** a large bract ensheathing an inflorescence or its peduncle. *adj.* spathaceous.
- Spatheate** like or with a spathe.
- Spathulate** spatula or spoon shaped; broad at the tip and narrowed towards the base.

Spicate borne in or forming a spike.

Spiculate spikelet-bearing.

Spike an unbranched, indeterminate inflorescence with sessile flowers or spikelets. *adj.* spicate, spiciform.

Spikelet a small or secondary spike characteristics of the grasses and sedges and, generally composed of 2 glumes and one or more florets. Also applied to the small spike-like inflorescence or inflorescence units commonly found in Apiaceae.

Spine a stiff, sharp, pointed structure, formed by modification of a plant organ. *adj.* spinose.

Spinescent ending in a spine; modified to form a spine

Spinulate covered with small spines.

Spinulose with small spines over the surface.

Spodosol see podsol.

Sporidia asexual spores of smut fungi.

Sporangium a spore bearing structure found in ferns, fern allies and gymnosperms. *pl.* sporangia. *adj.* sporangial.

Sporocarp a stalked specialized fruiting structure formed from modified sporophylls, containing sporangia or spores as found in ferns and fern allies.

Sporophore a spore-bearing structure, especially in fungi.

Sporophyll a leaf or bract which bears or subtends sporangia in the fern allies, ferns and gymnosperms.

Sporophyte the spore-producing phase in the life cycle of a plant that exhibits alternation of generations.

Spreading bending or spreading outwards and horizontally.

Spur a tubular or saclike extension of the corolla or calyx of a flower.

Squama structure shaped like a fish scale. *pl.* squamae.

Squamous covered in scales.

Squarrose having rough or spreading scale-like processes.

Stamen the male part of a flower, consisting typically of a stalk (filament) and a pollen-bearing portion (anther). *adj.* staminal, staminate.

Staminate unisexual flower bearing stamens but no functional pistils.

Staminode a sterile or abortive stamen, often reduced in size and lacking anther. *adj.* staminodial.

Standard refers to the adaxial petal in the flower of Papilionaceae. cf. keel, wing.

Starch a polysaccharide carbohydrate consisting of a large number of glucose units joined together by glycosidic bonds α -1-4 linkages.

Stellate star shaped, applies to hairs.

Stem the main axis of a plant, developed from the plumule of the embryo and typically bearing leaves.

Sterile lacking any functional sexual parts which are capable of fertilisation and seed production.

Stigma the sticky receptive tip of an ovary with or without a style which is receptive to pollen.

Stilt root a supporting root arising from the stem some distance above the ground as in some mangroves, sometimes also known as a prop root.

Stipe a stalk that support some other structure like the frond, ovary or fruit.

Stipel secondary stipule at the base of a leaflet. *pl.* stipellae. *adj.* stipellate.

Stipitate having a stalk or stipe, usually of an ovary or fruit.

Stipulated having stipules.

Stipule small leaf-like, scale-like or bristle-like appendages at the base of the leaf or on the petiole. *adj.* stipulate.

Stolon a horizontal, creeping stem rooting at the nodes and giving rise to another plant at its tip.

Stoloniferous bearing stolon or stolons.

Stoma a pore in the epidermis of the leaf or stem for gaseous exchange. *pl.* stomata.

Stone the hard endocarp of a drupe, containing the seed or seeds.

Stramineous chaffy; straw-liked.

Striae parallel longitudinal lines or ridges. *adj.* striate.

Striate marked with fine longitudinal parallel lines or ridges.

Strigose bearing stiff, straight, closely appressed hair; often the hairs have swollen bases.

Strobilus a cone-like structure formed from sporophylls or sporangiophores. *pl.* strobili.

Style the part of the pistil between the stigma and ovary.

Sub- a prefix meaning nearly or almost, as in subglobose or subequal.

Subcarnose nearly fleshy.

- Sub-family** taxonomic rank between the family and tribe.
- Subglobose** nearly spherical in shape.
- Subretuse** faintly notched at the apex.
- Subsessile** nearly stalkless or sessile.
- Subshrub** intermediate between a herb and shrub.
- Subspecies** a taxonomic rank subordinate to species.
- Substrate** surface on which a plant or organism grows or attached to.
- Subtend** attached below something.
- Subulate** narrow and tapering gradually to a fine point, awl-shaped.
- Succulent** fleshy, juicy, soft in texture and usually thickened.
- Suckers** young plants sprouting from the underground roots of a parent plant and appearing around the base of the parent plant.
- Sulcate** grooved longitudinally with deep furrows.
- Sulcus** a groove or depression running along the internodes of culms or branches.
- Superior** refers to the ovary is free and mostly above the level of insertion of the sepals, and petals. *cf.* inferior.
- Suture** line of dehiscence.
- Swidden** slash-and-burn or shifting cultivation.
- Syconium** a type of pseudocarp formed from a hollow receptacle with small flowers attached to the inner wall. After fertilization the ovaries of the female flowers develop into one-seeded achenes, e.g. fig.
- Symbiosis** describes close and often long-term mutualistic and beneficial interactions between different organisms.
- Sympetalous** having petals united.
- Sympodial** refers to a specialized lateral growth pattern in which the apical meristem. *cf.* monopodial.
- Synangium** an organ composed of united sporangia, divided internally into cells, each containing spores. *pl.* synangia.
- Syncarp** an aggregate or multiple fruit formed from two or more united carpels with a single style. *adj.* syncarpous.
- Syncarpous** carpels fused forming a compound pistil.
- Synteny** presence of two or more genetic loci on the same chromosome.
- Tannins** group of plant-derived phenolic compounds.
- Taxon** the taxonomic group of plants of any rank. e.g. a family, genus, species or any infraspecific category. *pl.* taxa.
- Tendril** a slender, threadlike organ formed from a modified stem, leaf or leaflet which, by coiling around objects, supports a climbing plant.
- Tepal** a segment of the perianth in a flower in which all the perianth segments are similar in appearance, and are not differentiated into calyx and corolla; a sepal or petal.
- Tetrasporangium** a sporangium containing four haploid spores as found in some algae.
- Terete** having a circular shape when cross-sectioned or a cylindrical shape that tapers at each end.
- Terminal** at the apex or distal end.
- Ternate** in threes as of leaf with 3 leaflets.
- Testa** a seed coat, outer integument of a seed.
- Thallus** plant body of algae, fungi, and other lower organisms.
- Thyrse** a dense, panicle-like inflorescence, as of the lilac, in which the lateral branches terminate in cymes.
- Tomentose** refers to plant hairs that are bent and matted forming a wooly coating.
- Tomentellose** mildly tomentose.
- Torus** receptacle of a flower.
- Transpiration** evaporation of water from the plant through leaf and stem pores.
- Tree** that has many secondary branches supported clear of the ground on a single main stem or trunk.
- Triangular** shaped like a triangle, 3-angled and 3-sided.
- Tribe** a category intermediate in rank between subfamily and genus.
- Trichome** a hair-like outgrowth of the epidermis.
- Trichotomous** divided almost equally into three parts or elements.
- Tridentate** three toothed or three pronged.
- Trifid** divided or cleft into three parts or lobes.
- Trifoliate** having three leaves.
- Trifoliolate** a leaf having three leaflets.
- Trifurcate** having three forks or branches.
- Trigonus** obtusely three-angled; triangular in cross-section with plane faces.
- Tripartite** consisting of three parts.
- Tripinnate** relating to leaves, pinnately divided three times with pinnate pinnules.

- Tripliveined** main laterals arising above base of lamina.
- Triploid** describing a nucleus or cell that has three times (3n) the haploid number (n) of chromosomes.
- Triveined** main laterals arising at the base of lamina.
- Triquetrous** three-edged; acutely 3-angled.
- Trullate** with the widest axis below the middle and with straight margins; ovate but margins straight and angled below middle, trowel-shaped.
- Truncate** with an abruptly transverse end as if cut off.
- Tuber** a stem, usually underground, enlarged as a storage organ and with minute scale-like leaves and buds. *adj.* tuberous.
- Tubercle** a wart-like protuberance. *adj.* tuberculate.
- Tuberculate** bearing tubercles; covered with warty lumps.
- Tuberization** formation of tubers in the soil.
- Tuft** a densely packed cluster arising from an axis. *adj.* tufted.
- Turbinate** having the shape of a top; cone-shaped, with the apex downward, inversely conic.
- Turgid** distended by water or other liquid.
- Turion** the tender young, scaly shoot such as asparagus, developed from an underground bud without branches or leaves.
- Turnery** articles made by the process of turning.
- Twining** winding spirally.
- Ultisols** mineral soils with no calcareous material, have less than 10% weatherable minerals in the extreme top layer of soil, and with less the 35% base saturation throughout the soil.
- Umbel** an inflorescence of pedicellate flowers of almost equal length arising from one point on top of the peduncle. *adj.* umbellate.
- Umbellet** a secondary umbel of a compound umbel. *cf.* umbellule.
- Umbellule** an, a secondary umbel of a compound umbel. *cf.* umbellet.
- Uncinate** bent at the end like a hook; unciform.
- Undershrub** subshrub; a small, usually sparsely branched woody shrub less than 1 m high. *cf.* shrub.
- Undulate** with an edge/margin or edges wavy in a vertical plane; may vary from weakly to strongly undulate or crisped. *cf.* crisped.
- Unifoliolate** a compound leaf which has been reduced to a single, usually terminal leaflet.
- Uniform** with one form, e.g. having stamens of a similar length or having one kind of leaf. *cf.* dimorphic.
- Uniseriate** arranged in one row or at one level.
- Unisexual** with one sex only, either bearing the anthers with pollen, or an ovary with ovules, referring to a flower, inflorescence or individual plant. *cf.* bisexual.
- Urceolate** shaped like a jug, urn or pitcher.
- Utricle** a small bladderly pericarp.
- Valvate** meeting without overlapping, as of sepals or petals in bud. *cf.* imbricate.
- Valve** one of the sections or portions into which a capsule separates when ripe.
- Variant** any definable individual or group of individuals which may or may not be regarded as representing a formal taxon after examination.
- Variegate, variegated** diverse in colour or marked with irregular patches of different colours, blotched.
- Variety** a taxonomic rank below that of subspecies.
- Vein** (Botany) a strand of vascular bundle tissue.
- Velum** a flap of tissue covering the sporangium in the fern, Isoetes.
- Velutinous** having the surface covered with a fine and dense silky pubescence of short fine hairs; velvety. *cf.* sericeous.
- Venation** distribution or arrangement of veins in a leaf.
- Veneer** thin sheet of wood.
- Ventral** (Botany) facing the central axis, opposed to dorsal.
- Vernation** the arrangement of young leaves or fronds in a bud or at a stem apex. *cf.* circinnate.
- Verrucose** warty.
- Verticil** a circular arrangement, as of flowers, leaves, or hairs, growing about a central point; a whorl.
- Verticillaster** false whorl composed of a pair of opposite cymes as in Lamiaceae.
- Verticillate** whorled, arranged in one or more whorls.
- Vertisol** a soil with a high content of expansive montmorillonite clay that forms deep cracks in drier seasons or years.

Vertosols soils that both contain more than 35% clay and possess deep cracks wider than 5 mm during most years.

Vesicle a small bladdery sac or cavity filled with air or fluid. *adj.* vesicular.

Vestigial the remaining trace or remnant of an organ which seemingly lost all or most of its original function in a species through evolution.

Vestiture covering; the type of hairiness, scabiness or other covering commonly found on the external parts of plants. *cf.* indumentum.

Vibratile capable of to and fro motion.

Villose covered with long, fine, soft hairs, finer than in pilose.

Villous covered with soft, shaggy unmatted hairs.

Vine a climbing or trailing plant.

Violaxanthin is a natural xanthophyll pigment with an orange color found in a variety of plants like pansies.

Viscid sticky, being of a consistency that resists flow.

Viviparous describes seeds or fruit which sprout before they fall from the parent plant.

Whorl a ring-like arrangement of leaves, sepals, stamens or other organs around an axis.

Winged having a flat, often membranous expansion or flange, e.g. on a seed, stem or one of the two lateral petals of a Papilionaceous flower or one of the petal-like sepals of Polygalaceae. *cf.* keel, standard.

Xanthophylls are yellow, carotenoid pigments found in plants. They are oxidized derivatives of carotenes.

Xeromorphic plant with special modified structure to help the plant to adapt to dry conditions.

Xerophyte a plant which naturally grows in dry regions and is often structurally modified to withstand dry conditions.

Zygomorphic having only one plane of symmetry, usually the vertical plane, referring to a flower, calyx or corolla. *cf.* actinomorphic.

Zygote the first cell formed by the union of two gametes in sexual reproduction. *adj.* zygotic.

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