T. K. Lim

Edible Medicinal and Non-Medicinal Plants

Volume 11, Modified Stems, Roots, Bulbs

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Contents

Introduction

This book continues as volume eleven of a multi-compendium on *Edible Medicinal and Non-Medicinal Plants*. It covers plants with edible modified storage subterranean stems (corms, rhizomes, stem tubers) and unmodifed subterranean stem stolons, above-ground swollen stems and hypocotyls, storage roots (tap root, lateral roots, root tubers) and bulbs that are eaten as conventional or functional food as vegetables and spices, as herbal teas, and may provide a source of food additive or neutraceuticals. A list of such edible plant species from families Acanthaceae to Zygophyllaceae are presented in a tabular form and 32 such edible species from the families Alismataceae, Amaryllidaceae, Apiaceae, Araceae, Araliaceae, Asparagaceae, Asteraceae, Basellaceae, Brassicaceae and Campanulaceae had been covered in detail in preceding volume 9. Nineteen edible species from the families Amaranthaceae, Cannaceae, Cibotiaceae, Convolvulaceae, Cyperaceae, Dioscoreaceae, Euphorbiaceae and Fabaceae had been covered in detail in volume 10. This volume 11 covers in detail 18 edible species in the families Iridaceae (1), Lamiaceae (1), Marantaceae (1), Nelumbonaceae (1), Nyctaginaceae (1), Nymphaeaceae (3), Orchidaceae (4), Oxalidaceae (1), Piperaceae (1), Poaceae (2), Rubiaceae (1) and Simaroubaceae (1). Other species from these families with edible modified stems, roots and bulbs are listed in Table 1. Many plants with such edible plant parts that are better known for their edible fruits or flowers have been covered in earlier volumes and for those better known for other non-reproductive plant parts will be covered in latter volumes.

As in the preceding ten 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.

A corm or bulbotuber is defined as a short, vertical, swollen underground plant stem that serves as a storage organ used by some plants to survive unfavourable adverse periods. It bears membranous or scaly leaves and buds. Some examples of plants with edible corms are found in *Amorphophallus* spp., *Colocasia esculenta* (taro), *Eleocharis dulcis* (Chinese water chestnut), *Sagittaria* spp. (arrowhead or wapato) and *Xanthosoma* spp. (cocoyam or tannia). Corms often give rise to many small secondary corms or cormlet called cormels at the end of very short stolons.

Rhizome is a modified subterranean stem of a plant that is usually found underground, producing roots and shoots. It is used by the plant as storage organ and whole rhizome or pieces of the rhizome serves as vegetative propagules to give rise to new plants. Examples of plants with edible

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rhizomes include gingers (*Zingibe*r spp.), turmeric (*Cucurma longa*), greater galangal (*Alpinia galanga*), lesser galangal *Alpinia officinarum*), sand ginger or kencur (*Kampferia galanga*), lotus root (*Nelumbo nucifera*), *Typha* spp., fingerroot (*Boesenbergia rotunda*) and arrowroot (*Maranta arundinacea*).

A stem tuber is a modified plant storage organ that is formed from thickened rhizome or stolon. The tops or sides of the tuber produce shoots that grow into typical stems and leaves and the undersides produce roots. The stem tuber has all the parts of a normal stem, including nodes (eyes) and internodes. A stem tuber may start off as an enlargement of the hypocotyls of the seedling and may include the epicotyl or upper section of the root as is in the case of maca (*Lepidium meyenni*). More commonly as in *Plectranthus esculenta* in the Lamiaceae family, numerous tubers are formed on short stolons that arise from the base of the stem, or as in potatoes tubers are formed as enlarged stolons thickened and enlarged into storage organs. In some *Cyperus* species e.g. tigernut or chufa (*C. esculentus*), the stolons end with the growth of tubers that can give rise to new plants. Other striking examples of plants with stem tubers include hog potato or groundnut (*Apios americana*), Jerusalem artichoke or sunchoke (*Helianthus tuberosus*), earthnut pea (*Lathyrus tuberosus*), oca or New Zealand yam (*Oxalis tuberosa*), Chinese artichoke or crosne (*Stachys affinis*), mashua or añu (*Tropaeolum tuberosum*) and ulluco (*Ullucus tuberosus*). In Botany, a stolon is an horizontal modified stem arising from the base of a plant that produces new plants from buds at its tip or nodes and forms adventitious roots at the nodes, it can be creeping above the ground surface or underground. An example of a plant with edible stolon is *Imperata cylindrica*. However, some botanists used the term stolons for stem branches that arise from the base of the stem that creeps above the ground and those that creeps horizontally underground as rhizomes. An example of a plant with swollen, above-ground storage stem is the kohlrabi.

Bulb is a much reduced underground stem bearing at its apex a growing or floral primordium surrounded by thick, fleshy modified scale leaves or leaf bases that serve as food storage organs during dormancy and enable the plant to survive through adverse periods. The fleshy leaves are arranged in a concentric manner. Bulbs can be tunicate i.e. with membranous papery covering (scale leaves) or tunic that protects the inner fleshy scale leaves from drying and mechanical injury. Examples of tunicate bulbs are the Alliums, onions, leeks, hyacinth and tulips. In imbricate or non-tunicate bulbs, the fleshy scale leaves are not in concentric rings but are loosely arranged or spreading, overlapping one another at the margin. Such a bulb is not a compact body and not usually covered by a common tunic. Examples are the garlic (*Allium sativum*) and some *Lilium* lilies.

Tap root is the true main root of the plant and in some species the tap root is modified and fleshy, rich in stored nutrients; they may or may not be fused with the hypocotyl or basal stem tissues and maybe napiform, globose, conical, fusiform or cylindrical in shape. Notable examples of plants with edible tap roots are *Abelmochu*s spp., beet (*Beta vulgaris*), rutabaga, turnip, *Bunium persicum*, burdock, carrot, radish and daikon, celeriac, jicama and ahipa (*Pachyrhizus* spp.), parsnips, parsley, skirret (*Sium sisarum*), bush potato (*Vigna lanceolata*), salsify (*Tragopogon porrifolius*), black salsify (*Scorzonera hispanica*), tongkat Ali (*Eurycoma longifolia*) and many others. Plants with edible root tubers or tuberous roots with enlarged root and lateral roots function as storage organs, lacking nodes, internodes and adventious buds. Notable examples include pignut or earthnut (*Conopodium majus*), sweet potato (*Ipomoea batatas*), desert yam (*Ipomoea costata*), cassava or yuca or manioc (*Manihot esculenta*), yams (*Dioscorea* spp.), mauka or chago (*Mirabilis expansa*), breadroot, tipsin, or prairie turnip (*Psoralea esculenta*) and yacón (*Smallanthus sonchifolius*).

Most terrestrial orchids are rhizomatous or have corms or tubers. Many orchid species produce edible tubers and roots while comparatively fewer species (e.g. *Cymbidium canaliculatum* and *Dendrobium tarberi*) produce edible pseudobulbs. These tubers contain a nutritious, starchy polysaccharide called glucomannan. These tubers provide a starchy flour called salep which

Table 1 Plants with edible modified stems, roots and bulbs in the families: Iridaceae, Lamiaceae, Marantaceae, Nelumbonaceae, Nyctaginaceae, Nymphaeaceae, Orchidaceae, Oxalidaceae, Piperaceae, Poaceae, Rubiaceae and Simaroubaceae

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Iridaceae	*Crocus sativus* L.	Saffron	Roots are eaten roasted	Hedrick (1972), Kunkel (1984), Morton (1976), Facciola (1990), and Lim (2014)
Iridaceae	*Iris cristata* Aiton	Dwarf Crested Iris	Roots used as a spice. Frequently chewed by local people to alleviate thirst. When first chewed, the roots have a pleasant sweet taste, within a few minutes this changes to a burning sensation far more pungent than capsicums	Hedrick (1972), Tanaka (1976), Kunkel (1984), and Coffey (1994)
Iridaceae	*Iris x germanica* L.	Bearded Iris, Flag, Orris Root, German Iris, Florentine Iris	Root used as spice, flavouring in ice cream, confectionery and baked goods; starch used as bread flour	Chase (1900), Parmentier (1781) cited by Freedman (2009), Uphof (1968), Morton (1976), Facciola (1990), Bender (2009), and Surhone et al. (2011)
Iridaceae	*Iris pallida* Lam.	Sweet Iris, Dalmation Iris	Orris oil from rhizome used to flavour soft drinks, candy and chewing gum	Morton (1976)
Iridaceae	*Iris setosa* Pall. ex Link	Hiogi-Ayame	Rhizomes eaten or used as source of starch	Uphof (1968), Hedrick (1972), Tanaka (1976), and Facciola (1990)
Iridaceae	*Morea fugax* (D. Delaroche) Jacq.	Uintjie	Bulbous root eaten roasted, boiled or stewed with milk	Hedrick (1972), Fox et al. (1982), and Facciola (1990)
Iridaceae	*Romulea bulbocodium* (L.) Sebast. & Mauri	NF	Bulbous root eaten	Fairchild (1930)
Iridaceae	*Tigrida pavonia* (L. f.) Redouté	Common Tiger Flower, Jockey Cap, Mexican Shellflower, Peacock Flower	Roasted starchy corms used as food by Mazatecs and other Indian tribes in Mexico	Uphof (1968) and Facciola (1990)
Lamiaceae	*Callicarpa rubella* Lindl.	Gopura Esing (Mishing) Bonmala (Assamese)	Bark and roots chewed like betel nut; roots eaten in Meghalaya	Patiri and Borah (2007) and Sawian et al. (2007)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Lamiaceae	*Callicarpa vestita* Wall. ex C.B.Clarke	Yarpo Esing (Mishing)	Bark and roots chewed like betel nut	Patiri and Borah (2007)
Lamiaceae	*Clerodendrum fragrans* (Vent.) R.Br. = *Clerodendrum chinense* (Osbeck) Mabb,	Fragrant Glorybower; Chou Mo Li, Chou Mu Dan (Chinese)	Roots dried, cooked with pork to strengthen elderly people and to remove pain and stiffness of muscles and joints	Hu (2005)
Lamiaceae	*Clerodendrum serratum* (L.) Moon = *Rotheca serrata* (L.) Steane & Mabb.	Phelang Riho (Assamese)	Roots eaten in Karbi, Assam	Kar and Borthakur (2008)
Lamiaceae	*Coleus blumei* Benth. = *Plectranthus scutellarioides* (L.) R.Br.	Coleus, Painted Nettle, Sayabana, Jacob's Coat	Tubers eaten	Burkill (1966) and Facciola (1990)
Lamiaceae	*Coleus dazo* A. Chev. = *Plectranthus esculentus* N.E.Br.	Daju, Rizuka	Starchy root peeled, boiled, served and eaten or pickled	Tanaka (1976) and Facciola (1990)
Lamiaceae	*Coleus parviflorus* Benth. = *Plectranthus rotundifolius* (Poir.) Spreng.	African Potato, Country Potato	Tubers eaten like potatoes	Tanaka (1976), Ochse and van den Brink (1980) and Facciola (1990)
Lamiaceae	*Coleus tuberosus* (Blume) Benth. = *Plectranthus rotundifolius* (Poir.) Spreng.	African Potato, Country Potato	Tubers usually eaten steamed or cooked with rice In Indonesia	Ochse and van den Brink (1980)
Lamiaceae	*Eriophyton wallichii* Benth. ex Wall.	Mian Shen (Chinese)	Roots used in food in north-western Yunnan	Hu (2005)
Lamiaceae	*Leonurus sibiricus* L.	Siberian Motherwort	In China, the roots are cooked with pork	Burkill (1966), Altschul (1973), Tanaka (1976), and Facciola (1990)
Lamiaceae	*Lycopus europaeus* L.	Gypsywort, Water Horehound	China: root eaten. Manchuria: starchy tubers eaten	Read (1946) and Baranov (1967)
Lamiaceae	*Lycopus lucidus* Turcz. ex benth.	Lycopos, Bugleweed; Di Gua Er Miao (Chinese)	Underground rhizomes eaten in northern china and Yunnan	Hu (2005)
Lamiaceae	*Lycopus uniflorus* Michx.	Northern Bugleweed	White tubers eaten raw in salads, boiled, pickled or added to soups and stews	Fernald et al. (1985) and Facciola (1990)
Lamiaceae	*Phlomis tuberosa* L.	Tuberous Jerusalem Sage; Bodmon Sok	Roots eaten by the Kalmucks in Eurasia	Hedrick (1972) and Facciola (1990)
Lamiaceae	*Plectranthus barbatus* Andrews	Indian Coleus	Tubers eaten	Jansen (1996)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Lamiaceae	*Plectranthus edulis* Agnew	Galla Potato	Tubers eaten	Jansen (1996)
Lamiaceae	*Plectranthus esculentus* N.E. Br.	Livinstone Potato, Kaffir Potato	Stem tubers eaten, eaten raw or boiled and eaten as vegetables	Jansen (1996), Phillips and Rix (1993), van Wyk (2006), and Codex (2014)
Lamiaceae	*Plectranthus madagascariensis* (Pers.) Benth.	Madagascar Spur Flower	Tubers eaten in Madagascar	Tanaka (1976) and Facciola (1990)
Lamiaceae	*Plectranthus rotundifolius* (Poir.) Spreng	Chinese Potato, Coleus Potato, Hausa Potato	Young aromatic tubers used in soup and vegetable dishes	Jansen (1996) and Codex (2014)
Lamiaceae	*Solenostemon rotundifolia* (Poir.) J.K. Morton. = *Plectranthus rotundifolius* (Poir.) Spreng	Huasa Potato, Fra-Fra Potato; Tumuku, Tamaka (Hausa)	Nigeria (Kano State, northern): tuber eaten like potato	Dalziel (1955), Fox et al. (1982), Mortimore (1989), Facciola (1990), and Codex (2014)
Lamiaceae	*Stachys adulterina* Hemsl.	Hubei Artichoke; Di Can Zi (Chinese)	Root tubers used as vegetables, cooked or pickled	Hu (2005)
Lamiaceae	*Stachys affinis* Bunge	Chinese Artichoke; Cao Shi Can (Chinese)	As above	Phillips and Rix (1993) and Hu (2005), Codex 2014
Lamiaceae	*Stachys chinensis* Bunge ex Benth	Hyssopleaf Hedgenettle	Manchuria: rhizome eaten	Baranov (1967)
Lamiaceae	*Stachys sieboldi* Miq.	Crosnes, Chinese Artichoke, Japanese Artichoke	Japan: tubers salted or preserved in plum vinegar	Read (1946), Facciola (1990), Van den Bergh (1996), and Codex (2014)
Marantaceae	*Calathea allouia* (Aublet) Lindl.	Guinea Arrowroot, Leren, Sweet Corn Tuber	Root tubers boiled and eaten like potato	Facciola (1990), Groen et al. (1996), and Codex (2014)
Marantaceae	*Halopegia blumei* (Körn) K Schum.	Jelantir (Javanese), Patat (Sundanese) Dong Nam (Vietnam)	Tubers eaten cooked or roasted	Groen et al. (1996), Ochse and van den Brink (1980), and Ochse and van den Brink (1980)
Marantaceae	*Maranta arundinacea* L.	Arrowrot, Tora Alu, Tha Lairusa, Hnathel, Hpogimbai (Assamese) Khaita Alu (Boro) Nginti Ali (Mishing)	Rhizomes are source of arrowroot, eaten cooked or raw Tuber eaten both raw and boiled, starch from rhizome	Ochse and van den Brink (1980), Facciola (1990), Villamayor Jr and Jukema (1996), Hu (2005), Patiri and Borah (2007), Medhi and Borthakur (2012), and Codex (2014)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Marantaceae	*Maranta dichotoma* (Roxb.) Wall. = *Schumannianthus dichotomus* (Roxb.) Gagnep.	Mohtra Reed, Sitalpati Plant; Tha Lairu, Hnathel, Hpogimbai (Assamese)	Tuber eaten both raw and boiled	Medhi and Borthakur (2012)
Marantaceae	*Phrynium capitatum* Willd. = *Phrynium pubinerve* Blume	Packing Leaf	Root tuber eaten in Meghalaya	Sawian et al. (2007)
Marantaceae	*Thalia geniculata* L.	Swamp Lily	Rhizomes baked and eaten or made into a kind of arrowroot	Tanaka (1976) and Facciola (1990)
Nelumbonaceae	*Nelumbium speciosum* Willd.	Pink Water Lily	India: root and seeds eaten	Gammie (1902) and Watt (1908)
Nelumbonaceae	*Nelumbo lutea* Pers.	American Lotus, Water Chinquapin	Large tubers, when baked, are sweet and mealy with a flavour somewhat like a sweetpotato	Facciola (1990) and Saunders (1920)
Nelumbonaceae	*Nelumbo nucifera* Gaertn.	Lotus, Lotus Root	Root eaten raw or cooked, sliced used in stir-fries, soups, stews or fried as a garnish or side dish. Sliced pieces can be candied or pickled. Lotus root flour is starch and can be used to make desserts	Burkill (1966), Cribb and Cribb (1987), Facciola (1990), Phillips and Rix (1993), Ong (1996), Hu (2005), Santich et al. (2008), van Wyk (2006), and Codex (2014)
Nyctaginaceae	*Abronia latifolia* Eschsch.	Yellow Sand Verbena	Root edible	Yanovsky (1936) and Facciola (1990)
Nyctaginaceae	*Boerhavia coccinea* Mill.	Tar Vine, Hog Weed	Bland fibrous tap root eaten	Cribb and Cribb (1987) and Harden (1990)
Nyctaginaceae	*Boerhavia diffusa* L.	Hog Weed, Horse Purslane; Zhu Er Yan, Huang Xi Xin (Chinese)	Fleshy portion of thick roots roasted and eaten, sweetish and nutritious	Hu (2005)
Nyctaginaceae	*Boerhavia* spp.	Tar Vines	Bland fibrous tap root eaten	Low (1991)
Nyctaginaceae	*Mirabilis expansa* (Ruiz & Pav.) Standl.	Mauka, Chago	Tuber dried, boiled or fried, eaten as vegetable	Tanaka (1976), Popenoe et al. (1989), Facciola (1990), Bermejo and Leon (1994), and Codex (2014)
Nymphaeaceae	*Euryale ferox* Salisb.	Chicken Head, Fos Nut	In China, roots and seeds eaten	Read (1946) and Facciola (1990)
Nymphaeaceae	*Nuphar advena* R.Br.	Common Spatterdock	Rootstock eaten raw, roasted or cooked with meat	Uphof (1968), Hedrick (1972), and Facciola (1990)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Nymphaeaceae	*Nuphar luteum* Sibth. & Sm.	Yellow Water Lily	Rootstock boiled as vegetable	Hedrick (1972), Fernald et al. (1985), and Facciola (1990)
Nymphaeaceae	*Nuphar polysepala* Engelm. = *Nuphar lutea* subsp. *polysepala* (Engelm.) E.O. Beal.	Cow Lily, Spatterdock, Pond Collard	Rich starchy rhizome used as survival food, after boiling, roasting or baked and skin removed	Schofield (2003)
Nymphaeaceae	*Nuphar pumilum* (Timm.) DC.	Yellow Pond Lily; Ping Peng Cao (Chinese)	Young tender rhizomes used as potherb in Yunnan and Hubei	Hu (2005)
Nymphaeaceae	*Nymphaea lotus* L.	Egyptian Lotus, White Lotus	Tubers edible	Tanaka (1976), Kunkel (1984), and Facciola (1990)
Nymphaeaceae	*Nymphaea stellata* Willd. = *Nymphaea nouchali* Burm.f.	Blue Lotus Of India	Rhizomes eaten raw or roasted	Uphof (1968), Hedrick (1972), Tanaka (1976), and Facciola (1990)
Nymphaeaceae	*Nymphaea alba* L.	White Lotus, European White Waterlily	In France, root recommended as a famine food after cooking in water and being flavoured	Parmentier (1781) (cited by Freedman (2009))
Nymphaeaceae	*Nymphaea caerulea* Savigny = *Nymphaea nouchali* var. *caerulea* (Savigny) Verdc.	Blue Lotus Of Egypt, Blue Water Lily	Starchy tubers eaten boiled or roasted	Tanaka (1976), Fox et al. (1982), and Facciola (1990)
Nymphaeaceae	*Nymphaea edulis* DC.	Red Water Lily; Shunguneer Pushpum (Tamil); Koteka, Kalharamu (Telugu)	In India (Madras Presidency), roots and seeds cooked and eaten	Shortt (1887–1888)
Nymphaeaceae	*Nymphaea gigantea* Hook.	Giant Water Lily	Tuberous rootstock eaten	Cribb and Cribb (1987)
Nymphaeaceae	*Nymphaea lotus* var. *pubescens* (Willd) Hook.f. & Thomson = *Nymphaea pubescens* Willd.	Red Water Lily	Root eaten baked or boiled with salt added	Paton and Dunlop (1904)
Nymphaeaceae	*Nymphaea lotus* L.	Egyptian Lotus, White Lotus; Bado (Hausa); Dambi (Kanuri)	In upper Guinea Africa, root used as a famine food, being either roasted in ashes or dried before being ground into flour. In Nigeria (Kano State, northern), rhizome and seeds eaten. In India (Bombay Presidency), roots and seeds eaten	Gammie (1902), Watt (1908), Irvine (1952), Uphof (1968), Hedrick (1972), Tanaka (1976), Pongpangan and Poobrasert (1985), Mortimore (1989), and Facciola (1990)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Nymphaeaceae	*Nymphaea nouchali* Burm.f.	Boga Bhet, Seluk (Assamese)	Rhizomes/roots eaten raw or cooked as vegetable in Assam	Van den burgh (1994) and Patiri and Borah (2007)
Nymphaeaceae	*Nymphaea odorata* Aiton	Frgarny Water Lily	Tubers edible	Tanaka (1976), Kunkel (1984), and Facciola (1990)
Nymphaeaceae	*Nymphaea rubra* Roxb. ex Andrew	Ronga Bhet, Mokua, Seluk (Assamese)	As above	Patiri and Borah (2007)
Nymphaeaceae	*Nymphaea* spp.	Waterlilies	Fibrous tubers edible	Cribb and Cribb (1987) and Low 1989
Nymphaeaceae	*Nymphaea stellata* Willd. = *Nymphaea nouchali* Burm.f.	Izibo (Zulu)	In Zululand (Ubombo district), tuber boiled and eaten. In India, roots and seeds eaten	Hely- Hutchinson (1898), Gammie (1902), Watt (1908) and Uphof (1968)
Nymphaeaceae	*Nymphaea tetragona* Georgi	Four Angled Water Lily; Shui Lian (Chinese)	Rhizomes used as food in north-west China	Hu (2005)
Nymphaeaceae	*Nymphaea tuberosa* Paine = *Nymphaea odorata* subsp. *tuberosa* (Paine) Wiersema & Hellq.	Tuberous Waterlily, White Water Lily	Tubers occasionally eaten	Gibbons and Tucker (1979), Fernald et al. (1985), and Facciola (1990)
Nymphaeaceae	*Ondinea purpurea* Hartog	NF	Corms eaten by Australian aborigines	Les (2003)
Orchidaceae	*Aceras antropophorum* (L.) R.Br. = *Orchis anthropophora* (L.) All.	Man Orchid	Starchy tubers used for making salep flour used in ice-cream production, confectionery and nutritious beverages	Sezik (2002)
Orchidaceae	*Acianthus apprimus* D.L. Jones	Mountain Gnat Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Acianthus collinus* D.L.Jones	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Acianthus exsertus* R.Br	Mosquito Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Acianthus pusillus* D.L. Jones	Gnat Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Anacamptis coriophora* (L.) R.M.Bateman	NF	Starchy tubers used for making salep flour used in ice-cream production, confectionery and nutritious beverages	Ghorbani et al. (2014) and Kreziou et al. (2015)
Orchidaceae	*Anacamptis morio* (L.) R.M.Bateman	Green-Winged Orchid, Green-Veined Orchid	As above	Kreziou et al. (2015)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Anacamptis morio* subsp. *picta* (Loisel.) Jacquet & Scappat	As above	As above	Ghorbani et al. (2014)
Orchidaceae	*Anacamptis palustris* (Jacq.) R.M.Bateman, Pridgeon & Chase	NF	As above	Ghorbani et al. (2014)
Orchidaceae	*Anacamptis papilionacea* (L.) R.M.Bateman	Butterfly Orchid	As above	Kreziou et al. (2015)
Orchidaceae	*Anacamptis pyramidalis* (L.) Rich.	Pyramidal Orchid	As above	Sezik (1967), Sezik and Özer (1983) cited by Tekinşen and Güner (2010), Sezik (2002), Ghorbani et al. (2014), and Kreziou et al. (2015)
Orchidaceae	*Arthrochilus huntianus* (F.Muell.) Blaxell	Elbow Orchid	Tubers probably edible	Steenbeeke (2001)
Orchidaceae	*Barlia robertiana* (Loisel.) Greuter	Giant Orchid, Orkida Kbira	Starchy tubers used for making salep flour used in ice-cream production, confectionery and nutritious beverages	Sezik (2002)
Ochidaceae	*Brachycorythis pleistophylla* Rchb.f.	Likos, Ligosi	As above	Mapunda (2007) and Hamisy (2010)
Orchidaceae	*Calendenia caerula* R.Br.	Blue Fairy Orchid, Blue Caladenia	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Calendenia carnea* R.Br.	Pink Fairies, Pink Fringe Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Calendenia filamentosa* R.Br.	Daddy Longlegs, Spider Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Calendenia fuscata* (Rchb.f.) M.A.Clem. & D.L.Jones	Dusky Fingers	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Calendenia gracilis* R.Br.	Musky Caladenia, Musky Finger Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Calendenia quadrifaria* (R.S.Rogers) D.L.Jones	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Calendenia tentaculata* Schltdl.	Green Combed Spider Orchid, Fringed Spider Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Chiloglottis diphylla* R.Br.	Common Ant Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Chiloglottis formicifera* Fitzg.	Ant Orchid	Tubers edible	Steenbeeke (2001)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Chiloglottis palachila* D.L. Jones & M.A. Clem.	Clubbed Ant Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Chiloglottis platyptera* D.L.Jones	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Chiloglottis pluricallata* D.L.Jones	Brown Bird Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Chiloglottis sphyrnoides* D.L.Jones	Ornate Ant Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Chiloglottis trapeziformis* Fitzg.	Broad-Lip Bird Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Chiloglottis trilabra* Fitzg.	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Coelogyne ovalis* Lindl.	Oval Coelogyne		Sotirov (2015)
Orchidaceae	*Comperia comperiana* (Steven) Asch. & Graebn. = *Himantoglossum comperianum* (Steven) P.Delforge	Komper's Orchid	Starchy tubers used for making salep flour used in ice-cream production, confectionery and nutritious beverages	Sezik (2002)
Orchidaceae	*Corybas fimbriatus* (R.Br.) Rchb.f.	Fringed Helmut Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Corybas hispidus* D.L.Jones	Bristly Helmut Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Corybas montanus* D.L.Jones	Mt Maroon Helmut Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Corybas* species A	Sphagnum Helmut Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Cryptostylis erecta* F. Muell. ex Benth.	Tartan Tongue Orchid, Turban Orchid, Bonnet Orchid	Fleshy starchy root eaten	Steenbeeke (2001)
Orchidaceae	*Cryptostylis humteriana* Nicholls	Leafless Tongue Orchid	Fleshy starchy root eaten	Steenbeeke (2001)
Orchidaceae	*Cryptostylis leptochila* R.Br.	Small Tongue Orchid, Red Tongue Orchid	Fleshy starchy root eaten	Steenbeeke (2001)
Orchidaceae	*Cryptostylis subulata* (Labill.) Rchb.f.	Large Tongue Orchid, Cowslip Orchid	Fleshy starchy root eaten	Steenbeeke (2001)
Orchidaceae	*Cymbidium canaliculatum* R.Br.	Tiger Orchid, Channelled Cymbidium, Inland Tree Orchid	Starch rich pseudobulbs eaten cooked or raw	Steenbeeke (2001)
Orchidaceae	*Dactylorhiza incarnata* (L.) Soó	Early Marsh Orchid	Starchy tubers used for making salep flour used in ice-cream production, confectionery and nutritious beverages	Ghorbani et al. (2014)
Orchidaceae	*Dactylorhiza osmanica* var. *osmanica* = *Dactylorhiza osmanica* (Klinge) P.F Hunt & Summerh.	The Ottoman Dactylorhiza	Starchy tubers used for making salep flour used in ice-cream production, confectionery and nutritious beverages	Tekinşen and Güner (2010) and Citil and Tekinşen (2011)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Dactylorhiza romana* (Sebast.) Soó	Roman Dactylorhiza	As above	Sezik (1967), Sezik and Özer (1983) cited by Tekinşen and Güner (2010), and Sezik (2002)
Orchidaceae	*Dactylorhiza romana* subsp. georgica (Klinge) Soó ex Renz & Taubenheim	Georgian Orchid	As above	Ghorbani et al. (2014)
Orchidaceae	*Dactylorhiza saccifera* (Brongn.) Soó	Sack-Carrying Dactylorhiza	As above	Kreziou et al. (2015)
Orchidaceae	*Dactylorhiza sambucina* (L.) Soó	Elder-Flowered Orchid	As above	Kreziou et al. (2015)
Orchidaceae	*Dactylorhiza umbrosa* (Kar. & Kir.) Wendelbo	Persian Marsh-Orchid	As above	Ghorbani et al. (2014)
Orchidaceae	*Dendrobium tarberi* M.A.Clem. & D.L.Jones	Rock Lily, King Orchid	Pseudobulbs eaten baked or raw	Steenbeeke (2001)
Orchidaceae	*Dipodium atropurpureum* D.L.Jones	Purple Hyacinth Orchid	Fleshy starchy thick roots are probably edible	Steenbeeke (2001)
Orchidaceae	*Dipodium hamiltonianum* F.M.Bailey	Yellow Hyacinth Orchid	Fleshy starchy thick roots are probably edible	Steenbeeke (2001)
Orchidaceae	*Dipodium pulchellum* D.L.Jones & M.A.Clem.	Dark Hyacinth Orchid	Fleshy starchy thick roots are probably edible	Steenbeeke (2001)
Orchidaceae	*Dipodium punctatum* (Sm.) R.Br.	Blotched Hyacinth Orchid	Fleshy starchy thick roots are probably edible	Steenbeeke (2001)
Orchidaceae	*Dipodium roseum* D.L.Jones & M.A. Clem.	Pink Hyacinth Orchid	Fleshy starchy thick roots are probably edible	Steenbeeke (2001)
Orchidaceae	*Dipodium variegatum* M.A.Clem. & D.L.Jones	Spotted Hyacinth Orchid	Fleshy starchy thick roots are probably edible	Steenbeeke (2001)
Orchidaceae	*Disa engleriana* Kraenzl.	NF	Tubers process into a meatless sausage called chikande and Kikande which is consumed as relish or as snack	Kasulo et al. (2009)
Orchidaceae	*Disa aequiloba* Summerh.	Chikanda Mbozi	Tubers edible	Nyomoro (2009)
Orchidaceae	*Disa erubescens* Rendle	Liseki, Liseku, Makaha Ga Mlutu, Masekele, Masekeni, Masekendi, Mbozi	Starchy tubers used for making salep flour, chikande meatless sausage	Mapunda (2007), Challe and Price (2009), Nyomoro (2009), and Hamisy (2010)
Orchidaceae	*Disa fragrans* Schltr.	NF	Tubers processed into meatless sausage kikande	Hamisy (2010)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Disa hamatopetala* Rendle = *Disa baurii* Bolus	Baur's Disa, Ntetemera	Tubers processed into meatless sausage kikande	Hamisy (2010)
Orchidaceae	*Disa ochrostachya* Reichb.f.	NF	As above	Mapunda (2007) and Hamisy (2010)
Orchidaceae	*Disa robusta* N.E.Br.	Chukande Kijike, Likose, Liisek, Manseke, Makaha Ga Mlutu, Masekele, Masekeni Makaha Ga Mlutu, Masekele, Masekeni Makaha Ga Mlutu, Masekele, Masekeni	As above	Mapunda (2007), challe and price (2009), Kasulo et al. (2009), and Hamisy (2010)
Orchidaceae	*Disa tanganyikensis* Summerh.	Chikanda Makete	Tubers edible	Nyomora (2009)
Orchidaceae	*Disa ukingensis* Schltr.	NF	Tubers processed into meatless sausage kikande	Hamisy (2010)
Orchidaceae	*Disa walleri* Rchb.f.	Chikanda Mbeya, Masekelesekele Njombe	Tubers edible	Nyomora (2009)
Orchidaceae	*Disa zombica* N.E.Br.	NF	Tubers processed into meatless sausage kikande	Kasulo et al. (2009) and Hamisy (2010)
Orchidaceae	*Diuris abbreviata* F. Muell. ex Benth.	Lemon Doubletail	Fleshy starchy tubers edible	Steenbeeke (2001)
Orchidaceae	*Diuris alba* R.Br.	White Donkey Orchid	Fleshy starchy tubers edible	Steenbeeke (2001)
Orchidaceae	*Diuris chrysantha* D.L.Jones & M.A.Clem.	Yellow Donkey Orchid	Fleshy starchy tubers edible	Steenbeeke (2001)
Orchidaceae	*Diuris dendrobioides* Fitzg.	Purple Donkey Orchid	Fleshy starchy tubers edible	Steenbeeke (2001)
Orchidaceae	*Diuris goonooensis* Rupp	Western Donkey orchid	Fleshy starchy tubers edible	Steenbeeke (2001)
Orchidaceae	*Diuris lanceolata* Lindl.	Golden Moths, Snake Orchid	Fleshy starchy tubers edible	Steenbeeke (2001)
Orchidaceae	*Diuris pedunculata* R.Br.	Golden Moths, Small Snake Orchid	Fleshy starchy tubers edible	Steenbeeke (2001)
Orchidaceae	*Diuris punctata* Sm.	Purple Donkey Orchid	Fleshy starchy tubers edible	Steenbeeke (2001)
Orchidaceae	*Diuris semilunata* Messmer	Donkey Orchid, Late Leopard Orchid, Spotted Doubletail Orchid	Starchy tubers edible	Cribb and Cribb (1987), Low (1989), and Low (1991)
Orchidaceae	*Diuris striata* Rupp	NF	Fleshy starchy tubers edible	Steenbeeke (2001)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Diuris sulphurea* R.Br	Hornet Orchid, Tiger Orchid, Yellow Tiger Orchid	Starchy tubers edible	Anonymous (2010a, b), Anonymous (2011), Cribb and Cribb (1987), Low (1989), Low (1991), and Steenbeeke (2001)
Orchidaceae	*Diuris tricolor* Fitzg.	Tricolor Donkey Orchid	Fleshy starchy tubers edible	Steenbeeke (2001)
Orchidaceae	*Diuris venosa* Rupp	Veined Doubletail, Veined Donkey Orchid, Goat Orchid	Fleshy starchy tubers edible	Steenbeeke (2001)
Orchidaceae	*Epipactis royleana* Lindl.	Chhasakrungai	Boiled roots eaten	Sotirov (2015)
Orchidaceae	*Eriochilus cucullatus* (Labill.) Rchb.f.	Smooth-Leaf Parson's Bands, Large Parson's-Bands	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Eulophia schweinfurthii* Kraenzl.	Ndulamo, Lisesa	Starchy tubers used for making salep flour, chikanda meatless sausage	Mapunda (2007), Challe and Price (2009) and Hamisy (2010)
Orchidaceae	*Gastrodia procera* G.W. Carr	Large Potato Orchid, Large Cinnamon Bells	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Gastrodia sesamoides* R.Br.	Potato Orchid, Cinnamon Bells	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Genoplesium archeri*	Vriable Midge Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Genoplesium filiforme* (Fitzg.) D.L.Jones & M.A.Clem.	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Genoplesium fimbriata* (R.Br.) D.L.Jones & M.A.Clem.	Fringed Midge Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Genoplesium nudiscapum* (Hook.f.) D.L.Jones & M.A.Clem.	Dense Midge Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Genoplesium nudum* (Hook.f.) D.L.Jones &	Tiny Midge Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Genoplesium pedersonii* D.L.Jones	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Genoplesium rufum* (R.Br.) D.L.Jones & M.A.Clem.	Red Midge Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Glossodia major* R.Br.	Large Waxlip Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Habenaria adolphii* Schultr.	Chinkanda, Vinying'inya, Songea	Tubers edible	Nyomora (2009)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Habenaria clavata* (Lindl.) Rchb. f.	Copper Plant	Tubers process into a meatless sausage called chikande and Kikande which is consumed as relish or as snack	Kasulo et al. (2009)
Orchidaceae	*Harbenaria cornuta* Lindl.	Chikanda	Tubers edible	Nyomora (2009)
Orchidaceae	*Habenaria humilior* Rchb.f.	Chikanda	Tubers edible	Nyomora (2009)
Orchidaceae	*Habenaria intermedia* D. Don	Intermediate Habenaria	Boiled roots eaten	Sotirov (2015)
Orchidaceae	*Habenaria keayi* Summerh.	NF	Tubers and roots are used to prepare a food called "napssié" or ground meat by the Bagam tribe in the subdivision of Galim, Western region of Cameroon	Menzepoh (2011)
Orchidaceae	*Habenaria praestans* Rendle	Chikanda Mbeya	Tubers edible	Nyomora (2009)
Orchidaceae	*Habenaria xanthochlora* Schltr.	Mamkumungu, Manseke, Mansekemakubwa, Mviringo, Likose, Liseke	Starchy tubers used for making chikanda meatless sausage	Challe and Price (2009) and Hamisy (2010)
Orchidaceae	*Habenaria zambesina* Rchb.f.	NF	As above	Menzepoh (2011)
Orchidaceae	*Himantoglossum affine* (Boiss.) Schltr.	NF	Starchy tubers used for making salep flour used in ice-cream production, confectionery and nutritious beverages	Sezik (1967), Sezik and Özer (1983) cited by Tekinşen and Güner (2010) and Ghorbani et al. (2014)
Orchidaceae	*Himantoglossum comperianum* (Steven) Delforge	Komper's Orchid	As above	Ghorbani et al. (2014)
Orchidaceae	*Malaxix cylindrostachy* (Lindl.) Kuntze	Cylindric Raceme Malaxis	Boiled roots eaten	Sotirov (2015)
Orchidaceae	*Neotinea maculata* (Desf.) Stearn	Dense-Flowered Orchid	Starchy tubers used for making salep flour used in ice-cream production, confectionery and nutritious beverages	Sezik (2002)
Orchidaceae	*Ophrys climacis* Heimeier & Perschke	NF	Starchy tubers used for making salep flour used in ice-cream production, confectionery and nutritious beverages	Deniz (2013)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Ophrys fusca* Link	Sombre Bee-Orchid, Dark Bee-Orchid	As above	Sezik (1967) and Sezik and Özer (1983) cited by Tekinşen and Güner (2010)
Orchidaceae	*Ophrys holosericea* (Burm. f.) Greuter	Late Spider Orchid	As above	Sezik (1967) and Sezik and Özer (1983) cited by Tekinşen and Güner (2010)
Orchidaceae	*Ophrys isaura* Renz & Taubenheim	NF	As above	Deniz (2013)
Orchidaceae	*Ophrys lycia* Renz & Taubenheim	Bee Orchid	As above	Deniz (2013)
Orchidaceae	*Ophrys mammosa* Desf.	Early Spider Orchid	As above	Tekinşen and Güner (2010)
Orchidaceae	*Ophrys phaseliana* D.Rückbr. & U.Rückbr	Sawfly Orchid	As above	Deniz (2013)
Orchidaceae	*Ophrys scolopax* Cav.	Woodcock Bee-Orchid, Woodcock Orchid	As above	Ghorbani et al. (2014)
Orchidaceae	*Ophrys sphegodes* Mill.	Early Spider Orchid	As above	Ghorbani et al. (2014)
Orchidaceae	*Ophrys sphegodes* subsp. *mammosa* (Desf.) Soó ex E.Nelson	NF	As above	Ghorbani et al. (2014)
Orchidaceae	*Orchis adenocheila* Czerniak	NF	As above	Ghorbani et al. (2014)
Orchidaceae	*Orchis anatolica* Boiss.	Anatolian Orchid	As above	Tekinşen and Güner (2010) and Citil and Tekinşen (2011)
Orchidaceae	*Orchis anthropophora* (L.) All.	Man Orchid	As above	Kreziou et al. (2015)
Orchidaceae	*Orchis conopea Gras* = *Gymnadenia conopsea (L.) R.Br.*	Fragrant Orchid	As above	Grieve (1971)
Orchidaceae	*Orchis coriophora* L. = *Anacamptis coriophora* (L.) R.M. Bateman, Pridgeon & MW Chase	Fragrant Orchid	As above	Grieve (1971), Tekinşen and Güner (2010), and Citil and Tekinşen (2011)
Orchidaceae	*Orchis italica* Poir	Naked Man Orchid, Italian Orchid	As above	Tekinşen and Güner (2010), Citil and Tekinşen (2011), and Kreziou et al. (2015)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Orchis latifolia* L. = *Dactylorhiza incarnata* (L.) Soó	Early Marsh Orchid	As above	Grieve (1971)
Orchidaceae	*Orchis longicruris* Link = *Orchis italica* Poir.	Naked Man Orchid	As above	Grieve (1971)
Orchidaceae	*Orchis maculata* L. = *Dactylorhiza maculata* (L.) Soó	Heath Spotted Orchid	As above	Grieve (1971)
Orchidaceae	*Orchis mascula (L.)L.*	Early Purple Orchid	Starchy tubers used for salep production	Ghorbani et al. (2014)
Orchidaceae	*Orchis mascula* subsp. *pinetorum* (Boiss. & Kotschy) E.G.Camus = *Orchis mascula* subsp. *mascula*	Early Purple Orchid	As above	Sezik (1967), Sezik and Özer (1983) cited by Tekinşen and Güner (2010), Grieve (1971), Hawkes (1944), and Kreziou et al. (2015)
Orchidaceae	*Orchis militaris* L.	Military Orchid	As above	Hawkes (1944), Grieve (1971), and Kreziou et al. (2015)
Orchidaceae	*Orchis morio* L = *Anacamptis morio* (L.) R.M. Bateman, Pridgeon & MW Chase	Green-Winged Orchid Green-Veined Orchid	As above	Hawkes 1944, Grieve 1971, and Tekinşen and Güner (2010), Citil and Tekinşen (2011)
Orchidaceae	*Orchis palustris* Jacq. = *Anacamptis palustris* (Jacq.) R.M. Bateman, Pridgeon &MW Chase	Toothed Orchid, Three-Toothed Orchid	As above	Tekinşen and Güner (2010) and Citil and Tekinşen (2011)
Orchidaceae	*Orchis provincialis* Balbis ex Lamarck & DC.	Provence Orchid, Orchis De Provence	As above	Kreziou et al. (2015)
Orchidaceae	*Orchis pyramidalis* L. = *Anacamptis pyramidalis* (L.)Rich.	Pyramidal Orchid	As above	Grieve (1971)
Orchidaceae	*Orchis saccifera Brong.* = *Dactylorhiza saccifera* (Brongn.) Soó.	NF	As above	Grieve (1971)
Orchidaceae	*Orchis simia* Lam	Monkey Orchid	As above	Tekinşen and Güner (2010) and Ghorbani et al. (2014)
Orchidaceae	*Orchis spitzelii* Saut. ex W.D.J.Koch	L'orchis De Spitzel	As above	Sezik (1967), Sezik and Özer (1983) cited by Tekinşen and Güner (2010)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Orchis tridentata* Scop. = *Neotinea tridentata* (Scop.) R.M. Bateman, Pridgeon MW Chase	Three-Toothed Orchid	Starchy tubers used for making salep flour used in ice-cream production, confectionery and nutritious beverages	Tekinşen and Güner (2010) and Citil and Tekinşen (2011)
Orchidaceae	*Orchis ustulata* L. = *Neotinea ustulata* (L.) R.M.Bateman, Pridgeon & M.W.Chase.	Burnt-Tip Orchid	As above	Grieve (1971)
Orchidaceae	*Orthoceras strictum* R.Br.	Horned Orchid, Birds's Mouth Orchid	Tuberoids probably edible	Steenbeeke (2001)
Orchidaceae	*Peristylus constrictus* Lindley) Lindley	Constricted Peristylus	Tubers eaten	Sotirov (2015)
Orchidaceae	*Platanthera calvigera* Lindl	Club Carrying Platanthera	Boiled roots eaten	Sotirov (2015)
Orchidaceae	*Platanthera bifolia (*L.) L.C.Rich	Lesser Butterefly Orchid	Starchy tubers used for making salep production	Ghorbani et al. (2014)
Orchidaceae	*Prasophyllum brevilabre* (Lindl.) Hook.f.	Short-Lipped Leek Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Prasophyllum campestre* R.J.Bates & D.L.Jones	Starry Leek Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Prasophyllum caudiculum* D.L. Jones	Ben Lomond Leek Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Prasophyllum dossenum* J.Bates & D.L.Jones	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Prasophyllum elatum* R.Br.	Tall Leek Orchid, Piano Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Prasophyllum flavum* R.Br.	Yellow leek Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Prasophyllum odoratum* R.S.Rogers	Scented Leek Orchid, Sweet Leek Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Prasophyllum patens* R.Br.	Broad-Lipped Leek Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Prasophyllum rogersii* Rupp	Marsh Leek Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Prasophyllum solstitium* R.J.Bates & D.L.Jones	Summer Leek Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Prasophyllum* species A	Tablelands Leek Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pteroglossaspis eustachya* Rchb.f.	Mbozi	As above	Nyomora (2009)
Orchidaceae	*Pterostylis abrupta* D.L.Jones	Abrupt Greenhood, Drooping Greenhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis alata* (Labill.) Rchb.f.	NF	Tubers edible	Steenbeeke 2001
Orchidaceae	*Pterostylis bicolor* M.A.Clem. & D.L.Jones	Two-Colour Greenhood	Tubers edible	Steenbeeke 2001

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Pterostylis boormanii* M.A.Clem. & D.L.Jones Rupp	Boorman's Greenhood	Tubers edible	Steenbeeke 2001
Orchidaceae	*Pterostylis chaetophora* M.A.Clem. & D.L.Jones	Hair-Lip Ruddyhood	Tubers edible	Steenbeeke 2001
Orchidaceae	*Pterostylis coccina* Fitzg.	Alpen Greenhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis curta* R. Br	Blunt Greenhood	Tubers edible	Anonymous (2010a, b) and Steenbeeke (2001)
Orchidaceae	*Pterostylis cycnocephala* Fitzg.	Swan Greenhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis daintreana* F.Muell. ex Benth.	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis decurva* R.S. Rogers	Summer Greenhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis fischii* Nicholls	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis hamata* Blackmore & Clemesha	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis hildae* Nicholls	Rainforest Greenhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis laxa* Blackmore	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis longicurva* Rupp	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis longifolia* R.Br.	Tall Greenhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis longipetala* Rupp	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis mutica* R.Br.	Midget Greenhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis nutans* R.Br.	Nodding Greenhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis obtusa* R.Br.	Jug-Lip Greenhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis parviflora* R.Br.	Tiny Greenhood, Jug Orchid, Green Snail Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis pedunculata* R.Br.	Maroonhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis praetermissa* M.A.Clem. & D.L.Jones	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis reflexa* R.Br.	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis setifera* M.A. Clem.	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis* species B	NF	Tubers edible	Steenbeeke (2001)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Pterostylis* species C	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis* species D	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis truncate* Fitzg.	Little Dumpies, Sasauge Greenhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Pterostylis woollsii* Fitzg.	Long-Tailed Greenhood, Chinaman Greenhood	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Roeperocharis wentzeliana* Kraenzl	Kaloba, Masekel	Tubers process into a meatless sausage called *chikande*	Challe and Price (2009) and Hamisy (2010)
Orchidaceae	*Satyrium acutirostrum* Summerh.	Chikande	As above	Hamisy (2010)
Orchidaceae	*Satyrium amblyosaccos* Schltr.	NF	Tubers process into a meatless sausage called *chikande* and *kikande*, which is consumed as relish or as snack	Kasulo et al. (2009)
Orchidaceae	*Satyrium atherstonei* Rchb.f. = *Satyrium trinerve* Lindl.	Chikande Ligos, Ingingi, Jike, Lidala, Lisekejike, Lisekeni, Lisekenilidala, Madala, Masekenimadala, Numbunumbu, Sidala, Visekenividala, Vijike	Starchy tubers used for making salep flour, chikanda meatless sausage	Mapunda (2007), Challe and Price (2009) and Hamisy (2010)
Orchidaceae	*Satyrium breve* Rolfe	Chikande	Tubers edible	Nyomora (2009)
Orchidaceae	*Satyrium buchananii* Schltr.	Dochamua, Ligosi, Likosi, Lisekedochamua, Lisekedume, Lisekekiume, Magosi, Masekenidume, Masekeni magosi, Sisekeni sigosi, Titisigosi, Visekenivikhosi, Visekenivigosi	Tubers process into a meatless sausage called *chikande* and *kikande*,which is consumed as relish or as snack, starchy tubers used for making salep flour	Mapunda (2007), Kasulo et al. (2009) and Hamisy (2010)
Orchidaceae	*Satyrium carsonii* Rolfe	NF	Tubers process into a meatless sausage called *chikande* and *kikande*, which is consumed as relish or as snack	Kasulo et al. (2009)
Orchidaceae	*Satyrium chlorocorys* Rolfe	Chikanda Jike Rukwa	Tubers edible	Nyomora (2009)
Orchidaceae	*Satyrium crassicaule* Rendle	Chikanda, Kikande, Makete, Simbegi	Tubers process into a meatless sausage called *chikande* and *kikande*, which is consumed as relish or as snack	Nyomora (2009) and Hamisy (2010)
Orchidaceae	*Satyrium nepalense* D.Don	Nepal Satyrium	Pseudobulbs eaten boiled	Sotirov (2015)
Orchidaceae	*Satyrium robustum* Schltr.	Kidume	Tubers processed into meatless sausage kikande	Hamisy (2010)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Orchidaceae	*Satyrium sacculatum* (Rendle) Rolfe	Chikanda, Kikande, Masehelesehele, Vikan, Dokando, Songea	Tubers edible	Nyomora (2009)
Orchidaceae	*Satyrium volkensii* Schltr.	Volkens 'Satyrium	Tubers processed into meatless sausage kikande	Hamisy (2010)
Orchidaceae	*Serapias vomeracea ssp. orientalis Grueter* = *Serapias orientalis* (Greuter) H. Baumann & Künkele	NF	Starchy tubers used for making salep	Tekinşen and Güner (2010), Citil and Tekinşen (2011), Sezik (1967), Sezik and Özer (1983) cited by Tekinşen and Güner (2010)
Orchidaceae	*Steveniella satyrioides* (Spreng.) Schltr	NF	Starchy tubers used for making salep	Ghorbani et al. (2014)
Orchidaceae	*Thelymitra carnea* R.Br.	Tiny Sun Orchid, Pink Sun Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Thelymitra circumsepta* Fitzg.	Naked Sun Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Thelymitra cyanea* (Lindl.) Benth.	Veined Sun Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Thelymitra fragrans* D.L.Jones & M.A.Clem.	NF	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Thelymitra megacalyptra* Fitzg.	Scented Sun Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Thelymitra nuda* R.Br.	Plain Sun Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Thelymitra pauciflora* R.Br.	Slender sun Orchid	Tubers edible	Steenbeeke (2001)
Orchidaceae	*Tipularia discolour* (Pursh) Nuttall	Crane Fly Orchid, Crippled Cranefly Orchid	Starchy corm eaten	Sotirov (2015)
Oxalidaceae	*Oxalis corymbosa* DC. = *Oxalis debilis* var. *corymbosa* (DC.) Lourteig.	Pink Shamrock	Sweet crisp swollen tap root eaten	Cribb and Cribb (1987)
Oxalidaceae	*Oxalis deppei* Lodd. ex Sweet	Orach, Deppei Wood Sorrel	Fleshy root eaten boiled in Mexico	Fernald et al. (1985) and Facciola (1990)
Oxalidaceae	*Oxalis perennans* Haw.	Grassland Wood Sorrel	Small tap roots eaten by aborigines	Low (1991)
Oxalidaceae	*Oxalis radicosa* A.Rich. = *Oxalis corniculata* L.	Dwarf Wood Sorrel	Small tap roots eaten by aborigines	Low (1991)
Oxalidaceae	*Oxalis* sp.	Wood Sorrel	Small tap roots eaten by aborigines	Low (1991)
Oxalidaceae	*Oxalis stricta* L.	Yellow Wood Sorrel	Roots edible	Yanovsky (1936), Uphof (1968), and Facciola (1990)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Oxalidaceae	*Oxalis tuberosa* Molina	Oca	Tubers eaten boiled, roasted or candied, one of the principal food crop of the Indians in the Andes, second to potato, tubers can be eaten unpeeled, raw, in salads, pickled, boiled, fried or in soups and stews. Also can be dried in sun to sweeten up	Facciola (1990), Groen et al. (1996), Flores et al. (2003), van Wyk (2006), and Santich et al. (2008),
Oxalidaceae	*Oxalis violacea* L. = *Oxalis debilis* var. *corymbosa* (DC.) Lourteig.	Violet Wood Sorrel	Roots edible	Yanovsky (1936) and Facciola (1990)
Piperaceae	*Piper methysticum* L.f.	Kava, Kava Kava, Awa, Kava Pepper	The root and rhizome (underground stem) of kava are used to prepare beverages, extracts, capsules, tablets and topical solutions. Kava is widely and commonly consumed as a social beverage to establish kinship in the Pacific island communities	McDonald and Jowitt (2000) and NCAM (2006)
Poaceae	*Agropyron repens* (L.) P. Beauv. = *Elymus repens* (L.) Gould	English Couch, Quick Grass	Roots ground into a meal and used to make bread	Cribb and Cribb (1987)
Poaceae	*Bambusa pallida* Munro	Mokal Bah (Assamese); Mai Phiu, Phai Song Kham (Thai)	Young rhizomes are eaten as vegetable after processing	Patiri and Borah (2007)
Poaceae	*Bambusa tulda* Roxb.	Spineless Indian Bamboo, Calcutta Cane; Jati Bah (Assamese)	As above	Patiri and Borah (2007)
Poaceae	*Chrysopogon zizanioides* (L.) Roberty	Vetiver Grass, Khas-Kahs, Khus Grass	Vetiver is used domestically in cooking; it's infused in tea and also used in baking	Balasankar et al. (2013)
Poaceae	*Eleusine indica* (L.) Gaertn.	Indian Goosegrass, Wiregrass, Crowfootgrass	Roots edible raw	Kunkel (1984)
Poaceae	*Hordeum bulbosum* L.	Abu Suwaif	Bulbous roots chewed and eaten occasionally	Tanaka (1976) and Facciola (1990)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Poaceae	*Imperata cylindrica* L.	Blady Grass, Alang-Alang, Lalang Wooly Grass	Aborigine children sucked the roots, underground shoots like sugarcane, used as survival food, a kind of beer is made from the roots in Peninsular Malaysia China: fresh rhizome chewed by rural people for the sweet juice	Burkill (1966), Cribb and Cribb (1987), Low (1991), and Hu (2005)
Poaceae	*Phragmites australis* (Cav.) Trin. Ex Steud.	Common Reed Grass	Rhizomes coked like potatoes	Tanaka (1976), Fernald et al. (1985), and Facciola (1990)
Poaceae	*Saccharum spontaneum* L.	Wild Cane, Wild Sugarcane, Fodder Cane; Khagori (Assamese); Mojora (Mishing)	Young shoots and rhizomes are eaten as sugarcane, sweet in taste	Patiri and Borah (2007)
Poaceae	*Triticum repens* L. = *Elymus repens* (L.) Gould.	Couch Grass, Twitch, Quick Grass, Quitch Grass, Dog Grass	In Norway, roots ground into flour	Sayce (1953)
Poaceae	*Vetiveria nigritana* (Benth.) Stapf = *Chrysopogon nigritanus* (Benth.) Veldkamp.	Black Vetiver grass; Jema (Huasa)	Nigeria (Kano State, northern): roots eaten.	Mortimore (1989)
Poaceae	*Vetiveria zizanioides* (L.) Nash = *Chrysopogon zizanioides* (L.) Roberty.	Vetiver Grass, Khas-Khas Grass, Akar Wangi (Malay)	Roots used to prepare sherbets or soft drinks during summer in Nothern India. Vetiver oil is used for flavouring syrups, ice-cream and food preservation. Khus essence is used in cool drinks, for reducing pungency of chewing tobacco preparations and to provide sweet note to other masticatories	Pareek and Kumar (2013) and Balasankar et al. (2013)
			Vetiver roots is used domestically in cooking; it's infused in tea and also used in baking	
Poaceae	*Zizaniopsis miliacea* (Michx.) Döll & Asch.	Water Millet, Southern Wild Rice	Young rhizome, cut into pieces cooked and served with butter	Gibbons and Tucker (1979), Fernald et al. (1985), and Facciola (1990)

(continued)

Table 1 (continued)

Family	Scientific Name	Common/Vernacular Names	Edible Part Use	Reference
Rubiaceae	*Ixora subsessilis* Wall. ex G.Don	Dieng Jowat (Meghalaya); Nang Guo Long Chuan Hua (Chinese)	Flower, shoot, root eaten in Meghalaya	Sawian et al. (2007)
Rubiaceae	*Morinda officinalis* F.C. How	Chinese Herbal Morinda, Medicinal Indian Mulberry, Morinda Root	In China, fresh or dried roots are cooked with pork for a broth as health food called Chinese bupin (Hu 2005). In South China, Hong Kong and Macao, this plant has been developed into various health foods, such as 'Ba-ji-tian wine', 'Ba-ji-zi-bu Gao' (Li et al. 2009)	Hu (2005), Li et al. (2009)
Rubiaceae	*Paederia foetida* L.	Rekang Nemthu	Roots eaten in Karbi Assam	Kar and Borthakur (2008)
Rubiaceae	*Paederia stenobotrya* Merr.	White Paedaria	Root ground with soaked soybean for a milk, cooked and given to people with jaundice	Hu (2005)
Simaroubaceae	*Eurycoma longifolia* Jack	Tongkat Ali (Malay)	Traditional users of *Tongkat* Ali brew *tea* from the dried chips of the tree's root. Tea, coffee and carbonated beverages, pre-mixed with the root extract are available commercially for the improvement of general health and libido in Malaysia	Low et al. (2013)

NF not found

is processed into nutritious and wholesome beverages, confectionary and ice-cream. Salep is especially popular in Middle East and some parts of Europe. The major salep producing orchid species are from the genera *Anacamptis*, *Orchis*, *Ophrys*, *Disa*, *Dactylorhiza* and *Himantoglossum.* In Africa, edible orchid tubers are collected from the wild and processed into a meatless sausage locally called *chinaka*, *chikande* and *kikande*, which is consumed as relish or just as a snack (Kasulo et al. 2009). The tubers are also used in soups which are reported to be served in some international tourist hotels (Hamisy 2010). The main orchid species used for this purpose are from the genera *Disa, Habenaria* and *Satyrium.* Many species in the orchid genera *Pterostylis, Diuris* and *Thelymitra* have edible tubers. Other orchid species with edible roots and tubers are listed in Table 1.

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Iris x germanica

Scientific Name

***Iris x germanica* L.**

Synonyms

Iris × *alba* Savi, *Iris* × *amoena* DC., *Iris* × *atroviolacea* Lange, *Iris* × *australis* Tod., *Iris* × *belouinii* Bois & Cornuault, *Iris* × *biliottii* Foster, *Iris* × *buiana* Prodán, *Iris* × *buiana* var. *virescens* Prodán, *Iris* × *croatica* Prodán, *Iris* × *croatica* Horvat & M.D.Horvat (Illeg.), *Iris* × *cypriana* Foster & Baker, *Iris* × *deflexa* Knowles & Westc., *Iris* × *florentina* L., *Iris* × *florentina* var. *pallida* Nyman, *Iris* × *florentinoides* Prodán ex Nyar., *Iris* × *germanica* var. *alba* Dykes, *Iris* × *germanica* var. *amas* Dykes, *Iris* × *germanica* var. *askabadensis* Dykes, *Iris* × *germanica* var. *australis* (Tod.) Dykes

Iris × *germanica* var. *florentina* (L.) Dykes, *Iris* × *germanica* var. *fontarabie* Dykes, *Iris* × *germanica* var. *gypsea* Rodigas, *Iris* × *germanica* var. *kharput* Dykes, *Iris* × *germanica* var. *lurida* (Aiton) Nyman, *Iris* × *germanica* var. *nepalensis* (Wall. ex Lindl.) Herb., *Iris* × *germanica* var. *sivas* G.Nicholson, *Iris* × *humei* G.Don, *Iris* × *laciniata* Berg, *Iris* × *latifolia* Gilib. (Inval.), *Iris* × *lurida* Aiton, *Iris* × *macrantha* Simonet, *Iris* × *mesopotamica* Dykes, *Iris* × *murorum* Gaterau, *Iris* × *neglecta* Hornem., *Iris* × *nepalensis* Wall. ex Lindl., *Iris* × *nostras* Garsault (Inval.), *Iris* × *nyaradyana* Prodán, *Iris* × *officinalis* Salisb., *Iris* × *pallida* Ten. (Illeg.), *Iris pallida* subsp. *australis* (Tod.) K.Richt., *Iris* × *piatrae* Prodán, *Iris* × *redouteana* Spach, *Iris* × *repanda* Berg, *Iris* × *rothschildii* Degen, *Iris* × *sambucina* L., *Iris* × *spectabilis* Salisb., *Iris* × *squalens* L., *Iris* × *squalens* var. *biflora* Prodán & Buia, *Iris* × *squalens* var. *rosea* Prodán & Buia, *Iris* × *superba* Berg, *Iris* × *tardiflora* Berg, *Iris* × *trojana* A.Kern. ex Stapf, *Iris* × *varbossania* K.Malý, *Iris variegata* var. *lurida* (Aiton) Nyman, *Iris* × *venusta* J.Booth ex Berg, *Iris* × *violacea* Savi, *Iris* × *vulgaris* Pohl

Family

Iridaceae

Common/English Names

Bearded Iris, Common Orrisroot, Flag, Florentine Orris, Florentine Iris, Garden Iris, German Iris, German Orrisroot, Iris, Orris, Orrisroot, Purple Flag, Queen Elizabeth Root, Tall Bearded German Iris, Tall Bearded Iris

Vernacular Names

Arabic: Irsa

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Chinese: Déguó Yuānwěi
Czech: Kosatec Německý
Danish: Have-Iris, Iris, Sværdlilie
Dutch: Blauwe Lis, Duitse Lis, Duitse Lis Sort, Lis Sort
Esperanto: Irido Ĝardena, Irido Germana
Estonian: Aediiris
Finnish: Saksankurjenmiekka, Sininen Kurjenmiekka
French: Flambe, Iris, Iris Allemande, Iris d'Allemagne, Iris Germanique
German: Deutsche Schwertlilie, Echte Schwertlilie, Gelbe Schwertlilie, Himmelschwertel, Ritter-Schwertlilie, Türk Schwertlilie
Hungarian: Kerti Nőszirom, Kék Nőszirom, Nepáli Nőszirom
India: Puskaramulam (Malayalam), Kombirei (Manipuri), Haimavati, Mulam, Padma-Pushkara, Parasikavaca, Puskaramulam (Sanskrit)
Italian: Giaggiolo Paonazzo, Giaggiolo Maggiore
Japanese: Ayame, Hanashoubu, Kakitsubata
Korean: Ailiseu Germanica
Persian: Bikh-I-Banafshah
Polish: Kosaciec Bródkowy, Kosaciec Niemiecki, Kosaciec Ogrodowy
Portuguese: Lírio-Cardano, Lírio-Cardeno, Lírio-Da-Alemanha, Lírio-Germânico, Lírio-Roxo
Slovaščina: Bradata Perunika, Nemška Perunika, Perunika Nemška
Slovencina: Kosatec Nemecký
Spanish: Iris, Lirio Cardeno, Lirio Común
Swedish: Trädgårdsiris
Thai: Māntā Germanica
Tibetan: Su Dag Dkar Po
Turkish: Mor Süsen, Navruzu, Türk Süzeni
Vietnamese: Diên Vỹ German hoa tím
Welsh: Gellesgen Farfog

Origin/Distribution

*I. x germanic*a probably originated in central southern Europe and the Balkan Peninsula. *Iris germanica* is considered to be a natural and fertile hybrid between *I. pallida* and *I. variegata* L., both of which also have the chromosome number $2n = 24$ (Henderson 1992, 2002).

Agroecology

Iris x germanica thrives in full sun, in fertile, well-drained, neutral to slightly acidic soil with pH 6–7. It needs light watering. It is widely grown as a garden ornamental in the temperate regions of Australia and has become naturalised along roadsides, in waste areas and in bushland.

Edible Plant Parts and Uses

Orrisroot is often included as one of the many ingredients of *Ras el hanout*, a blend of herbs and spices used across the Middle East and North Africa, primarily associated with Moroccan cuisine (Surhone et al. 2011). Peeled rhizomes of *I. germanica* (orrisroots) can be used as a flavouring in ice cream, confectionery and baked goods (Bender 2009). Orris is also an ingredient in many brands of gin. Orrisroot has been used in tinctures to flavour syrups; its taste is said to be indistinguishable from raspberry (Chase 1900). In France, starch of *I. germanica* root had been recommended a famine food for extending bread flour, after removal of the bitter element (Parmentier 1781, cited by Freedman 2009).

Botany

Iris x germanica is a rhizomatous, perennial herb, growing to 120 cm high, forming a large clump to 30 cm wide (Plate 1). Rhizomes are homogeneous, creeping on soil surface or to 10 cm depth, usually many-branched, light brown, 1.2–2 cm in diameter and smooth, with nodal rings; branches may arise in the fan or as many as 15–20 nodes are produced prior to active leaves. Stems are green, 2–3-branched, solid, 60–120 cm × 1–1.5 cm and glaucous. Leaves are purplish at base and folded midrib to base, glaucous, ensiform and 45 cm long by 3.5 cm wide. Inflorescences with

Plate 1 Orrisroot plant habit

terminal unit are 2–3-flowered, and branch units 1–2-flowered; spathes are green, sometimes with purple base, and 2–5 cm, with narrow, scarious margins and tip. For the flowers, the perianth has shades of blue-violet, yellow, brown or white (Plate 2) with various patterns of pigment distribution; floral tubes are 1–2.5 cm; sepals are spreading, drooping or reflexed and have shades of blue-violet, yellow, brown or white with patterned overlay of darker blue-violet, with white or yellow beard along midrib of claw and lower part of limb; obovate limbs taper gradually to claw, 6–7.5 by 4–5.5 cm; petals alternate with sepals and are erect and obovate, 5–7 by 4–5.5 cm, with short, 1.5–2 cm, channelled claw; the ovary is bluntly trigonal, 1.5–2.5 cm and slightly wider than floral tube. Capsules are bluntly angled, 3-lobed borne on ends of stems and branches and 3–5 × 2.5 cm containing reddish-brown, wrinkled, oval seeds, 3–4 mm in 2 rows per locule.

Nutritive/Medicinal Properties

Rhizome Phytochemicals

The following compounds were isolated from *I. germanica* rhizomes: irisolone (Dhar and Kalla 1972), 5,4′-dihydroxy-6,7-methylenedioxyisoflavone (irilone) (Dhar and Kalla 1973) and 2,4,6,4′-tetrahydroxybenzophenone (Dhar and Kalla 1974). Acetovanillon (4-hydroxy-3-methoxyacetophenon) and the known flavonoids irisolidone, irigenin, irisolone, tectorigenin and dihydroquercetin-7.3′-dimethylether were detected in *Iris germanica* rhizomes (Pailer and Franke 1973). Also, a few unknown compounds were isolated and their structure elucidated as 9-methoxy-7-(3′.4′.5′-trimethoxyphenyl)-8H-1.3-dioxolo[4.5-g] [1]-benzopyran-8-on (=5.3′.4′.5′-tetramethoxy-6.7-methylenedioxyisoflavone (III A); 9-methoxy-7-(3′.4′-dimethoxyphenyl)-8H-1.3-dioxolo[4.5-g] [1]-benzopyran-8-on (=5.3′.4′-trimethoxy-6.7-methylenedioxyisoflavone(III B); 9-hydroxy-7-(p-hydroxyphenyl)-8H-1.3-dioxolo[4.5-g] [1]-benzopyran-8-on (=5.4′-dihydroxy-6.7-methylenedioxyiosoflavone (IX); 5.7-dihydroxy-3-(3′-hydroxy-4′-methoxyphenyl)-6-methoxy-4H-1-benzopyran-4-on (=5.7.3′-trihydroxy-6.4′-dimethoxyisoflavone (XI B); 5.7-dihydroxy-3-(4′-hydroxy-3′-methoxyphenyl)-6-methoxy-4H-1-benzopyran-4-on (=5.7.4′-trihydroxy-6.3′-dimethoxyisoflavone (XI C). The ethanol rhizome extract of *I. germanica* afforded an isoflavone homotectoridin with the structure 5, 4′-dihydroxy-8, 3′-dimethoxyisoflavone-7-*O*-mono-D-glucoside and tectoridin (Kawase et al. 1973). Acetovanillon, irigenin and its glucoside iridin, *β*-sitosterol, *α*-amyrin and *β*-amyrin were isolated from the fresh rhizomes of *I. germanica* (El-Moghazzy et al. 1980). Bicyclic triterpenoids, *α*-irigermanal and *γ*-irigermanal, and a monocyclic triterpenoid, iridogermanal, were the major extractable lipids isolated from the rhizomes, constituting about 1 % of the fresh weight (Marner et al. 1982). From the rhizome, one new hexaoxygenated isoflavone, 5,3′-dihydroxy-4′,5′-dimethoxy-6,7-methylenedioxyisoflavone; two new polyox-

Plate 2 White flowers

ygenated isoflavone glucosides, 5-hydroxy-6,4′-dimethoxyisoflavone 7-glucoside and 5,3′-dihydroxy-4′,5′-dimethoxyisoflavone 7-glucoside; and the known isoflavonoids irisolidone, irigenin and iridin and acetovanillone, sitosterol, α-amyrin and β-amyrin were isolated (Ali et al. 1983).

Glucose content of *I. germanica* rhizomes, kept under anoxia (absence of oxygen), rapidly and dramatically decreased during the first 30 days and then increased at the same time as adenylate energy charge values started to decline (Hanhijarvi 1995). The amount of non-reducing sugars decreased gradually during the anoxic incubation. Under aerobic control conditions, adenylate energy charge (AEC) of *I. germanica* rhizome tissue was 0.81. Under anoxia the energy charge of *I. germanica* rhizome tissue remained above 0.6 for 4 days only. Large amounts of ethanol were found in anoxic rhizome (0.06 M) after 8 days. Long-lived free radicals were rapidly generated in *I. germanica* plant tissues when treated anoxically and subsequently returned to aerobic conditions (Crawford et al. 1994). The free radicals in *I. germanica* rhizomes were extracted into aqueous alkali and found to be flavonoids including quercetin, irisolone, selenone and derivatives of irigenin. The main flavonoids had more reduced and/or more alkylated structures than those from *I. germanica* grown under normal aerobic conditions. Semiquinone radical anions could readily be generated from quercetin, and similar flavonoids with 1,2-dihydroxy-, 1,4-dihydroxy- or trihydroxy-substitution patterns, by interaction with superoxide.

Three piscidal triterpenes named irisgermanicals A, B and C and seven known iridal-type tripenes, namely, iripallidal, iriflorental, α-irigermanal, γ-irigermanal, isoiridogermanal, 16-*O*-acetyl-isoirigermanal and α-dehydroirigermanal, were isolated (Ito et al. 1995). Iridal triterpenoids isolated from the rhizome included irisgermanicals A, B and C, isoiridogermanal, 16-*O*-acetylisoiridogermanal, a-irigermanal, g-irigermanal, a-dehydroirigermanal, iridal, iriflorental and iripallidal (Miyake et al. 1997). Four isoflavones glycoside iriskashmirianin 4′-*O*-β-D-glucoside, nigricin 4′-*O*-β-D-glucoside, irilone 4′-*O*-β-D-glucoside and iridin were isolated from the rhizomes (Atta-ur-Rahman et al. 2002). A monocyclic triterpene ester iristectorone K was isolated from the rhizomes of *Iris germanica* from Turkey (Orhan et al. 2002). Six known isoflavones, irisolidone, irisolidone 7-O-α-D-glucoside, irigenin, irilone, iriflogenin and iriskashmirianin, were isolated from *Iris germanica* rhizomes (Wollenweber et al. 2003). Five new di- and triglycosides, irigenin 7-[*O*-β-D-glucopyranosyl-(1 → 6)-β-D-glucopyranoside]; 6-hydroxygenistein 4′-[*O*-β-D-glucopyranosyl-(1 → 6)-β-D-glucopyranoside]; nigricin 4′-[*O*-β-D-glucopyanosyl-(1 → 6)-β-D-glucopyranoside]; nigricin 4′-[*O*-β-D-glucopyanosyl-(1 → 2)-*O*-[α-L-rhamnopyranosyl-(1 → 6)]-β-D-glucopyranoside]; and 7-4′-{[2″-*O*-(4‴′-acetyl-2‴′-methoxyphenyl)-β-D-glucopyranosyl]oxy}-3′-(β-D-glucopyranosyloxy)phenyl]-9-methoxy-8*H*-1,3-dioxolo[4,5-*g*]-[1 benzopyran-8-one-]

along with a known compound, nigricin 4′-(*β*-D-glucopyranoside), were isolated from *Iris germanica* rhizomes (Atta-ur-Rahman et al. 2003a). Nine isoflavonoids: 5,7-dihydroxy-3-(3′-hydroxy-4′,5′dimethoxy)-8-methoxy-4*H*-1-benzopyran-4-one; 5,7-dihydroxy-3-(3′-hydroxyl-4′, 5′-dimethoxy)-6-methoxy-4*H*-1-benzopyran-4-one; 5,7-dihydroxy-3-(4′-hydroxy)-6-methoxy-4*H*-1-benzopyrane-4-one; 5-hydroxy-3-(4′-hydroxy)-6,7-methylenedioxy-4*H*-1-benzopyran-4-one; 5-hydroxy-3-(4′-methoxy)-6,7-methylenedioxy-4*H*-1-benzopyran-4-one; 5-methoxy-3-(4′-hydroxy)-6,7-methyenedioxy-4*H*-1-benzopyran-4-one; 5,7-dihydroxy-3-(3′-hydroxy-4′-methoxy)-6-methoxy-4*H*-1-benzopyran-4-one; 5,7-dihydroxy-3-(3′-methoxy-4′-hydroxy)-6-methoxy-4*H*-1-benzopyran-4-one and isopeonol were isolated from the rhizome (Atta-ur-Rahman et al. 2003b). Five new di- and triglycosides, irigenin 7-[*O*-*β*-D-glucopyranosyl-(1 → 6)-*β*-D-glucopyranoside] (1);6-hydroxygenistein4′-[*O*-*β*-D-glucopyranosyl-(1 → 6)-*β*-D-glucopyranoside] (2); nigricin 4′-[*O*-*β*-D-glucopyanosyl-(1 → 6)-*β*-D-glucopyranoside] (3); nigricin 4′-[*O*-*β*-D-glucopyanosyl-(1 → 2)-*O*-[*α*-L-rhamnopyranosyl-(1 → 6)]-*β*-D-glucopyranoside] (4) and 7-{4′-{[2″-*O*-(4‴′-acetyl-2‴′-methoxyphenyl)-*β*-D-glucopyranosyl]oxy}-3′-(*β*-D-glucopyranosyloxy)phenyl]-9-methoxy-8*H*-1,3-dioxolo[4,5-*g*]-[1 benzopyran-8-one-] (5), along with a known compound, nigricin 4′-(*β*-D-glucopyranoside), were isolated from *Iris germanica* rhizomes (Nasim et al. 2003). Irigenin (5,7,3′-trihydroxy-6,4′,5′-trimethoxyisoflavone) and iristectorigenin A (5,7,3′-trihydroxy-6,4′-dimethoxyisoflavone) along with their 7-O-*β*-D-glucosides, iridin and iristectorin A, respectively, were found as the major components in adventitious roots in the liquid medium, and the total isoflavone content was about 3.6 µmol per g fresh weight in 3-week-old *I. germanica* cultures (Akashi et al. 2005). The total isoflavone content (glucosides + aglycones) at 6 h after the start of $CuCl_2$ treatment was 1.4-fold the initial value, and nearly the same content was maintained for 48 h. Thus, the main effect of $CuCl_2$ treatment appeared to be the induction of hydrolysis of isoflavone glucosides. Two novel compounds 5,2-dihydroxy-3-methoxy-6,7-methylenedioxyflavone and 5,7,2-trihydroxy-6-methoxyflavanone were isolated from the fraction B of the rhizome chloroform extract (Singab et al. 2006). The methanol extract of *Iris germanica* rhizome afforded one new compound, 6,6-ditetradecyl-6,7-dihydrooxepin-2(3H)-one and five known compounds, 1-(2-(6′-hydroxy-2′-methylcyclohex-1′-enyloxy)-5-methoxyphenyl) ethanone; 4-hydroxy-3-methoxyacetophenone; irisolone; irisolidone and 2-acetoxy-3,6-dimethoxy-1,4-benzoquinone (Asghar et al. 2009).

A total of 20 compounds identified as isoflavones, isoflavone glycosides and acetovanillone were isolated from the lipophilic and polar extracts of *Iris germanica* rhizomes (Schütz et al. 2011). A new isoflavone glycoside, iriflogenin-4′-O-gentiobioside, was isolated. Nine isoflavones (totalling 180 mg/g) were identified in *I. germanica* resinoid: irigenin, iristectorigenin A, nigricin, nigricanin, irisflorentin, iriskumaonin methyl ether, irilone, iriflogenin and irisolidone (Roger et al. 2012). The methanolic extract of *Iris germanica* rhizomes yielded two new compounds, irigenin S and iriside A, together with known compounds: stigmasterol, *α*-irone, *γ*-irone, 3-hydroxy-5-methoxyacetophenone, irilone, irisolidone, irigenin, stigmasterol-3-*O*-*β*-D-glucopyranoside, irilone 4′-O-*β*-D-glucopyranoside and iridin (Ibrahim et al. 2012). Two new compounds, 5-methoxy-3′,4′-dihydroxy-6,7-methylenedioxy-4*H*-1-benzopyran-4-one (iriskashmirianin A) and 5,3′-dihydroxy-3-(4′-*β*-D-glucopyranosyl)-6,7-methylenedioxy-4*H*-1-benzopyran-4-one (germanaism H), along with eight known compounds, namely, irilone, iriskumaonin methyl ether, iriflogenin, irisolone, irifloside, irilone 4′-*O*-*β*-glucopyranoside, germanaism A and germanaism B were isolated from the rhizomes (Xie et al. 2013). New ceramides irisamides A and B and isoflavone iridin S were isolated from the rhizome (Mohamed et al. 2013). The methanol extract of *Iris germanica* afforded a new benzene derivative 2′-methyl-6′-hydroxy cyclohexenyl-

3-methyl-1-acetophenone ether and another known benzene derivative isopenol together with two known isoflavones, irisolone and irisolidone (Asghar et al. 2010). Twenty-one compounds were isolated from the rhizomes of *Iris germanica* and identified as ombuin (1); 5, 3, 3′-trihydroxy-7, 4′-dimethoxyflavanone (2); naringenin (3); cirsiliol-4′-glucoside (4); 3*β*, 4′-dihydroxy-7,3′-dimethoxyflavonone-5-*O*-*β*-D--glucopyranoside (5); genistein (6); irilin D (7); muningin (8); 5, 7, 4′-trihydroxy-6, 3′, 5′-trimethoxyisoflavone (9); tectorigenin (10); irigenin (11); tectoridin (12); iridin (13); mangiferin (14); irisxanthone (15); pyroglutamic acid (16); 2, 4′, 6-trihydroxy-4-methoxybenzophenone-2-*O*-*β*-D-glucoside (17); apocynin (18); androsin (19); *β*-sitosterol (20); and daucosterol (21) (Xie et al. 2014).

Eleven compounds were identified in the petroleum ether extract (oil) of *I. germanica*: 9-hexadecanoic acid methyl ester; 9-octadecenoic acid methyl ester; 8-octadecenoic acid methyl ester; 11-octadecenoic acid methyl; 10-octadecenoic acid methyl ester; 13-octadecenoic acid methyl ester; 16-octadecenoic acid methyl ester; 1, 2-benzenedicarboxylic acid diisooctyl ester; bis(2-ethylhexyl) phthalate; methyl 6-methyl heptanoate; and nonanoic acid, 9-oxo-methyl ester (Asghar et al. 2011). Twenty-three compounds were identified in the essential oil of Syrian *Iris germanica* with myristic acid (61.42 %) as the major component (Almaarri et al. 2013). The other sub-major compounds obtained were elaidic acid methyl ester (9-octadecenoic acid methyl ester) (6.61 %), lauric acid (5.69 %), octadecanoic acid methyl ester (stearic acid methyl ester) (5.40 %), palmitic acid methyl ester (5.10 %) and palmitic acid (4.87 %). The minor compounds were linoleic acid methyl ester (1.19 %); linoleic acid (1.1 %); docosane (1.08 %);10-octadecenoic acid, methyl ester (0.7 %); 3-methyl-1,2-benzoisoselenazple (0.61 %); nonadecane (0.55 %); oleic acid (0.53 %); sulphurous acid,2-propyl tetradecyl ester (0.28 %); *α*-irone (0.25 %); 2-propenoic acid, 3-4(-methoxy-phenyl)-2ethyl-hexyl ester (0.16 %); 1,2-benzenedicarboxylic acid, dioctyl ester (0.15 %); decanoic acid (capric acid) (0.14 %); benzoic acid, 4-ethoxy-, ethylester (0.12 %); hexadecane (0.11 %); thiosulfuric acid, S-(2aminoethyl) ester (0.1 %); tetradecane (0.08 %); and decane (0.06 %).

Orrisroot is used as an aromatic agent. *Iris pallida* is the best for extractive purposes followed by *I. germanica* and *I. florentina* for botanical sources of orrisroot preparations (concrete, liquid, oil, root extract) (Fenaroli 1994). Orris absolute consists mainly of isomeric irones (Guenther 1952). Orris absolute (alcoholic extraction or distillation of orris concrete) was reported to have a yield of 0.03–0.05 % dried rhizome and to contain 55–58 % ketones (irones), free or partially esterified fatty acids (methyl myristate, methyl caprylate, methyl laurate, methyl oleate, methyl linoleate), aldehydes (oleic, benzoic), alcohols (benzylic), terpene and sesquiterpene (Burdock 1994). Orris resinoid (yield 1–3.3 %) was reported to contain 62–78 % ketones (irones) (Burdock 1994). Orris absolute prepared from *Iris x germanica* was reported to contain (Z)-*a*-irone (558.4–62.7 %), (*Z*)-*γ*-irone (32.2–36.9), (*E*)-*α*-irone (1.7–3.9 %) and (*Z*)-*β*-irone (0.4–2.3 %) and orris essential oil to contain (*Z*)-*α*-irone (57.6–66.2 %), (*Z*)-*γ*-irone (33.8–39.4 %), (*E*)-*α*-irone (0.5–2.7 %) and (*Z*)-*β*-irone (0–2.2 %) (Galfre et al. 1993). (+)-*cis*-*γ*-Irone and (+)-*cis*-*α*-irone were found to have the most interesting organoleptic properties. Orris essential oil is a cream-coloured solid and is often referred to as orris butter and often and erroneously referred to as orris concrete which is a dark, viscous material perhaps more correctly referred to as a resinoid.

Irones extracted from *Iris* species are aromatic principles used in the perfume and flavour industry to impart violet fragrance. Four major irone compounds (*trans α*-, *cis α*-, *cis γ*- and *β*-irones) had been described (Naves et al. 1947; Schinz et al. 1947; Jaenick and Marner 1990) as responsible for the characteristic scent of Iris oil. Natural irones (terpenoids) in essential oil of Iris rhizomes were found to be formed by oxidative degradation of other higher terpenes C31-triterpenoids produced by the plant (Krick et al. 1984). Triterpenoids called iridals were shown to be

irone precursors (Jaenick and Marner 1990). Iridals originated from C30 olefin squalene (Jaenick and Marner 1990, Marner et al. 1988; Marner 1997). The incorporation of [2-^{14}C]acetate, [2-^{14}C]mevalonate and [^{3}H]squalene proved the squalenoid nature of the iridals (Marner et al. 1988). Methionine was readily incorporated into cycloiridals of *Iris pallida dalmatica*, thus indicating that the methylation of iridals via S-adenosyl-L-methionine led to the formation of the irone moiety of the bicyclic compounds. The cycloiridals, C31-triterpenoids, also served as precursors of the irones (Marner et al. 1990). Since 1982, more than 25 different iridal structures were characterised (Jannick and Marner 1990, Abe et al. 1991; Marner and Kerp 1992) and separated into 3 classes monocycloiridals, bicycloiridals and spiroiridals. Rhizomes of both *I. pallida* varieties were found to contain 0.1–1.1 %, and *I. germanica* 0.1–0.5 % of iridals and their esters (Marner and Kerp 1992). Bonfils et al. (1996) found iridals were membrane located. Two triterpenoids iripallidal and iriflorental, known irone precursors, were found to be solubilised by phosphatidylcholine. These cycloiridals were found to be integrated within liposomal membranes and appeared to have a structural role within cells comparable to that of sterols. *Iris germanica* had high levels of (+)*cis*-*α*-irone and low content of *trans*-*α*-irone, while *I. pallida* had a high content of (-) *cis*-*α*-irone (Maurer et al. 1989; Firmin et al. 1998). Dehydration of rhizome slices led to an increase of iridal esters with a concomitant drop of free iridals, as well as phospholipids, in the drought-resistant species, *Iris germanica* (Bonfils et al. 1994). Analysis of the intracellular membranes of *Iris germanica* rhizomes indicated high amounts of iridals when compared to sterols and lower sterol amounts than in other plant microsomes (Bonfils et al. 1995). Incubation of a monocyclic iridal (a triterpenoid from *Iris* species) with rat liver microsomes in the presence of NADPH led to the degradation of this substrate and to the generation of 16-hydroxy-iridal (isoiridogermanal) (Bonfils et al. 1955). Iridal composition was also found to differ, depending on the age of *Iris germanica* rhizomes (Bonfils and Sauvaire 1996). Monocycloiridals were mostly represented in young rhizomes, whereas cycloiridals appeared to be the main iridal formed in the old ones. The study of the ratio of free iridals (FI)/iridal esters (IE) revealed a higher ratio in the youngest rhizomes. In addition 20 irone-related compounds containing 10-16C-atoms were detected in orris concrete of Moroccan origin (*I. germanica*) (Maurer et al. 1989). *Iris germanica* was found to have a fresh mass of 1342 g/plant and a dry mass of 437 g/plant and to contain 595 mg/kg DM irone content that was composed of 79.1 % *cis*-*γ*-irone and 20.9 % *cis*-*α*-irone (Firmin et al. 1998). An epoxidised iridal 18,19-epoxy-10-deoxyiridal was isolated from rhizomes of *Iris germanica* var. 'Rococo' (Bonfils et al. 1998). Ten enantiopure isomers of irone were reported to be the odoriferous principle of orrisroot oil, by means of enzyme-mediated approaches, starting from commercial racemic *Irone alpha*® (Brenna et al. 2003). A new iridal irigermanone and nine known congeners were isolated from the dried rhizomes of German iris *(Iris germanica*) (Potterat et al. 2014). The compound was a structurally unique noriridal and possessed an unprecedented methylcarbonyl group instead of the *α*,*β*-unsaturated aldehyde function typical for this group of triterpenes.

Other Plant Parts' Phytochemicals

A C-glycosyl flavone, embinin, is isolated from the petals of *I. germanica* (Kawase and Yagishita 1968). In *Iris germanica*, flower colour was found to be determined by two distinct biochemical pathways, the anthocyanin biosynthetic and the carotenoid biosynthetics (Warburton et al. 1978; Meckenstock 2005). In cyanic iris flowers, the main pigments reported were delphinidin-type anthocyanins imparting blue, violet and maroon colours, while in acyanic flowers, the main pigments were carotenoids, producing orange, yellow and pink colours. A red iris does not naturally exist because of a deficiency in the synthesis of pelargonidin- and cyanidin-type

anthocyanins, usually responsible for red and orange hues or that red carotenoids, such as lycopene, do not accumulate in large concentrations, thus producing only pink flowers, as opposed to red ones (Jeknić et al. 2014). With a goal of developing iris cultivars with red flowers, they transformed a pink iris *I. germanica*, 'Fire Bride', with a bacterial phytoene synthase gene (*crtB*) from *Pantoea agglomeran*s under the control of the promoter region of a gene for capsanthin–capsorubin synthase from *Lilium lancifolium* (Llccs). They showed that ectopic expression of a *crtB* could be used to successfully alter the colour of certain flower parts in *I. germanica* 'Fire Bride' and produce new flower traits. The colour changes were confirmed primarily due to the accumulation of lycopene. Other carotenoids and chlorophyll found in both control and *crtB* perigon (standards and falls), ovaries and flower stalk were neoxanthin, violaxanthin, lutein, lycopene, chlorophyll *a*, chlorophyll *b* and $\alpha+\beta$-carotene.

Carotenoids β-carotene 7.1 % (4.3 mg), lutein 87.8 % (53.2 mg), neochrome (zeaxanthin furanoxide) 3.5 % (2.1 mg) and 7 minor constituents 1.6 % (1 mg) were found in the green aerial parts of *I. germanica* (Bucheckerand and Liaaen-Jensen 1975). From the leaves of *I. pallida*, 0.1–0.7 % of iridals and their esters were extracted and from *I. germanica* leaves 0.05–0.3 % (Marner and Kerp 1992).

Antioxidant Activity

Both aqueous and ethanol *I. germanica* rhizome extracts exhibited strong total antioxidant activity, showing 95.9, 88.4, 79.9 % and 90.5, 78.0, 65.3 % inhibition on peroxidation of linoleic acid emulsion at concentrations of 10, 30 and 50 μg/ml, respectively, and in all cases exceeded the effect of 30 μg/ml α-tocopherol solution (36.6 %) (Nadaroğlu et al. 2007). Both extracts also possessed effective reducing power and exhibited free radical scavenging, superoxide anion radical scavenging, hydrogen peroxide scavenging and metal chelating activities at concentrations of 20, 40 and 60 μg/ml. The reducing power of aqueous and ethanol iris extracts and reference compounds was rated in the following order: BHA > BHT > α-tocopherol >> aqueous iris extract > ethanol iris extract. The scavenging effect of the aqueous and ethanol iris extracts and the reference compounds on the DPPH* radical decreased in the following order: BHA > α-tocopherol > BHT > aqueous iris > ethanol iris extract. These results indicated that both iris extracts produced a noticeable scavenging of free radicals; free radical scavenging activity also increased with the concentration of iris extracts. The metal chelating effect of both iris extracts and the reference compounds decreased in the following order: aqueous iris extract > ethanol iris extract > BHA > α-tocopherol > BHT. The results indicated that iris had in-vitro antioxidant properties, which could be the major factor responsible for the inhibition of lipid peroxidation. The petroleum ether extract (oil) of *I. germanica* exhibited good DPPH scavenging activity but showed moderate inhibition in linoleic acid oxidation as compared to BHT (Asghar et al. 2011). The radical scavenging activity of the ethanolic extracts of the aerial parts and rhizomes of *I. germanica* were found to have IC_{50} values of 5.38 and 12.3 mg/ml, respectively, whereas total antioxidant activity of the extracts (at 3.15 mg/ml) was 98.7 % and 97.4 %, respectively, and total phenolic content was 267.36 and 331.96 8 mg gallic acid equivalent/g extract, respectively (Burcu et al. 2014). HPLC analysis of phenolic compounds identified protocatechuic acid (0.356 mg/g extract), chlorogenic acid (0.164 mg/g extract) and ferulic acid (0.164 mg/g extract) as the main phenolic acids contained in the extract of the aerial parts of *I. germanica*, whereas chlorogenic acid (2.44 mg/g extract), (+)-catechin (2.14 mg/g extract) and ferulic acid (0.452 8 mg/g extract) were identified as the main phenolic acids contained in the extract of the rhizome.

Anticancer Activity

Isoflavones from *I. germanica* rhizomes, irigenin, irilone and iriskashmirianin exhibited moderate activity as inducers of NAD(P)H:quinone reduc-

tase (QR) in cultured mouse Hepa 1c1c7 cells, with CD values (concentration required to double the specific activity of QR) of 3.5–16.7 μM, whereas weak activity was observed with compounds iriflogenin and iriskashmirianin in the radical (DPPH) scavenging bioassay (IC_{50} values 89.6 and 120.3 μM, respectively) (Ito et al. 1995). Iridals extracted from *Iris germanica* exhibited antitumour effects in-vitro against human tumour cell lines: A2780 and K562 (and for each one, a drug-sensitive and a drug-resistant cell line) with IC_{50} values of 0.1–5.3 μg/ml (Bonfils et al. 2001). Some of them were shown to be more effective than doxorubicin. Studies by Halpert et al. (2011) found that the lipidic extract from *Iris germanica* was able to increase HeLa cell area and adhesion and augment the formation of actin stress fibres. This effect was not observed when Ref52 fibroblasts were tested and was not the result of disruption of microtubules. Further, the increase in cell area was Rac1 dependent, and the iris extract led to slight Rac activation. The increase in HeLa cell area in the presence of iris extract was accompanied by impairment of cell migration and arrest of the cell cycle at G1 although there is involvement of Rac1. The active compounds were found to iridals, a known group of triterpenoid. Purified iripallidal was able to increase cell area of both HeLa and SW480 cells.

With respect to antitumour-promoting potential based on anti-inflammatory mechanisms, none of the compounds demonstrated significant activity in the concentration range tested. *Iris germanica* ceramides irisamides A and B were active against mouse lymphoma L5178Y and cervical cancer HeLa cell lines, but inactive against PC12 rat pheochromocytoma (Mohamed et al. 2013). Irisamides A and B gave 76 % and 63 % growth suppression against the L5178Y and HeLa cell lines at a concentration of 12.67 mM as well as 68 % and 49 % at a concentration of 3.81 mM, with ED_{50}(s) of 0.91 and 2.40 mM, respectively. The isoflavone iridin S was inactive against the three cell lines. Among the compounds isolated from the rhizome, the isoflavone iriskashmirianin A possessed the best cytotoxic activity in Ehrlich's ascites carcinoma (EAC) cancer cell line with IC_{50} of 20.9 7 and 4.3 μM for 3-(4, 5-dimethylthiazole-2-yl)-2, 5-diphenyltetrazoli-umbromide (MTT) and ATP assay methods, respectively (Xie et al. 2013).

Antimutagenic Activity

The ethanolic extract of the aerial parts of *I. germanica* exhibited antimutagenic effects at 3 and 0.3 mg/plate concentrations as assessed using the Ames *Salmonella typhimurium*/microsome mutagenicity test (Burcu et al. 2014). The rhizomes also exhibited antimutagenic effects at 1.5, 0.15 and 0.015 mg/plate concentrations.

Antimicrobial Activity

The chloroform and ethyl acetate extracts of *I. germanica* rhizomes exhibited bactericidal activity, while the petroleum ether extract did not exhibit any bactericidal, fungicidal and insecticidal activities (Orhan et al. 2003). It was also inactive in the brine shrimp toxicity test, whereas it showed significant phytotoxicity against the plant *Lemna aequinoctialis.* The hexane fraction of the methanol rhizome extract showed significant inhibitory activity against *Fusarium solani* (70 %) and moderate activity against *Trichophyton longifusus* (50 %) and *Microsporum canis* (30 %), while the ethyl acetate and chloroform fractions exhibited moderate activity against the tested fungi (Asghar et al. 2009). It was observed that the growth of bacteria (*Pasteurella multocida*, *Escherichia coli*, *Bacillus subtilis*, *Staphylococcus aureus*) and fungi (*Ganoderma lucidum*, *Aspergillus flavus*, *A. niger*, *Alternaria alternata*) were inhibited in *I. germanica* petroleum ether extract (oil) as compared to the reference standards (rifampicin/terbinafine) (Asghar et al. 2011). The methanolic rhizome extract showed antimicrobial activity against *Staphylococcus aureus*, *Serratia marcescens*, *Escherichia coli*, *Candida albicans* and *Aspergillus flavus* with

the highest antimicrobial effect against *S. aureus* (Ibrahim et al. 2012).

Antihyperlipidemic Activity

Administration of the ethanolic extract of *Iris germanica* rhizomes for 10 weeks significantly lowered the lipid components especially the cholesterol and triglycerides in rats fed a high-fat diet (Choudhary et al. 2005)

Drug Metabolising Activity

Six isoflavones irisolidone, irisolidone 7-*O*-*α*-D-glucoside, irigenin, irilone, iriflogenin and iris-kashmirianin isolated from *Iris germanica* rhizomes were shown to be potent inhibitors of cytochrome P450 1A activity with IC_{50} values in the range of 0.25–4.9 μM (Wollenweber et al. 2003).

Anti-inflammatory Activity

Isoflavonoids isolated from *I. germanica* rhizome exhibited ant-inflammatory activity determined by a spectrophotometric assay using the activated human neutrophils (Attar-ur-Rahman et al. 2003b). The methanolic rhizome extract and the isolated flavonoids exhibited potent anti-inflammatory effects by suppressing hind paw oedema (skin oedema) induced by 4 % formalin in albino rats (Ibrahim et al. 2012). Irigenin S showed activity similar to that of dexamethasone.

Immunomodulatory Activity

Two isoflavones, 5,7-dihydroxy-6,4′-dimethoxyisoflavone (irisolidone) and 5,4′-dihydroxy-6,7-methylenedioxyisoflavone (irilone) isolated from *Iris germanica*, exhibited immunomodulatory activities (Nazir et al. 2009). They influenced the production of T lymphocytes (CD4+ and CD8+ cells) and T cell cytokines, namely, Th1: IL-2, IFN-gamma and Th2: IL-4 and IL-5 in a dose-dependent manner, as studied by the flow cytometric method. Oral administration of the isoflavones in Balb/c mice at doses of 0.1–0.8 mg/kg per oral dose showed irisolidone to possess stimulatory activity on T lymphocytes (CD4+ and CD8+ cells) and Th1: IL-2, IFN-gamma cytokine production, while irilone acted as an immunosuppressant for T lymphocytes (CD4+ and CD8+ cells) and T cell cytokines, namely, Th1: IL-2, IFN-gamma and Th2: IL-4 and IL-5. The methylated products of both isoflavones showed a similar trend to that of their parent compounds, but their activity was drastically decreased revealing the importance of free phenolic groups for their immunomodulating activities.

Antimalarial Activity

Iridal, a triterpenoidic compound isolated from *I. germanic*a, exhibited antiplasmodial activity (Benoit-Vical et al. 2003). The IC_{50} obtained in-vitro on human malaria *Plasmodium falciparum* chloroquine-resistant and chloroquine-sensitive strains ranged from 1.8 to 26.0 μg/ml and the ED_{50} in-vivo for *P. vincke* was about 85 mg/kg/day by intraperitoneal route. Iridal presented an antiplasmodial activity similar to that obtained with extracts from the plant *Azadirachta indica* classically taken as reference in malaria phytomedicine

Molluscicidal Activity

Iris germanica rhizome chloroform extract showed the highest molluscicidal activity (LC_{90} = 1.26 mg/l) against *Biomphalaria alexandrina* snails among the tested extracts of the rhizomes (Singab et al. 2006). Fraction B prepared from the chloroform extract was the most potent molluscicide (LC_{90} = 0.96 mg/l); in addition, it showed a significant heart rate reduction in the snail after a 6- to 24-h exposure period. It also displayed a significant level of cercaricidal potential in a time-concentration-dependent manner.

Piscidal Activity

Among the iridals isolated from the rhizome, the most potent piscidal activity was observed for iriflorental with medial tolerance (TL_m) value after 24 h of 0.1 µg/ml (Ito et al. 1995). The TL_m of the bicyclic iridals irisgermanical A was 0.8 µg/ml and irisgermanicals Band C were 3 µg/ml. The monocyclic iridals, isoiridogermanal and 16-*O*-acetyl-isoirigermanal, were inactive. Of the iridals isolated from *I. germanica*, iriflorental, iripallidal and *γ*-irigermanal exhibited a potent piscidal activity (using killifish, *Oryzias latipes*) at a concentration of less than 1 µg/mL (Miyake et al. 1997).

Allergy Issue

Allergic manifestations caused by the use of a dentifrice containing orrisroot *(Iris* × *germanica* L. nothovar. *Florentina)* powder was reported by Winter (1948).

Toxicological Studies

The acute oral LD_{50} value for orris absolute in rats was reported as 9.4 g/kg (Moreno 1972). Undiluted orris absolute applied to the backs of hairless mice and swine was found to be not irritating (Urbach and Forbes 1972). No phototoxic effects were reported for undiluted orris absolute on hairless mice and swine. A patch test using orris at full strength for 24 h produced no irritation reactions in 20 subjects (Katz 1946). Orris absolute tested at 3 % in petrolatum produced no irritation after a 48-h closed-patch test on human subjects (Kligman 1972). Orris produced no primary irritation in a repeated insult patch test on 43 human subjects (Majors 1972).

Traditional Medicinal Uses

The root is diuretic, emetic, expectorant and mildly purgative (Grieve 1971; Usher 1974; Launert 1981; Chiej 1984). Juice from the root is a powerful cathartic and used for the treatment of dropsy (Grieve 1971). Orrisroot is also employed for complaints of the lungs, coughs and hoarseness, bronchitis and chronic diarrhoea. If taken in large doses, it can cause nausea, vomiting, purging and colic (Grieve 1971).

Other Uses

Iris resinoid obtained from *Iris germanica* or *Iris pallida* rhizomes is widely used in the perfume industry (Roger et al. 2012). Whole roots of Orris, resembling the human form, are used in voodoo performances, and the powdered root is an ingredient in 'love potions'. A black dye is obtained from the roots and a blue dye from the flowers (Grae 1974). The seeds are used as rosary beads (Usher 1974). Powdered orrisroot is sometimes put into rinsing water in laundries and imparts a refreshing and fragrant scent to the linen (Grieve 1971). Orrisroot, mixed with anise, was used in England as a perfume for linen as early as 1480. The root is a source of orris powder which is much used as a fixative and base note in perfumery and pot-pourri, as an ingredient of dentifrices, toothpastes, breath fresheners, face powders, foot powders, sachet powder, violet-scented soaps and cachous and as a food flavouring. Orris oil is used commercially in the preparation of the finest scents and is also blended with artificial violet perfumes, the odour of which it renders more subtle (Grieve 1971).

Comments

Bearded iris is propagated by division or cutting from the original rhizome and by seed.

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Stachys affinis

Scientific Name

***Stachys affinis* Bunge**

Synonyms

Stachys geobombycis var. *alba* C.Y.Wu & H.W.Li, *Stachys pauciflora* Benth., *Stachys sieboldii* Miquel, *Stachys sieboldii* var. *alba* (C.Y.Wu & H.W.Li) H.B. Chen, *Stachys sieboldii* var. *glabrescens* C.Y.Wu & H.W.Li, *Stachys sieboldii* var. *malacotricha* Hand.-Mazz., *Stachys tuberifera* Naudin

Family

Lamiaceae

Common/English Names

Artichoke Betony, Chinese Artichoke, Crosne, Japanese Artichoke, Knotroot

Vernacular Names

Afrikaans: Sjinese Artisjok
Brazil: Estachida Do Japão (Portuguese)
Bulgaria: Ranilist
Chinese: Gan Lu Zi, Kan-Lu-Tzu Cao-Shi-Can (Sweet As Dew), T'sao-Shih-Ts'an (Herbaceous Rock Silk Worm), Di-Gu-Niu, Ti-Ku-Niu (Ground Slug), Bao-Ta-Cai, Pao-T'a-Ts'ai (Precious Pagoda Vegetable), Kon Loh (Cantonese)
Czech: Čistec Hlíznatý
Danish: Jcrosne, Apankartofler, Kinaskok, Knold-Galtetand, Stachysknolde
Dutch: Chinese Artisjok, Crosne Wortelknolletjes, Japanse Andoorn
Eastonian: Mugul-Nõianõges
Finland: Mukulapähkämö
French: Crosnes, Crosne Du Japon, Épiaire Affine, Stachys Tubereux
German: Chinesische Artischocke, Crosnes De Japon, Japanische Kartoffel, Japanknollen, Knollen-Ziest, Lippenblütler, Stachys, Ziestknolle
Greek: Stocchis
Hebrew: Eshbal
Italian: Betonica Bianca, Stregona Giapponese, Tuberina
Japanese: Chorogi
Korean: Mongulsuso
Lithuanian: Gumbuotoji Notra
Macedonian: Čistec, Japonska Artičoka;
Malaysia: Tung-Tung Chow (Cantonese)
Mongolian: Argui
Norwegian: Knollsvinerot, Svinerot
Polish: Czysciec Bulwiasty

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Portuguese: Alcachofra Chinesa, Crosne Do Japao, Estaque, Rab-De-Raposa, Urtiga Japonesa
Slovaščina: Sieboldov Čišljak
Spanish: Alcachofa China, Alachofra Tuberose, Crosne Del Japón, Estaquídea Del Japón, Ortigs Japonesa
Swedish: Korogi
Tajiki: Anganor
Thailand: Thua-Duang
Turkish: Japon Enginari, Karabos, Cine Enginar
Vietnamese: Trung Quốc Atisô
Welsh: March Ysgall

Origin/Distribution

S. sieboldii is a native of China – Gansu, Hebei, Hubei, Nei Monggol, Ningxia, Qinghai, Shaanxi, Shandong, Shanxi, Sichuan and Xinjiang. It has been cultivated as a food plant for its tubers since ancient times in China and Japan. Chinese artichoke referred to as Crosne in France has been cultivated on a small scale since the end of the nineteenth century and in Malaysia (Cameron Highlands) since the 1980s. It is occasionally planted in Mongolia, Korea, India, Great Britain, Belgium, Switzerland, Germany, Italy, Russia, North America, Brazil, Argentina, South Africa and New Zealand as a vegetable and medicinal plant.

Agroecology

Chinese artichoke is a cool climate temperate species. In its native range, it occurs in lowlands, hillside and highlands from 0 to 3200 m altitude. It grows best in well-drained, moderately fertile, friable sandy soil in full sun. Excessive fertilisers promote leaf growth and reduce tuber production. For optimum vegetative growth, a day temperature of 23 °C is required and for tuberization 15 °C. It needs to be watered well during dry weather. The whole plant dies back in autumn, which is when harvest occurs.

Edible Plant Parts and Uses

The edible tuber is used as vegetable (Facciola 1990; Larkcom 1991; van den Burgh 1996; Hu 2005). Chinese artichokes are valued as a food in the Chinese Five Systems, for feeding and strengthening the respiratory and lymphatic system. They are an attractive, gourmet vegetable with a crisp, crunchy texture and a sweet, nutty flavour. The tubers are eaten raw or added to salads or any cooked dish: stir-fries, casseroles, soups, sweet and sour, sea food and curries. Tubers can be prepared in batter and fried as *tempura*. They can be mixed with noodles, egg, mushrooms or tofu. They can be steamed with other vegetables like carrots, peas, zucchini and onions. They can be steamed then tossed with butter and herbs like chervil, parsley, savoury, chives and coriander or serve steamed artichokes with a sauce, dressing or lemon juice. They can be consumed with dips – avocado, kefir or cheese. Tubers can also be pickled or dried, for later use. In China, they are used mainly for pickling. In Japan, the tubers are a part of *Osechi-ryōri* (traditional Japanese New Year Foods), which is cooked to celebrate the Japanese New Year on 1st January each year. In Japan, the tubers are pickled in salt/vinegar, and purple perilla leaves are added for flavour and the red colour.

Botany

A perennial, deciduous, erect or inclined herb, 30–120 cm high, hirsute throughout, stems quadrangular and soft, base furnished with short rhizomes thickened at the ends into fleshy, white, fusiform worm-like tubers, 3–5 cm long, 1–1.2 cm wide, slightly constricted at the nodes resembling a witchetty grub (Plates 1 and 2). Leaves opposite, green, vary in shape and size, ovate-cordate to ovate oblong, 2.5–9.5 cm by 1.5–3.5 cm wide, acute to shortly acuminate, base cordate, serrate margin, petioles of leaves at the middle of the stem 1–2 cm long, becoming gradually shorter towards the stem apex. Flowers rose purple, in terminal spicate panicles 10–15 cm

Plate 1 Fresh worm-like crosne tubers

Plate 2 Dried crosne tubers

long, verticils of 6-flowers, subsessile; lowest verticil subtended by lanceolate sessile leaves. Calyx turbinate, 6–7 mm long, 5 toothed, teeth subequal, ovate, acute, corolla 12–13 mm long, tube 9 mm long, limb bilabiate, upper lip arched, hairy, lower lipped 3-lobed, reflexed, stamens 4, ascending, anthers ovoid, nutlets 4 obovoid, dark brown, 1.5 mm across, tuberculate.

Nutritive/Medicinal Properties

Tuber Phytochemicals

Tetraploid *S. sieboldii* was found to be more superior in economic value than the diploid *S. sieboldii* as the former contain higher levels of

nutritional components (Kuan 2012). The dry matter content, soluble protein content and soluble sugar content increased 43.16 %, 9.46 % and 21.74 %, respectively, in the tetraploid leaf than that in the diploid one; while they increased 13.12 %, 21.89 % and 7.42 %, respectively, in the tetraploid tuber than that in the diploid one.

Tubers are rich in the oligosaccharide (tetrasaccharide) carbohydrate – stachyose (α-galactose (1→6) α- galactose (1→6) α-glucose (1→2) β-fructose), which is stored exclusively in the vacuoles in the tubers (Keller and Matile 1985; Keller 1992b; Greutert and Keller 1993). Vacuoles of *Stachys sieboldii* tubers were reported to accumulate up to 180 mM stachyose against a concentration gradient, probably by means of an active stachyose/H+ antiporter situated on the tonoplast (Greutert and Keller 1993). In dry tubers, 80 % of the dry weight comprised stachyose. During an 18-day sprouting period, the stachyose content decreased by 70 % and was correlated with a twofold increase of the activity of α-galactosidase, the key-enzyme responsible for the degradation of galactosyl saccharides. Galactinol (gal-inositol), the precursor of galactosyl saccharides, and sucrose were mainly present in the cytoplasm. Galactinol synthase (GS, UDP-α-D-galactose: 1l-myo-inositol-1-*O*-α-D-galactopyranosyltransferase) a key enzyme in the biosynthetic pathway of the raffinose family of oligosaccharides was found to be an extravacuolar enzyme in the tubers (Keller 1992a). The content of stachyose in dry tubers was determined to be 236.0 mg/g, and the purity of the extracted stachyose flour was calculated to be 87.34 % (Yin et al. 2006). The tubers also contained sucrose raffinose and verbascose (van den Burgh 1996; Yin et al. 2006). Stachyose being a kind of sugar is used as a bulk sweetener and has been reported to be better for health than normal white sugar and has some interesting functional oligosaccharide properties for the food industry, the cosmetic industry and the pharmaceutical industry. The tubers also contained stachysoside A, B and C acteoside with six known glycosides (Miyase et al. 1990); acteoside (1000 mg), stachysoside B (280 mg), stachysoside C (50 mg), martynoside (150 mg), leucosceptoside A (630 mg) and phenylethanoid glycoside (Yamahara et al. 1990).

Leaf/Aerial Parts Phytochemicals

From the aerial parts, the following glucosides were isolated: isoscutellarein 4'methyl ether 7-*O*-B-(6"'-*O*-acetyl-2"-allosyl)glucoside, isoscutellarein 7-*O*-β-(6"'-*O*-acetyl-2"-allosyl)glucoside and aceteoside (Takeda et al. 1985). Three new phenethyl alcohol glycosides together with six known compounds stachysoside, acteoside, decaffeoylacteoside, isoacteoside, leucosceptoside A and martynoside were isolated from *Stachys sieboldii* leaves (Nishimura et al. 1991). The structures of three new compounds named stachysosides A, B and C were established as 2-(3,4-dihydroxyphenyl)ethyl *O*-α-L-arabinopyranosyl-(1→2)-α-L-rhamnopyranosyl-(1→3)-4-*O*-E-caffeoyl-β-D-glucopyranoside; 2-(3,4-dihydroxyphenyl)ethyl *O*-α-L-arabinopyranosyl-(1→2)-α-L-rhamnopyranosyl-(1→3)-4-*O*-E-feruloyl-β-D-glucopyranoside and 2-(3 -hydroxy-4-methoxyphenyl)ethyl O-α-L-arabinopyranosyl-(1→2)-α-L-rhamnopyranosyl- (1→3)-4-*O*-E- feruloyl-β-D-glucopyranoside, respectively.

Antioxidant Activity

Methanolic roots extracts of *Stachys sieboldii* containing 3.02 % of polyphenols and 1.97 % of flavonoids exhibited strong antioxidant activities (Baek et al. 2004). The fraction extracted by ethyl acetate showed higher antioxidation value than that of α-tocopherol, butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) at the same concentration. The fraction ES-RS exhibited the strongest activity on antioxidation whereas the ES-R5 fraction showed similar pattern to flavones.

Antimicrobial Activity

Stachys sieboldii root extract exhibited antimicrobial activity in-vitro against food-borne bacteria – *Bacillus cereus* with MIc value of 250 μg/ml, *Listeria monocytogenes* MIC =250–500 μg/ml, *Staphylococcus aureus* and *Psedomonas aeruginosa* MICs of 500 μg/ml (Ryu and Park 2002).

Anti-Anoxia Activity

Studies using mice models also showed that methanolic extract of the tubers had anti-anoxia effect (Yamahara et al. 1990). The extract significantly inhibited the lethal anoxia induced by potassium cyanide (KCN) in mice. The methanolic extract on fractionation yielded bioactive constituents, acteoside and stachysoside C, phenylethanoid glycoside, which had a significant effect on the KCN-induced anoxia model.

Antitumour Activity

Administration of *S. sieboldii* ethanol extract to mice accelerated mouse spleen cell growth but inhibited FM3A/S°-breast cancer cell growth (Ryu et al. 2002). *S. sieboldii* fed mice showed a significant enhancement of interleukin IL-2 receptor expression, increased numbers of CD4+ T cells and CD8+ T cells. The extract also stimulated the production of NO by peritoneal macrophages and spleen cells. The extract also inhibited Bl6Fl0 lung melanoma cells.

Antinephritic Activity

Acteoside from *S. sieboldii* roots was found to have a suppressive effect on the accumulation of leukocytes in the nephritic glomeruli through prevention of the upregulation of adhesion molecules (Hayashi et al. 1994a, b, 1996). Acteoside administered p.o. for 5 or 15 consecutive days markedly suppressed the accumulation of total leukocytes, ED-1-positive cells (monocytes/macrophages), CD4-positive cells, CD8-positive cells, interleukin-2-receptor-positive cells (activated T cells) and Ia-positive cells in the glomeruli of rats with crescentic-type anti-glomerular basement membrane (GBM) nephritis. Acteoside inhibited the elevation of protein excretion into urine. In acetoside-treated rats, cholesterol and creatinine contents and antibody production against rabbit gamma-globulin in the plasmas were lower than those of the nephritic control rats. Acteoside also suppressed hypercellularity and the incidence of crescent formation, adhesion of capillary wall to Bowman's capsule and fibrinoid necrosis in the glomeruli. Furthermore, rat-IgG and C3 deposits on the GBM were significantly less in the ACT-treated group than in the control nephritic group. Acteoside also suppressed the up-regulation of ICAM-1 expression in nephritic glomeruli and prevented the up-regulation of ICAM-1 expression mediated by inflammatory cytokines or phorbol 12-myristate 13-acetate on HUVECs and rat mesangial cells. The results suggested that acteoside may be a useful medicine against rapidly progressive glomerulonephritis, characterized by severe glomerular lesions with diffuse crescents.

Central Nervous System Activity

Administration of *Stachys sieboldii* methanolic extracts in the diet of rats for 20 days caused significant inhibitory effects on acetylcholine esterase activity, monoamine oxidase and xanthine oxidase activities in the rat brain tissues (Ryu and Kim 2004). Lipid peroxide levels were also decreased in a dose-dependent manner.

Traditional Medicinal Uses

The entire plant has been used in the treatment of colds and pneumonia in traditional medicine in China (Li and Hedge 1994). The dried and powdered root is regarded as an anodyne (Duke and Ayensu 1985).

Other Uses

The plant is used mainly as a vegetable crop with incidental medicinal uses and no other uses.

Comments

The plant is readily propagated from tubers.

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Maranta arundinacea

Scientific Name

***Maranta arundinacea* L.**

Synonyms

Maranta arundinacea var. *arundinacea*, *Maranta arundinacea* var. *indica* (Tussac) Petersen, *Maranta arundinacea* f. *sylvestris* Matuda, *Maranta arundinacea* var. *variegata* Ridl., *Maranta indica* Tussac, *Maranta ramosissima* Wall., *Maranta silvatica* Roscoe, *Maranta sylvatica* Roscoe ex Sm., *Maranta tessellata* var. *kegeljanii* E.Morren, *Phrynium variegatum* N.E.Br. (illeg.)

Family

Marantaceae

Common/English Names

Arrow Head, Arrow-root, Arrowroot, Bermuda Arrowroot, Maranta, Obedience Plant, St. Vincent Arrowroot, West Indian Arrowroot

Vernacular Names

Argentina: Jamaichipeke
Bolivia: Guate, Jamachipeke, Jamaichepeque, Juá-Juá
Brazil: Agoutiguepe, Agutiguepa, Araruta, Araruta-comum, Araruta- palmeira (Portuguese)
Cambodia: Daem Run, Saku
Chinese: Zhu Yu
Costa Rica: Rizoma De Maranta, Sagú
Cuba: Juá-Juá, Sagú De San Vicente
Czech: Maranta Rákosovitá
Danish: Salepmaranta, Salepplante
Dutch: Pijlwortel, Salepwortel
Eastonian: Roogmaranta
French: Arrowroot Des Antilles, Dictame (Antilles), Dictame Barbed, Fécule De Dictame, Herbe Aux Fleches
German: Maranta, Pfeilwurz
Guatemala: Shimipampana Blanco, Shimi-pampana Negro, Silú, Sucu, Sulú, Tacea, Tamalera
Hungarian: Bermudai Maranta, Maranta
India: Tikhor, Tikkor (Hindi); kuvehittu, tavak-siri (Kannada), Kuva, kuvva (Malayalam), Tavaksiri, Tugaksiri (Sanskrit), Aruruttukkilangu, Aruruttukkilangu, Kookai

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Neer, Koovai Kizhangu, Kuamau, Kukai Niru, Kuvai (Tamil), Palagunda, Palagunta (Telugu)
Indonesia: Angrik, Arus, Gaerut, Garut, Iruk, Jelarut, Larut, Nggarut, Rarut, Waerut (Javanese), Larut, Patat Sagu (Sundanese), Medawit Cina, Sugu Rarut (Sumatra)
Japanese: Kuzuukon, Maranta
Laos: Sa:kh'u
Malaysia: Ararut, Berolu, Beruwi, Sagu Belanda, Ubi bemban, Ubi Garut, Ubi Karut
Papiamento: Ararut
Peru: Saguero, Shimi pampana
Philippines: Sagu (Bikol), Galamaka (Bontok), Araru (Ibanag), Sagu (Iloko), Araru (Itogon), Bai (Ivatan), Araro, Araru, Aroru, Aruru, Uraro (Tagalog)
Portuguese: Agutiguepa, Araruta-comum, Araruta-Especial, Araruta-palmeira, Aru-Aru
Puerto Rico: Juá-Juá, Maranta
Russian: Maranta Trostnikovaia, Maranty Trostnikovoi
Spanish: Ararú, Araruta, Caña Flecha, Chuchute Tamalera, Guape, Guate, Jamachipeke, Jamaichepeque, Juájuá, Juá-juá, Maranta, Rizoma De Maranta, Sagú, Sagú De San Vicente, Saguero, Silú, Sucu, Sulú, Shimipampana, Tacea, Tamalera, Tubérculo De maranta, Yerén, Yuquilla
Swedish: Arrowrot
Thailand: Sakhu (Central)
Turkish: Ararot
Uruguay: Tubérculo De Maranta
Venezuela: Ararú, Araruta, Arrarú, Arrorúz, Arrorruz, Arrurruz, Arruruz, Caña Flecha, Chuchute Tamalera, Cuba, Guape, Guapo
Vietnamese: Dong Củ

Origin/Distribution

Maranta arundinacea is native to South America, the Caribbean and Mexico. The plant has naturalized elsewhere in Florida, Australia, Southeast Asia and South and East Africa. It is chiefly cultivated in the West Indies (especially Jamaica and St. Vincent).

Agroecology

Arrowroot flourishes in warm, humid areas with mean annual temperatures of 25–28 °C and mean annual precipitation of 1500–1800 mm. It thrives in well-drained, alluvial and volcanic soils and is also cultivated on yellow and brown latosols with loamy-clayey texture as found in St. Vincent. It prefers partial shade as found in rainforest habitats.

Edible Plant Parts and Uses

Arrowroot rhizome and starch are used as food in the form of puddings, jellies, cakes, pastries, biscuits, cookies hot sauces and used with beef tea, milk, meal, broth and noodles in Vietnamese and Korean cuisines. It provides easily digestible, nourishing food for children and people with dietary restrictions and convalescents. It is well suited as weaning food for infants from breast milk. Arrowroot makes clear, shimmering fruit gels and prevents ice crystals from forming in homemade ice cream. It can also be used as a thickener for acidic foods, such as Asian sweet and sour sauce. The absence of gluten in arrowroot flour makes it useful as a replacement for wheat flour in baking.

Botany

A clumping perennial herb which is 30–130 cm high with erect slender stems often apically branched (Plates 1 and 2). Rhizomes are white, sympodial, cylindric, fleshy, starchy and loosely scaly (Plates 5 and 6). Basal leaves are 4–8; cauline leaves 1–8; alternate, petiole 3.5–20 cm in basal leaves, often absent in cauline leaves; pulvinus 0.2–1.8 cm, glabrous, adaxially slightly tomentose; lamina ovate-oblong, 3.5–35 by 3–11 cm, pale-green, adaxially sparsely pilose, abaxially glabrous or sparsely pilose, base rounded to truncate, apex acuminate (Plates 3 and 4). Inflorescences terminal, lax, several per leafy shoot, with 1–3 bracts each subtending 2–3

Plate 1 Young arrowroot plants

Plate 2 Mature arrowroot clump

flower pairs, 2.5–6 cm. Flowers on common pedicel; sepals green, narrowly ovate, corolla white, tubular, base inflated, lobes 8–10 mm; staminodes white, obovate, ovary three-loculed, densely pubescent, to sub-glabrous. Fruit, green or reddish-brown tinged, dehiscent, subglobose capsule, 7–8 mm by 4–5 mm. Seeds brown, rugose with basal aril.

Nutritive/Medicinal Properties

Nutrients and Phytochemicals

Nutrient composition of the raw tuber per 100 g edible portion was reported as energy 125 cal, moisture 67.4 g, protein 1.7 g, fat 0.2 g, total carbohydrates 29.5 g, dietary fibre 2.0 g, ash 1.2 g, Ca 15 mg, P 18 mg, Fe 1.9 mg, thiamin 0.13 mg, riboflavin 0.02 mg, niacin 0.5 mg and ascorbic acid 7 mg (Leung et al. 1972). Starch obtained

Plate 3 Large, ovate-oblong green leaves

from *Maranta arundinacea* tuber had an amylose content of 24.8 % (Madineni et al. 2012). The starch granules were small range of 2.92–6.42 μm, (mean of 4.84 μm), indented and spherical, with length/degree of 1.20, and roundness of 0.73. Maranta starch had a gelatinization temperature of 74.8°C, peak viscosity of 498BU and cold paste viscosity of 669 BU. It also possessed higher freeze-thaw stability (15 cycles) 1.6,

Plate 4 Arrowroot with variegated leaves

Plate 5 Immature young arrowroot rhizome

swelling power at 30 °C =2.4 g/g, swelling power at 80 °C 12.1 g/g, solubility at 30 °C was 6.3 % and solubility at 80 °C was 37.8 %. Arrowroot starch contained moisture 8.1 %, crude protein 0.8 %, crude fat 1 %, ash 1.5 %, soluble fibre 1.7 %, insoluble fibre 2.9 %, starch 81.6 %, sugar after inversion 1 %, sugar before inversion 0.2 %, amylose 24.8 % and minerals (mg/100 g) such as P 73.5 mg, Ca 17.2 mg, Mg 17 mg, K 27.4 mg, Fe 12.2 mg, Mn 10.9 mg and Zn 3 mg (Madineni et al. 2012). In an earlier analysis, Perez and Lares (2005) reported that arrowroot starch had 15.34 % moisture, 0.50 % crude protein, 0.18 % crude fat, 0.47 % crude fibre, 0.21 % ash, 15.2 % amylase, 84.79 % amylopectin and minerals (mg/100 g) Na 57.26 mg, K 28.60 mg, P 75.10 mg, Ca 2.79 mg, Mg 12.24 mg, Fe 14.27 mg and Zn 3.82 mg. Ensiled aerial biomass and coarse and fine arrowroot processing residues contained 10.8–21.1 % crude protein; 11.1–30.2 % crude fibre; 3.8–17.0 % ash; and an in-vitro dry matter digestibility of 38.5–60.3 % (Erdman and Erdman 1984).

Jyothi et al. (2009) found that extrusion cooking of arrowroot starch resulted in products with very good expansion, colour and lower digestibility, which can be exploited for its potential use as a snack food. The expansion ratio of arrowroot starch extrudates ranged from 3.22 to 6.09 The water absorption index (6.52–8.85 g gel/g dry sample), water solubility index (15.92–41.31 %) and oil absorption index (0.50–1.70 g/g) were higher for the extrudates in comparison to native starch (1.81 g gel/g dry sample, 1.16 % and 0.60 g/g, respectively). The rheological properties, storage modulus and loss modulus of the gelatinized powdered extrudates were significantly lower and these behaved like solutions rather than a paste or a gel. Hardness and toughness were more for the samples extruded at higher feed moisture and lower extrusion temperature, whereas snap force and energy were higher at lower feed moisture and temperature. There was a significant decrease in the percentage digestibility of arrowroot starch (30.07 % after 30 min of incubation with the enzyme) after extrusion (25.27–30.56 %).

Modification of native arrowroot starch with butyric anhydride increased swelling power and paste clarity, but decreased viscosity and solubility (Haryadi et al. 2008). Butyrylated arrowroot starch at degree of substitution (DS) 0.04 at 2 % (w/v) gave edible film of 0.05 mm thickness, 0.32 MPa tensile strength, 1.66% elongation, 16.4 g/m^2/h water vapour transmission rate

Plate 6 Mature arrowroot rhizome

(WVTR) and highest film solubility (46.8 %), which completely dissolved after 1.40 min dipping in boiling water. The films could be applied to provide instant arrowroot food powder.

Dual modification of arrowroot starch using hydroxypropylation and cross-linking was found to overcome the lack of native arrowroot starch in food processing application (Maulani et al. 2013). These modifications significantly affected the composition of the amylose and amylopectin and the amount of phosphorus in the granules. Higher amounts of phosphate salt gave a higher phosphorus content, which increased the degree of substitution (DS) and the degree of cross link. Arrowroot starch that was modified using a concentration of 8–10 % propylene oxide and 1–2 % STMP (sodium trimeta phosphate): 3–5 % STPP (sodium tri poly phosphate) produced a starch with <0.4 % phosphorus content. A higher concentration of propylene oxide provided a higher degree of hydroxypropyl.

The ethanolic extract of *M. arundinacea* tuber exhibited a total phenol content of 390 mg GAE (gallic acid equivalent)/100 g, total flavonoid content of 290 QE (quercetin equivalent)/100 g and total flavonol content of 150 mg QE/100 g. (Nishaa et al. 2013a). Also present were unidentified steroid, tannin and glycoside compounds.

Forty-nine compounds were identified in the ethanol extract of arrowroot rhizome (Nishaa et al. 2013b): cyclohexanone; 2-hydroxy-cyclopenta-2,4-dienone; 2,3-dimethoxy-succunic acid dimethyl ester; 5-diethylsilanyloxy-4-ethyl-2-phenyl-3a,4,7,7a-tetrahydro-isoindole-1,3-dione; triethyl-3-(3-methyl sulfanyl-1-vinyl-pent-1-enyloxy)-silane; (2-methyl-thiiranyl)-methanol; 2-tert-butoxy-tetrahydro-furan; *cis*-2(7-octynyl) cyclohexanol; 4-tert-butyl-[1,3,2]dioxathiolane-2-oxide;(2-acetoxy-1-methyl-vinyl)-methylidyne-ammonium; tetradecane; cyclohepta-2,4,6-trienecarboxyclic acid ethyl ester; benzyl-butyl-amine; 1-ethoxymethyl-4-methyl benzene; 1-(4-methoxy-cyclohexyl)-hex-5-en-1-one; 9-(4-methoxy-phenyl)-9-oxo-nonanoic acid methyl ester; 2,6-dimethoxy phenol; 2-tert-butyl-1,2-dimethyl-cyclopropane, carboxylic acid methyl ester; 1,1,2,2-tetramethyl-3-oxo-octahydro-4-oxa-cyclobuta(α)naphthalene-2a-carbonitrile; C-[2,2-dimethyl-3-(2-methyl-propenyl)-1-phenylsulfanyl-cyclopropyl]-methylamine; 2-phenoxysulfonyl-acetimidic acid methyl ester; 2-phenoxysulfonyl-acetimidic acid methyl ester hydrochloride; 3,6,10-trimethyl-8,11-dihydro-7H-cyclodeca[b]furan-4-one;1-benzyl-4-tert-butyl-4,5-dihydro-1H[1,2,3,4,5]-thiatetrazoborole; 4-ethoxymethylene-7,7-dimethyl-bicyclo[3.2.0] hept-2-en-6-one; 2-(2-nitroallyl)-cyclohexanone; 1,4,7,10,10-pentamethyl-2,4,6,8,9-pentaaza-tricyclo[5.2.1.$0^{2,6}$]dec-8-ene-3,5-dione; 2,3,3,4,7-pentamethyl-1,5,7-triaza-ricyclo [3.3.0.$0^{2,4}$]octane-6,8-dione; 6-chloro-3,4,4a,5,6, 8a-hexahydro-2H-chromene;5-(1-chloro-1-methyl-

ethyl)-3,5-dimethyl-cyclopent-2-enone; 7a-(2-methoxy-ethyl)-1-methyl-1,2,3,6,7,7a-hexahydro-inden-5-one; 3-3-(methoxy-phenyl)-2-methyl-oxetan-3-ol;2-benzyloxy-7-(tetrahydro-pyran-2-yloxy)-heptan-1-ol; (1-acetyl-5-formyl-6-methyl-cyclohexa-2,4-dienyl)-acetic acid ethyl ester;3-phenyl-1-(toluene-4-sulfonyl)-pyrrolidine-2,5-dicarboxylic acid 2-benzyl ester 5-tert-butyl ester; cyclopropyl-oxo-acetic acid methyl ester; 2-allyl-5a-hydroxy-octahydro-5-oxa-2-aza-cyclopenta[c]inden-1-one;cyclohexylmethyl-diethyl-methoxy-silane; 2,2-dimethoxy-4a,5,6,7,8,8a-hexahydro-2H-benzo[e][1,2]oxasilane; 2,2-dimethoxy-2H-benzo[e][1,2]oxasilane; 4-(3,4-dimethoxy-phenyl)-butan-1-ol; 1,1,diethoxy-2-methyl-propane; 2,4'-dimethyl-[2,4']bi[[1,3]dioxanyl]; 2-methyl-3,3-bis-(2-trimethylsilane-ethoxy)-propionic acid methyl ester; 2-methoxyimino-4-methyl-pentanoic acid benzyl ester; 2-(benzyl-{2-[(dimethyl carbamoyl-phenyl-methylene)-hydrazino]-ethyl}-hydrazono)-N,N-dimethyl-2-phenyl-acetamide; and 3-methylene-1-oxa-spiro[3,6]decane.

Antioxidant Activity

The ethanolic extract of *M. arundinacea* rhizome exhibited high antiradical activity against 1,1-diphenyl-2-picryl hydroxyl (DPPH) ABTS (2,2′-azinobis-3-ethylbenzothiozoline-6-sulfonic acid), hydrogen peroxide and nitric oxide radicals with IC50 value of 293.4, 297.4, 336.1 and 258.7 μg/ml, respectively (Nishaa et al. 2012). The reducing power and ferric reducing antioxidant power (FRAP) increased with increasing concentration of the sample. The antioxidant activity of the sample was comparable with that of the standard butylated hydroxyl toluene (BHT).

Immunostimulatory Activity

Studies showed the arrowroot tuber extract stimulated IgM production by human hybridoma HB4C5 cells and immunoglobulin (IgG, IgA and IgM) production by murine splenocytes in-vitro (Kumalasari et al. 2012). In addition, the arrowroot tuber extracts strongly enhanced interferon γ production by splenocytes. In in-vivo study, the diet containing arrowroot extracts increased the serum IgG, IgA and IgM levels in mice.

Anti-Diarrhoeal Activity

In a small clinical study of 11 patients with diarrhoea, the administration of arrowroot powder (thrice daily) for a month was found to be an effective treatment for diarrhoea (Cooke et al. 2000). Arrowroot reduced diarrhoea and had a long-term effect on constipation. It also eased abdominal pain. Its action was attributed to an increase in faecal bulk leading to more efficient bowel action.

Probiotics Enhancing Activity

Studies showed that arrowroot carbohydrates could be used to enhance probiotic Lactobacilli population in bio-yoghurt during refrigerated storage (Abesinghe et al. 2012). Arrowroot carbohydrates and Raftilose® increased Lactobacilli population by 1.44 log CFU/mL and 1.17log CFU/mL, respectively, compared to the control.

Antibacterial Activity

Studies by Kim and Fung (2003) found that 0.63 % of arrowroot tea was effective in inhibiting four food-borne pathogenic bacteria, *Escherichia coli*, *Salmonella enteritidis*, *Listeria monocytogenes* and *Staphylococcus aureus* to the minimum detection limit of 1 log cfu/ml at 5 day in brain heart infusion (BHI) medium.

Enterokinase Acitivty

Maranta arundinacea tuber exhibited endogenous esterase activity towards benzoyl arginine

ethyl ester (Bhat et al. 1981). Enterokinase is a serine proteinase required for the activation of pancreatic proenzymes in the duodenum.

Traditional Medicinal Uses

Traditionally the tuberous rhizomes are used in the treatment of diarrhoea (Nishaa et al. 2012). Arrowroot is mainly useful as an easily digested, nourishing diet for convalescents especially for bowel complaints as it has demulcent properties (Grieve 1971). Arrowroot starch in jelly form is suitable as weaning food for infants. Mashed rhizomes are applied topically for wounds from poisoned arrows, scorpion and black spider bites and to arrest gangrene. Freshly expressed juice mixed with water is used as antidote internally for vegetable poisons.

Other Uses

Arrowroot was found to be a food, feed, fuel and fibre resource (Erdman and Erdman 1984). Theoretical yields of 0.27 and 1.60 l of methane at standard temperature and pressure per litre of arrowroot rhizome wash water and starch-settling water were calculated, respectively. Fuel alcohol production potential from yeast-supplemented aerial biomass and coarse residue of arrowroot were identified. Arrowroot coarse residue had qualities that may be suited to tear-resistant specialty grade papers, such as wrapping paper and bags. Studies involving production of extract, fermentation and distillation processes conducted in the Philippines reported arrowroot rhizome to be a promising source of ethanol with 56 % purity (Anonymous 2002). In remote Philippine barrios, arrowroot starch is also used for starching clothes (Stuart 2013).

Arrowroot can be used as screens between neighbouring houses. It provides excellent compost and mulch. Shoot tips and leaves can be utilised as feed for pigs, goats and chickens. The individual leaves can be used as plates during picnics.

Comments

Arrowroot can be propagated by suckers and rootstock or rhizomes.

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Nelumbo nucifera

Scientific Name

***Nelumbo nucifera* Gaertner**

Synonyms

Nelumbium album Bercht. & J.Presl, *Nelumbium asiaticum* Rich., *Nelumbium caspicum* Fisch. ex DC., *Nelumbium caspium* Eichw., *Nelumbium discolor* Steud., *Nelumbium indicum* Poir., *Nelumbium javanicum* Poir., *Nelumbium marginatum* Steud., *Nelumbium nelumbo* Druce, *Nelumbium nuciferum* Gaertn., *Nelumbium rheedii* C.Presl, *Nelumbium speciosum* Willd., *Nelumbium tamara* Sweet, *Nelumbium transversum* C.Presl, *Nelumbium turbinatum* Blanco, *Nelumbium venosum* C.Presl, *Nelumbo caspica* (Fisch.) Schipcz., *Nelumbo caspica* Fisch., *Nelumbo indica* Pers., *Nelumbo komarovii* Grossh., *Nelumbo nelumbo* (L.) H.Karst., *Nelumbo nucifera* var. *macrorhizomata* Nakai, *Nelumbo speciosa* Willd., *Nelumbo speciosa* var. *alba* F.M.Bailey, *Nymphaea nelumbo* L., *Tamara alba* Roxb. ex Steud., *Tamara hemisphaerica* Buch.-Ham. ex Pritz., *Tamara rubra* Roxb. ex Steud.

Family

Nelumbonaceae

Common/English Names

Baladi Bean, Bean Of India, Chinese Water Lily, East Indian Lotus, Egyptian Bean, Hindu Lotus, Indian Lotus, Lotus, Lotus Bean, Oriental Lotus, Sacred Lotus, Sacred Water Lotus, Water Lotus

Vernacular Names

Arabic: Karambeulma, Kanwal Gatta, Nilufer, Ussulnilufer
Brazil: Lotus
Burmese: Padung Ma
Chinese: Lian, Lien (Plant), Ou (rhizome), He-Hua, Ho-Hua (flower), Lian Zi, Lien Tzu (Seed), He-Ye, Ho-Yeh (Leaf), Lien-Yong, Lien Yung (Mashed Cooked Lotus Seed), Ou-Fen (Dried Rhizome Starch)
Czech: Lotos Indický
Danish: Indisk Lotus, Lotus
Dutch: Indische Lotusbloem, Lotus
Estonian: India Lootos
French: Fève d'Egypte, Lotier Lotus Sacré, Lotus Égyiptien, Lotus Indien, Lis Du Nil, Lotus Des Indes, Lotus Magnolia, Racines De Lotus, Rose Du Nil
German: Agyptische Bohne, Indische Lotosblume, Indischer Lotos, Indischer Lotus, Lotos, Lotosblume, Lotus, Nilli Lili, Padma
Hungarian: Indiai Lótusz (Virág)

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***Indonesia*:** Patma, Tarate (Malay), Tarate, Trate (Javanese), Tarate (Sundanese)

India: Podum (Assamese), Kamal, Kombol, Komal, Padama, Padma, Pudmapudu (Bengali), Ambuj, Kamal, Kamal-Kakri, Kanwal, Kanval, Lalkamal, Padam (Hindu), Kamala, Tavare, Tavaribija, Tavarigadde, Thaavare (Kannada), Bem-Tamara, Bemtamara, Centamara, Tamara, Ventamara (Malayalam), Thambal (Manipuri), Kamal, Kamala (Marathi), Kamal (Oriya), Abja, Ambhoja, Ambhoruha, Amboruha, Ambuja, Ambujanma, Ambupadma, Amburoha, Amlana, Aranala, Aravinda, Arvinda, Bisakusuma, Bisaprasuna, Drishopadma, Harivetra, Indiralaya, Jalajanma, Kalhara, Kamala, Kamalam, Kamalodbhavamrajah, Kanval, Kawar, Kunja, Kusesaya, Kusheshaya, Kutapa, Mahapadma, Mahotpala, Nala, Nalika, Nalina, Padma, Padmadrajah, Padmam, Pankaj, Pankaja, Pankajam, Pankeruha, Pathoja, Pundarika, Pundra, Pushkara, Puskara, Putaka, Rajiva, Sahasrapatra, Sahsrapatra, Sarasa, Sarasiruha, Sarojanma, Saroruha, Sarsija, Sarsiruha, Satapatra, Sharada, Sharapadma, Shatapatra, Shri, Shriparna, Shrivasa, Shuklapadma, Sitambuja, Sujala, Svetakamala Tamarasa, Tumarasa, Vanashobhana, Varisoha, Tra (Sanskrit), Acaiyapattipam, Acaiyappattiram, Aciyapattiarm, Akiyapattiram, Allakam, Ambal, Ampala, Ampo, Ampocam, Ampocayoni, Ampucam, Ampucani, Ampucanmam, Ampucatam, Ampucini, Ampunecam, Ampuracam, Ampurecam, Ampuru, Amputam, Ampuyakkoti, Ampuyam, Ampuyatam, Anikini, Anikini, Appucam, Arantam, Arappatumam, Arpakantam, Arpatumam, Arukanvakanam, Arunakamalam, Arunkalaccevvital, Aunikam, Ayamalar, Aymalar, Caccatam, Calacanam, Calacanmam, Calacappu, Calacarakkuli, Calakankakkoti, Calakankam, Calakarankam, Calarukakkoti, Calarukam, Calcam, Calilikam, Cantiram, Caracakkoti, Caracam, Caracijam, Caracirukam, Caravanam, Carocini, Carokkam, Carokulam, Catalam, Catapattiram, Catapatumam, Catippakitakkoti, Catippakitam, Cattalam, Catti, Cattika, Cattikakkoti, Caturaccakan, Cekkamalar, Cenkalam, Centamarai,Ceppilai, Ceyyatamarai, Cirukam, Cirukam, Citalam, Citampocam, Citampucam, Cittetan, Civacattipakirtan, Comakkiyam, Copanam, Cuceyam, Cultalai, Cultalai, Curiyanatpu,, Elimanai, Ellimanai, Intai, Iracacupakkoti, Iracacuyam, Iracalam, Iraciyam, Iramapiriyam, Iramappiriyam, Iramappiriyam, Iramappiriyam, Irampu, Iratacanniyakam, Iratikantal, Iratikantan, Irattacantiyakam, Irattacarorukam, Irattakamalam, Irattakkumutam, Irattakokanam, Irattakumutam, Irattalamutam, Irattamantalam, Irattorpalam, Iravikantam, Irciyam, Jalacam, Kacam, Kamalam, Kamalini, Kancam, Kancamalar, Kancankoti, Kantokakkoti, Kantokam, Kantotam, Karkam, Katirppari, Kauravakkoti, Kauravam, Kokanakam, Kokanakam, Kokayam, Makorpalakkoti, Makorpalam, Malunti, Maraikkoti, Matanalam, Mirinalam, Mirunalakkoti, Mirunalam, Mirunali, Mirunarakkoti, Mirunaram, Mirunarram, Mirutalakkoti, Mirutalam, Muntakakkoti, Muntakam, Nalaki, Nalaki, Nalakikkoti, Nalalmatu, Nalam, Nalikam, Nalini, Nalitam, Nallatamarai, Naticam, Naticam, Nattuttamarai, Nicakaci, NicakacikkotiNirmelcevvanti, Nirmelpaccilai, Nirnatittamarai, Nirniti, Nirorukakkoti, Nirorukam, Palututainayakam, Panikam, Panikkanci, Panikkancikkoti, Pankacam, Pankacatam, Pankacatamakkoti, Pankacatamam, Pankarukam, Pankatam, Pankecam, Pankeram, Panmam, Pannaci, Parparakam, Patmam, Patocam, Patotam, Patumakam, Patumanalakkoti, Ponmanai, Potu, Poykainari, Poykainarinir, Puntaram, Puntarikam, Putpan, Rattorpalam, Tamaracam, Tamaram, Tantamarai, Tantar, Tantulam, Tanturam, Tarutam, Tevanam, Tikkayam, Tirumalarkkoti, Tirumalkompar, Tirumalunti, Totakam, Toyacam, Tunaparicam, Sivapputamarai, Tamarai, Thamarai, Thaamarai, Tamaray, Ventamarai Vicappicuranam, Vicappiracunam, Vicaputpam, Vintu, Vintukam Visaputpam,

Urocanai, Urocani, Urokani, Vacanakkoti, Vacanam, Vanacakkoti, Vanacopanam, Vanicam, Vannivannam, Vantuni, Vantunikkoti, Varicam, Varicam, Varikam, Vaucikakkoti, Vaucikam (Tamil), Damara, Erratamara, Errathaamara, Kalung, Kamalam, Kamalamu, Padmamu, Pundreekamu, Soungadhikamu, Tamara, Thaamara, Thaamara Puvvu, Thella Thaamara, Thellane Padmanu (Telugu), Nilufer (Urdu)

Italian: Fior Di Loto, Giglio De Nilo, Loto d'Egitto, Ninfea d'Egetto

Japanese: Hasu, Hasu-N-Né, Hasu-No-Mi, Renkon

Khmer: Chhuk

Korean: Yeongeun, Yon Puri (Rhizome)

Laotian: Bwà

Malaysia: Bunga Padam, Bunga Telepok, Padema, Seroja, Teratai

Nepal: Kamal, Raato Kamal, Raato Thuulo Kamal

Persian: Beykhneelufer, Nilufer, Nilufu

Philippines: Liñgaling (Ibanag), Sukau (Iloko), Saua (Maguindanao), Baino (Tagalog)

Portuguese: Flor-De- Lótus, Lótus Do Egipto, Lótus-Do-Egito, Lótus Índico, Lótus-Sagrado, Sementes De Lótus

Spanish: Habas De Egipto, Loto Sagrado, Rosa Del Nilo, Semillas De Loto, Nelumbio Raiz De Lotus (Root)

Sri Lanka: Nelum (Sinhalese)

Taiwan: Lian

Thailand: Bua-Luang, Sattabut, Ubon

Tibetan: Pa Dma Dkar Po, Pa Dma Dmar Po, U-Tpa-La

Vietnam: Hoa Sen, Sen, Lien, Ngau (Tay), Bo Bua (Thai), Lin Ngo (Dao)

Origin/Distribution

The species is distributed from the Caspian Sea and Iran through Asia to northern Australian – China (predominantly in Zhejiang, Jiangsu, Anhui, Hunan, Hubei), Bhutan, India, Indonesia (Java), Japan, Korea, Malaysia, Myanmar, Nepal, New Guinea, Pakistan, Philippines, Russia (Far East), Sri Lanka, Thailand, Vietnam, Laos, Kampuchea and northern Australia.

Agroecology

Lotus is strictly aquatic. It grows wild and is cultivated in the mud of shallow, sheltered waters of lakes, ponds and inundated rice fields from sea level to 1500 m elevation in the tropics and subtropics.

Edible Plant Parts and Uses

Lotus is well known as a food and medicinal plant, and its every part is utilised. All parts of the lotus plant, including flowers, seeds, leaves, stems and roots are consumed (Sridhar and Bhat 2007) (Plate 7). In Korea, lotus leaf, root and seed are usually consumed as a tea, or in braised dishes or soups (Ha et al. 2010). Tender rhizomes, stems and leaves of lotus are edible and can be cooked along with other vegetables, soaked in syrup or pickled in vinegar (Phillips and Rix 1993). Rhizomes have mild flavour and are extensively used in Chinese recipe, while stem is used in cooking as food and it tastes like beet (Hedrick 1972; Tanaka and Nguyen 2007). Ogle et al. (2001) reported the use of lotus stem (consisting of 6, 2.4 and 0.2 mg/100 g calcium, iron and zinc, respectively) as a vegetable used in salads at Vietnam. The seeds can be popped like popcorn, ground into powder and eaten dry or used in bread making. The roasted seeds are good coffee substitute and possess saponins. The products of lotus rhizome, such as fresh, salted and boiled lotus rhizome and lotus rhizome starch, drinks, teas and lotus seeds, are very popular in the daily diet (Hu and Skibsted 2007; Zhong et al. 2007). Starches extracted from lotus rhizomes are commercially available in China and consumed in fast food and as breakfast, traditional confectionery and food additives (Zhong et al. 2007). The Korean traditional lotus liquor (Yunyupju) is made from lotus blossom and leaves (Lee et al. 2005). Lotus leaves are used for tea in China

(Zhou et al. 2013a). Lotus leaves are used for tea or food like *yeon yip bap* in Korea (Ahn et al. 2013).

The main types of lotus rhizome processed products are the salt bloated lotus, deep frozen lotus and vacuum-packed lotus (Guo 2009). All these products are mainly exported to Japan, followed by South Korean and other southeast Asian countries. Lotus is one of 26 vegetables with largest sale in China (Jiang and Cao 2005). Currently, the lotus herb is becoming more popular in China as a 'tea drink' or as a main ingredient of some herbal formulations (Ye et al. 2014a). Lotus leaf is used as food or beverage in Taiwan (Lee et al. 2010). In Sulawesi, the young shoots and unexpanded leaves are eaten boiled, and the leaves may be eaten raw (Burkill 1966). The rhizomes are cooked as food or steam and eaten in salad. They are also pickled in salt or vinegar.

The unripe seeds are eaten raw, boiled or roasted, while the ripe seeds are boiled or roasted. Lotus seeds are used in soups, food dishes, sweetmeat, cakes, pastries, desserts and nourishing herbal 'bupin' tea. Dried seeds, sometimes called 'lotus nuts,' must be boiled until softens. The seeds can be crystallised with sugar as part of Chinese New Year sweet offerings, cooked into a sweet soup called 'tong sui' together with dried longan and rock sugar and mashed and cooked into sweetened lotus nut paste ('Lien-yong') which is used as a filling for Chinese moon cakes (in mid-Autumn, it is customary to serve 'moon cakes' which have a filling made of lotus seeds and walnuts), 'daifuku' (Japanese glutinous rice cake with sweet lotus past as fillings), rice flour pudding, pastries, buns, bread and sauces. The seeds are used to prepare 'tong sui' (sweet soup). The seeds can be cooked in soups, usually with chicken or beans. An example of the latter is a 'red bean and lotus seed soup' served at banquets for newlyweds, comprising red beans and lotus seeds. Red beans (*hong dou*) represent strength, while lotus seeds (*lian zi*) symbolise the newlyweds being blessed with a child each year. The soup is also presented at the Chinese New Year's festival. Other popular and common dishes is the 'cream lotus seed soup' which is prepared with crushed pineapple pieces and the 'sweet lotus seed soup dessert' with longan aril seeds, which can be served warm or cold with ice. The Chinese in China and elsewhere also use lotus seeds as a common ingredient in cooling 'bupin' mixtures. In India, the seeds after removal of the outer testa is consumed raw, or dried and puffed like popcorn.

The roots (rhizomes) are a food used extensively in China, Korea and Japan and in southeast Asia are sold whole or in cut pieces, fresh, frozen or canned. It has a crunchy texture with sweet-tangy flavours. The fresh rhizomes are commonly sliced and eaten raw or cooked with meat in soups or fried with salad, prawns, meat, sesame oil and/or coriander leaves in many Asian cuisines. In Thailand, the young rhizomes are peeled and eaten fresh in salads, while in China, Japan, Malaysia and elsewhere, the mature rhizomes are stir-fried, stuffed and deep fried or cooked in soups. Lotus rhizome is also common in Japanese 'bento' food boxes and 'nimono'. In Korea, the root is used as a vegetable in soups and deep-fried, stir-fried and braised dishes. Lotus roots are often pickled with rice vinegar, sugar, chilli and or garlic. Dried rhizome pieces are also fried as chips. A high-quality edible starch is obtained from the rhizomes and is used as baby food and as a special diet for healing sickness in China.

The young leaf petioles, after the rough, outer layer has been scraped off, can be found in local markets and are used in preparing salads and soups or cooked as vegetable with other meat dishes in Thailand, Vietnam and Indonesia (Plate 9). The petioles are also slivered (Plate 10).

In China and Indo-China, flower stamens are used to perfume herbal tea called 'liánhuā cha' in China and trà sen and chè sen in Vietnam. Likewise in India, the stamens of the flowers infused with water are employed to make a fragrant tea. The dried lotus flowers are used in cooking dishes, such as 'Mandarin duck and lotus flowers', and the fresh petals are also edible. In Thailand, young tender leaves are cooked and eaten with a savoury sauce, and the flower petals can be dipped in 'nam prik' or used as garnish. Dried leaves are used for herbal tea in China. In Korea, the leaves and petals are used as a tisane: 'yeonkkotcha' made with dried petals of

white lotus and 'yeonipcha' made with leaves. Lotus leaves are used as wrapper for Chinese 'tamale', a special Chinese pastry in China. The leaves are used as flavouring and wrapping for rice preparations in making dim sum and other sticky, glutinous rice preparations. Lotus leaves are also used for wrapping whole chicken, marinated and douched with rice wine, soy sauce, mushroom and sometimes with some other Chinese herbs before the whole entity is encased in mud or clay and cooked to give the much-relished restaurant specialty called 'beggars chicken' or 'drunken beggars chicken'.

Botany

Nelumbo nucifera is a perennial, rhizomatous, aquatic herb with the horizontal creeping rhizomes and roots buried in the mud (Plate 1). The rhizome has nodes externally and forms roots at these nodes, and internally it has aerenchyma, which is a parenchyma tissue with large intercellular air spaces (Plate 6). The leaves are raised above the water or floating, on terete, fistulous, glabrous or prickly, hollow, 1–2 m long petiole (Plates 9, 10). Leaf's blade is large, abaxially blue-green, orbicular, peltate, 25–90 cm in diameter, papery, glabrous, glaucous and water repellent, having margin entirely (Plates 2, 5). Flowers are large, showy, solitary 10–23 cm in diameter on scape longer than petioles, glabrous or sparsely spinulate (Plates 1, 3). Tepals are caducous, pink or white, oblong elliptic to obovate, 5–10 × 3–5 cm and spirally arranged. Stamens are numerous, slightly longer than receptacle; filament is slender; anther is linear, 1–2 mm; and connective appendage is clavate, 7 mm long and incurved. Ovary is apocarpous, embedded in an obconical, spongy, accrescent, turbinate 5–10 cm in diameter receptacle. Its fruit is a nut oblong to ovoid, 1.0–2.0 × 7–1.5 cm and glabrous; pericarp is thick, hardened (bony) and brown (Plates 4, 5). Seed is having a reddish brown testa, two yellowish-white mealy cotyledons and a stalked green embryo (Plates 5, 7, 8).

Nutritive/Medicinal Properties

Seed/Pod/Receptacle Nutrient/ Phytochemicals

Analyses carried out in the United States reported that raw mature lotus seeds had the following proximate composition (per 100 g value): water, 77 g; energy, 89 kcal (372 kJ); protein, 4.13 g; total lipid, 0.53 g; ash, 1.07 g; carbohydrates, 17.28 g; Ca, 44 mg; Fe, 0.95 mg; Mg, 56 mg; P, 168 mg; K, 367 mg; Na, 1 mg; Zn, 0.28 mg; Cu, 0.094 mg; Mn, 0.621 mg; vitamin C, 0 mg; thiamine, 0.171 mg; riboflavin, 0.040 mg; niacin, 10.429 mg; pantothenic acid, 0.228 mg; vitamin B-6, 0.168 mg; total folate, 28 µg; vitamin A,

Plate 1 Lotus flowers, fruit and leaves

Plate 2 Large peltate, orbicular, waxy leaf

Plate 3 Close up of fertilised lotus flower

13 IU; total saturated fatty acids, 0.088 g; 14:0 (myristic acid), 0.001 g; 16:0 (palmitic acid), 0.077 g; total monounsaturated fatty acids, 0.104 g; 18:1 undifferentiated (oleic acid), 0.062 g; 20:1 undifferentiated (eicosenoic acid), 0.012 g; 22:1 undifferentiated (erucic acid), 0.031 g; total polyunsaturated fatty acids 0.312 g; 18:2 undifferentiated (linoleic acid), 0.285 g; 18:3 undifferentiated (linolenic acid) 0.027 g; tryptophan, 0.059 g; threonine, 0.200 g; isoleucine, 0.205 g; leucine, 0.326 g; lysine, 0.264 g; methionine, 0.072 g; cystine, 0.054 g; phenylalanine, 0.206 g; tyrosine, 0.100 g; valine, 0.266 g; arginine, 0.338 g; histidine, 0.115 g; alanine, 0.239 g; aspartic acid, 0.505 g; glutamic acid,

Plate 4 Lotus fruit

Plate 5 Lotus fruit (TS) and peeled an unpeeled fresh lotus seeds

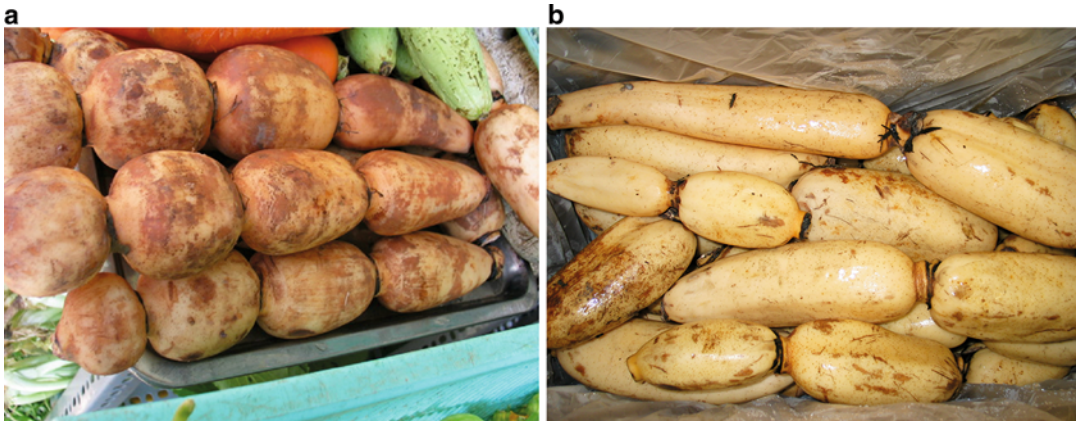

Plate 6 (**a**, **b**) Harvested lotus roots

Plate 7 Lotus root (*left*) lotus seeds and leaves sold in the market

Plate 8 Dried processed lotus seeds

Plate 9 Lotus leaf petioles, peeled and used as food

0.957 g; glycine, 0.221 g; proline, 0.344 g; and serine, 0.252 g (USDA-ARS 2014). The crude protein of lotus seeds was found to be 14.81 % (Ibrahim and El-Eraqy 1996). The essential amino acids found were threonine, 2.43 %; methionine, 0.82 %; leucine, 3.33 %; isoleucine, 1.11 %; and phenylalanine, 12.64 %. The semi-essential amino acids were 7.45 % arginine and 10.79 % histidine. Other amino acids found in adequate amount were glutamic, 26.56 %; proline, 10.76 %; aspartic, 6.17 %; tyrosine, 4.65 %; serine, 4.27 %; glycine, 2.43 %; alanine, 2.77 %; and cysteine, 3.71 %.

Plate 10 Lotus leaf petiole peeled and slivered

The ethanol extract of lotus seeds contained more total fatty acids and total phytosterols than did the ethanol extract of lotus rhizomes.

Most of the fatty acids were in the triglyceride ester form in lotus seeds (Zhou et al. 2013b). Linoleic acid was the most abundant fatty acid compound in lotus seeds and rhizomes. Fatty acids in lotus seeds existed in the glyceride form (59.8 %) and to a lesser extent in their free acid form (12.0 %). The concentration of fatty acid and phytosterol in the triglyceride and stearyl-fatty acid ester (non-polar components) in lotus seeds (g/kg hexane extract) was determined as myristic (C14:0), 0.86 g; palmitic (C16:0), 59.46 g; linoleic, (C18:2), 176.4 g; linolenic (C18:3), 6.66 g; oleic (*cis*-C18:1), 43.19 g; elaidic (*trans*-C18:1), 3.87 g; stearic (C18:0), 5.40 g; gondoic (C20:1), 1.47 g; arachidic (C20:0), 7.77 g; heneicosylic (C21:0), 1.04 g; behenic (C22:0), 28.94 g; tricosylic (C23:0), 1.64 g; lignoceric acid (C24:0), 8.34 g; total fatty acids, 345.97 g; campesterol, 1.55 g; isofucosterol, 0.12 g; β-sitosterol, 10.57 g; β-amyrin, 5.34 g; and total phytosterol, 17.58 g. The concentration of diglycerides, monoglycerides, free fatty acids and free phytosterol (polar components) in lotus seeds (g/kg hexane extract) was determined as diglycerides (1,3-dipalmitoylglycerol, 0.27 g; 1-palmitoyl-2-linoleoylglycerol, 13.17 g; 1-palmitoyl-3-linoleoylglycerol, 32.56 g; 1-oleoyl-2-linolenoylglycerol, 4.91 g; 1-oleoyl-3-linolenoylglycerol, 14.44 g), monoglycerides (1-palmitoylglycerol, 0.80 g; 2-palmitoylglycerol, 12.64 g; 1-linoleoylglycerol, 3.60 g; 1-oleoylglycerol, 2.06 g; 2-behenoylglycerol, 0.26 g), free fatty acids (myristic (C14:0), 0.31 g; palmitic (C16:0), 43.26 g; linoleic (C18:2), 26.06 g; linolenic (C18:3), 1.26 g; oleic (*cis*-C18:1), 13.20 g; elaidic (*trans*-C18:1), 0.74 g; stearic (C18:0), 1.10 g; gondoic (C20:1), 0.45 g; arachidic (C20:0), 0.37 g; behenic (C22:0), 2.24 g; tricosylic (C23:0), 0.38 g; lignoceric acid (C24:0), 0.85 g; total fatty acids, 83.91 g) and free phytosterols (campesterol, 5.25 g; stigmasterol, 0.31 g; β-sitosterol, 56.77 g; β-amyrin, 1.61 g; total phytosterol, 63.94 g). The concentration of diglycerides, monoglycerides, free fatty acids and free phytosterol (polar components) in lotus seeds (g/kg hexane extract) was determined as diglycerides (1,3-dipalmitoylglycerol 0.27 g; 1-palmitoyl-2-linoleoylglycerol 13.17 g; 1-palmitoyl-3-linoleoylglycerol 32.56 g; 1-oleoyl-2-linolenoylglycerol 4.91 g; 1-oleoyl-3-linolenoylglycerol 14.44 g), monoglycerides (1-palmitoylglycerol 0.80 g; 2-palmitoylglycerol 12.64 g; 1-linoleoylglycerol 3.60 g, 1-oleoylglycerol 2.06 g; 2-behenoylglycerol 0.26 g), free fatty acids (myristic (C14:0) 0.31 g, palmitic (C16:0) 43.26 g, linoleic (C18:2) 26.06 g, linolenic (C18:3) 1.26 g, oleic (*cis*-C18:1) 13.20 g, elaidic (*trans*-C18:1) 0.74 g, stearic (C18:0) 1.10 g, gondoic (C20:1) 0.45 g, arachidic (C20:0) 0.37 g, behenic (C22:0) 2.24 g, tricosylic (C23:0) 0.38 g, lignoceric acid (C24:0) 0.85 g, total fatty acids 83.91 g) and free phytosterols (campesterol 5.25 g, stigmasterol 0.31 g, β-sitosterol 56.77 g, β-amyrin 1.61 g, total phytosterol 63.94 g). Lotus seed oil was found to be an excellent source of crude oil, 3.52 g/100 g dw (Anitha and Arunkumar 2012). The oils had an acid value of 26.66 mg KOH, saponification value of 210.43 mg KOH, peroxide value of 10.60 g/100 g, iodine value of 6.00 and free fatty acids of 3.50 g. Crude fat content of lotus seed oil hexane extract was 38.6 %, and fatty acid methyl esters found included capric acid methyl ester (C10:0), lauric acid methyl ester (C12:0), tridecanoic acid methyl ester (C13:0), palmitic acid methyl ester (C16:0), pentadecanoic acid methyl ester (C15:0), *cis*-10-pentadecanoic acid methyl ester (C15:1), palmitoleic acid methyl ester (16:1), *cis*-10-heptadecanoic acid methyl ester (C17:1) and nonadecanoic acid methyl ester (C19:1).

Seed starch grain was oval and contained higher amylase content starch and gelatinisation temperature than rhizome (Man et al. 2012). Seed starches exhibited an A-type X-ray diffraction pattern with higher crystalline degree. Seed starch had lower acid hydrolysis and higher porcine pancreatic α-amylase hydrolysis than rhizome starch. A novel lotus plumule polysaccharide

(LPPS) comprising two components F1 and F2 was purified and characterised (Liao and Lin 2012). The molecular weights of native F1 and F2 were approximately distributed at >2000 and 25.7 kDa, respectively. The total protein and carbohydrate constituent ratios in LPPS, F1 and F2 were 30.0 % vs. 70.0 %, 30.1 % vs. 69.9 % and 96.5 % vs. 3.5 % (w/w), respectively, suggesting that F1 may be a major proteo-polysaccharide component and F2 a glycoprotein constituent in LPPS.

Nn-9 was a non-crystalline alkaloid isolated from lotus embryo (Chen et al. 1962). Bisbenzylisoquinoline alkaloids liensinine (Chao et al. 1962; Pan et al. 1962; Hsieh et al. 1964a; Guo and Chen 1984) and isoliensinine were isolated from lotus embryo (Tomita et al. 1964; Guo and Chen 1984). Liensinine was also totally synthesised by Ullmann condensation of 1-(3-bromo-4-benzyloxy-benzyl)-2-methyl-6,7-dimethoxy-1,2,3,4-tetrahydroisoquinoline and 1-(4-benzyloxy-benzyl)-2-methyl-6-methoxy-7-hydroxy-1,2,3,4-tetrahydroisoquinoline (Hsieh et al. 1964b). Pronuciferin is a benzylisoquinoline with para-cyclohexadienone grouping (Bernauer 1963, 1964); the noraporphine alkaloid anonaine, besides the aporphines nuciferine, roemerine and 5-methoxy-6-hydroxy-aporphine, was isolated from lotus cotyledons (Bernauer 1964). Isoliensinine, a new phenolic biscoclaurine-type alkaloid, was isolated from Formosan "Lien Tze Hsin," lotus seed embryo (Tomita et al. 1965). A new, water-soluble, quaternary base alkaloid named lotusine was isolated from a Formosan lotus embryo besides the earlier reported isoliensinine (Furukawa et al. 1965). A new base, neferine as well as isoliensinine, were isolated from "Lien Tze Hsin" (*Nelumbo nucifera* embryo), from Hong Kong market (Furukawa 1965a). Liensinine was found to be the main alkaloid in Japanese lotus embryo, besides a small amount of neferine (Furukawa 1965b). *O*-Methylneferine (styphnate) was found to be completely identical with the synthesised O, *O*-dimethylisoliensinine, reported previously. When *O*-methylneferine was subjected to the cleavage reaction by metallic sodium in liquid ammonia, D-1, 2, 3, 4-tetrahydro-6-methoxy-1-(*p*-methoxybenzyl)-2-methyl-7-isoquinolinol and D-*O*-ethylarmepavine were obtained. Following the isolation of biscoclaurine alkaloids, isoliensinine and neferine, from Lien Tze Hsin (*N. nucifera* embryo), from Hong Kong market, nuciferine and pronuciferine were isolated from the non-phenolic portion and lotusine from the water-soluble quaternary base portion (Furukawa 1966a). Also, neferine and liensinine were found in lotus seeds from Nepal. Three kinds of phenolic biscoclaurine-type bases were obtained from lotus embryo (Lien Tze Hsin) liensinine, isoliensinine and neferine (Furukawa 1966b). A tertiary tetrahydroisoquinoline alkaloid, methylcorypalline and the biscoclaurine base neferine were isolated from lotus embryo besides the known isoliensinine and lotusine (Yang and Chen 1970a, b).

A tetrahydroisoquinoline alkaloid with a secondary base was isolated in crystalline form from *N. nucifera* embryo and identified with 1-(*p*-hydroxybenzyl)-6, 7-dihydroxy-1, 2, 3, 4-tetrahydroisoquinoline (demethylcoclaurine) (Koshiyama et al. 1970). Three kinds of phenolic biscoclaurine-type bases liensinine, isoliensinine and neferine plus *O*-dimethylliensinine were obtained from lotus embryo (Lien Tze Hsin) of lotus (Furukawa 1971). The structure of nornuciferine, an aporphine-type tertiary phenolic base isolated from the domestic lotus, was proved to be correct (Tomita et al. 1971). From lotus receptacle, four alkaloids, nuciferine, *N*-nornuciferine, oxoushinsunine and *N*-norarmepavine, were isolated (Yang et al. 1972). Isoliensinine, neferine, (±)-armepavine and 4′-methtyl-*N*-methylcoclaurine were isolated from lotus embryo (Nishibe et al. 1986). Six alkaloids lotusine, nuciferine, pronuciferine, liensinine, isoliensinine and neferine were isolated from lotus green seed embryo (Wang et al. 1991). Liensinine was extracted from lotus embryo by impregnating and refluxing, yielding content of 0.853 % and 0.939 % and with average recovery of 97.9 % and 100.9 %, respectively (Hu et al. 1993).

The pronucerine monomer was isolated from lotus seed (Xiao et al. 2007). Using the first solvent system of light petroleum–ethyl acetate–tetrachloromethane–chloroform–methanol–water

solvent system, 1102 mg of the crude lotus embryo was purified yielding 350 mg neferine, 100 mg isoliensinine and 95 mg liensinine with over 95 % purity (Wu et al. 2004). While using the second solvent system ethyl acetate–tetrachloromethane–methanol–water, 5850 mg of the crude alkaloid was purified yielding 2545 mg neferine, 698 mg isoliensinine and 650 mg liensinine with over 97 % purity. Three bisbenzylisoquinoline alkaloids (liensinine, isoliensinine and neferine) were isolated from lotus embryo (Chen et al. 2007). The mass fractions of liensinine, isoliensinine and neferine in the crude extract and the phenolic alkaloid sample of lotus embryo were 16.5 and 228.6 mg/g for liensinine, 45.7 and 640.7 mg/g for isoliensinine and 59.7 and 58.8 mg/g for neferine, respectively. Neferine, a bisbenzylisoquinoline alkaloid, is extracted (isolated) from the green seed embryo (Chen et al. 2008). From 200 mg of crude extract, 18.4 mg of liensinine, 19.6 mg of isoliensinine and 58.4 mg of neferine were obtained with the purity of 96.8, 95.9, and 98.6 %, respectively from lotus seed embryo (Liu et al. 2009). In a separate study, 200 mg of crude lotus embryo extract, 33 mg of liensinine, 42 mg of isoliensinine and 67 mg of neferine were obtained all with purities over 98 % (Duanmu et al. 2010). A 2.5 g crude alkaloid extract from lotus seed yielded 151 mg of liensinine, 118 mg of isoliensinine and 572 mg of neferine with purities of 93.0, 95.1 and 97.0 %, respectively (Wang et al. 2010). From the embryos of lotus seeds, three bisbenzylisoquinoline alkaloids, nelumboferine and nelumborines A and B, were isolated along with four known compounds, neferine, liensinine, isoliensinine and anisic acid (Itoh et al. 2011). Bisbenzylisoquinoline alkaloid, nelumboferine which was recently isolated from the embryo of *Nelumbo nucifera* and stereoisomers of neferine, a major alkaloid of the embryo of *N. nucifera*, were stereoselectively synthesised (Nishimura et al. 2013). Ten major anti-inflammatory compounds were identified from lotus plumule, i.e. higenamine, lotusine, 4′-methylcoclaurine, isoliensinine, liensinine, neferine, armepavine, 4′-methyl-*N*-methylcoclaurine, apigenin-6-*O*-α-L-glucopyanosyl-8-*O*-β-D-glucopyranoside and apigenin-6-*O*-α-L-arabofuranosyl-8-*O*-β-D-glucopyranoside, and from seeds apigenin-6-*O*-α-L-arabofuranosyl-8-*O*-β-D-glucopyranoside and unknown compound (Zhou et al. 2013a).

The flavonoid content of lotus seed embryos was high, 730.95 mg 100/g DW (dry weight), seed coats had much less total flavonoid (<40 mg/100 g FW) and seed kernels had no flavonoids (Chen et al. 2012b). Seed coats contained myricetin 3-*O*-glucoside; quercetin 3-*O*-arabinopyranosyl-(1 → 2)-galactopyranoside; myricetin 3-*O*-glucuronide; quercetin 3-*O*-rhamnopyranosyl-(1 → 6)-glucopyranoside (rutin); quercetin 3-*O*-galactoside (hyperoside), quercetin 3-*O*-glucoside (isoquercitrin); quercetin 3-*O*-glucuronide; isorhamnetin 3-*O*-rutinoside; kaempferol 3-*O*-glucoside (astragalin); syringetin 3-*O*-glucoside; isorhamnetin 3-*O*-glucoside and kaempferol 3-*O*-glucuronide. Fruit coats contained similar flavonoids plus kaempferol 3-*O*-galactoside; diosmetin 7-*O*-hexose; isorhamnetin 3-*O*-glucuronide; quercetin and diosmetin. Four known alkyl 4-hydroxybenzoates, i.e. methyl 4-hydroxybenzoate; ethyl 4-hydroxybenzoate; propyl 4-hydroxybenzoate and butyl 4-hydroxybenzoate, were isolated from lotus seeds (Youn et al. 2010). Four aglycones of Fr2 fraction from lotus seed epicarp (seed coat) were identified as myricetin, quercetin, kaempferol and isorhamnetin (Kredy et al. 2010). The results indicated that the quercetin content in Fr2 (10.2 mg/g of dry fraction) was higher than isorhamnetin (6.2 mg/g of dry fraction), followed by kaempferol (2.8 mg/g of dry fraction) and myricetin (0.4 mg/g of dry fraction). Six glycosylated flavonols were found in Fr2 fraction; they were myricetin monohexosides (may be myricetin 3-*O*-galactoside or myricetin 3-*O*-glucoside); quercetin diglycoside, confirmed as rutin (quercetin 3-*O*-rutionoside); quercetin monohexoside (the hexose could be glucoside or galactoside); kaempferol-monodeoxyhexoside-monohexoside, possibly kaempferol 3-*O*-rutinoside; isorhamnetin-monodeoxyhexoside-monohexoside, possibly isorhamnetin 3-*O*-rutinoside; and an isorhamnetin monohexoside (the hexose may be glucoside or galactoside) (Kredy et al. 2010).

The procyanidins of lotus seedpod were extracted with aqueous acetone with a purity of >98 % (Lin et al. 2005). The main molecular weight distribution of procyanidins ranged from 291 to 1155, with M+H peak values of 291.1, 579.2, 731.2, 867.2, 1019.4 and 1155.3, respectively, indicating the extract contained monomers, dimers and tetramers of procyanidins, in which the amounts of dimers were greatest, and catechin and epicatechin were the base units. The procyanidins of lotus seedpod were extracted with aqueous acetone with a purity of >98 % (Lin et al. 2005). The main molecular weight distribution of procyanidins ranged from 291 to 1155, with M+H peak values of 291.1, 579.2, 731.2, 867.2, 1019.4 and 1155.3, respectively, indicating the extract contained monomers, dimers and tetramers of procyanidins, in which the amounts of dimers were greatest, and catechin and epicatechin were the base units. Five flavonol glycosides, including hyperoside, isoquercitrin, quercetin-3-*O*-ß-D-glucuronide, isorhamnetin-3-*O*-ß-D-galactoside and syringetin-3-*O*-ß-D--glucoside, were determined in lotus receptacle with recoveries in the range of 98.31–100.32 % (Wu et al. 2013). The oligomeric and polymeric fraction of the 60 % aqueous methanol lotus seed pod extract had a mean degree of polymerisation of 3.2 and 15.4, respectively, and consisted of (+)-catechin (m/z 289), gallocatechin or epigallocatechin (m/z 305), quercetin glycoside (m/z 463), quercetin glucuronide (m/z 477), procyanidin dimers (m/z 577.1), proanthocyanidin dimer gallate (m/z 593.3), prodelphinidin dimers (m/z 609.1), procyanidin trimers (m/z 865.1), etc (Xiao et al. 2012). Quercetin glucuronide was further purified and identified as quercetin -3-*O*-β-glucuronide. A flavonoid quercetin [2-(3,4-dihydroxy)-3, 5, 7-trihydroxy-4*H*-1-benzopyran-4-one] was isolated from lotus dried receptacle (Ishida et al. 1988). Five flavonol glycosides, namely, hyperoside, isoquercitrin, quercetin-3-*O*-β-D-glucuronide, isorhamnetin-3-*O*-β-D-galactoside and syringetin-3-*O*-β-D-glucoside, were isolated from lotus receptacle (Wu et al. 2012).

Lotus seeds were found to contain annexins, multifunctional proteins (Chu et al. 2012). A heat-induced annexin, NnANN1, was identified from lotus embryonic axes that was found to play an important role in seed thermotolerance and germination vigour. Compared to the wild-type seeds, transgenic seeds ectopically expressing NnANN1 exhibited improved resistance to accelerated ageing treatment. Also transgenic seeds showed enhanced peroxidase activities, accompanied with reduced lipid peroxidation and reduced ROS release levels compared to the wild-type seeds. Studies by Shen-Miller et al. (2013) showed that in proteins of *N. nucifera* fruit that were able to withstand heating, 31 % of which remained soluble in the 110 °C-treated embryo-axis of a 549-yr-old fruit and 76 % retained fluidity in its cotyledons. At 110 °C for 10 min, 22.6 μg/mg of thermal proteins were recovered from the embryo-axis of a 549-year-old lotus seed versus 7.1 μg/mg from modern seeds; 11.1 μg/mg were recovered from the cotyledons of a 549-year-old seed versus 21.9 μg/mg from the cotyledons of modern seeds. The amino-acid sequences of 11 "thermal proteins" (soluble at 100 °C) of modern *Nelumbo* embryo-axes and cotyledons were identified as dehydrin (glutamine, lysine), 55 % total amino acid; HSP80 (lysine/glutamine, asparagine), 38 %; CPN60 (lysine, glutamine), 33 %; vicilin (glutamine, lysine, arginine/asparagine), 30 %; EF-1α (lysine, asparagine, glutamine), 29 %; met-synthase (glutamine, lysine, asparagine), 36 %; 1-CysPRX (lysine, asparagine), 26 %; ENO1 (lysine, glutamine), 24 %; CPN20 (lysine, glutamine, asparagine), 22 %; PIMT (glutamine, lysine, asparagine), 21 %; and CuZn-SOD (asparagine, lysine, glutamine), 18 %. The 11 Nelumbo thermal proteins studied could be grouped into four functionally defined categories: antioxidant and membrane maintenance (CuZn-SOD,1-CysPRX, dehydrin); chaperonins, chaperone and stress proteins (Cpn20, Cpn60, HSP80, EF-1α); defence, food and repair (vicilin, Met-Synthase, PIMT); and anaerobic glycolytic protein (Enolase1 (ENO1)). In addition, 30 other heat-stable proteins of *N. nucifera* cv. China Antique were identified: actin 12, aldose reductase, allergen Ara h1 clone, nep1 aspartic proteinase nepenthesin 1, chaperone protein yajL, embry-

onic protein DC-8, pistil-specific extensin-like protein, FBA fructose biphosphate aldolase (cytosol enzyme), 11S globulin β, FA02 13S globulin seed storage protein 1, GluA1 glutelin type A1, GluB1 glutelin type B1, GAPC glyceraldehye-3-phosphate dehydrogenase (cytosol), HSP18.2 18.2 kDa Class 1 heat shock protein and HSP70; late embryonic abundant (LEA) proteins Dc3, Dc 8 and Dc 34; and Legumin A (LEGA), Legumin B (LEGB), low temperature-induced 65 kDA (LT65) protein, malate dehydrogenase (MDH), 5-methyltetrahyd ropteroyl-triglutamate-homocysteine methyl-transferase (metE), early nodulin-like protein 1(Atg25060), protein notum homolog (NOTUM), pectiesterase 2 (PECS-2.1), PCKR 1 peptidyl-prolyl *cis*-trans isomerise, peroxidase 12 (PER12), phosphoglycerate kinase (cytosol) and tricohyalin and triose-phosphate isomerase (TCHH).

The main constituents in the essential oils from the various rhizome and seed samples were l-(+)-ascorbic acid 2,6-dihexadecanoate (0–33.5 %), *trans*-phytol (5.1–24.1 %), hexahydrofarnesyl acetone (5.6–15.3 %), pentadecyl acrylate (2.2–12.4 %), geranyl acetone (1.9–8.0 %) and β-ionone (0–8.0 %) (Huang et al. 2010a). The rhizome lotus and seed lotus samples were clustered into separate groups by hierarchical cluster analysis according to the composition of the corresponding essential oils. No significant relationship was found between essential oil composition and geographical distribution of the 11 populations.

Young chloroplasts were found in shoots of mature dry lotus seeds, and they gave rise to mature chloroplasts during germination, even in darkness (Ushimaru et al. 2003). These shoots contained chlorophyll and chlorophyll-binding proteins CP1 and LHCP.

Rhizome Nutrients/Phytochemicals

The nutrient composition of raw rhizome per 100 g edible portion was reported as follows: water, 79.10 g; energy, 74 kcal (311 kJ); protein, 2.60 g; total lipid, 0.10 g; ash, 0.97 g; carbohydrates, 17.23 g; total dietary fibre, 4.9 g; Ca, 45 mg; Fe, 1.16 g; Mg, 23 mg; P, 100 mg; K, 556 mg; Na, 40 mg; Zn, 0.39 mg; Cu, 0.257 mg; Mn, 0.261 mg; Se, 0.7 µg; vitamin C, 44 mg; thiamine, 0.160 mg; riboflavin, 0.220 mg; niacin, 0.400 mg; pantothenic acid, 0.377 mg; vitamin B-6, 0.258 mg; total folate, 13 µg; total saturated fatty acids, 0.030 g; 16:0 (palmitic acid), 0.028 g; 18:0 (stearic acid), 0.001 g; total monounsaturated fatty acids, 0.020 g; 16:1 undifferentiated (palmitoleic acid), 0.002 g; 18:1 undifferentiated (oleic acid), 0.014 g; 20:1 (eicosenoic acid), 0.002 g; total polyunsaturated fatty acids, 0.020 g; 18:2 undifferentiated (linoleic acid), 0.014 g; 18:3 undifferentiated (linolenic acid), 0.02706 g; tryptophan, 0.020 g; threonine, 0.051 g; isoleucine, 0.054 g; leucine, 0.069 g; lysine, 0.094 g; methionine, 0.022 g; cystine, 0.022 g; phenylalanine, 0.047 g; tyrosine, 0.029 g; valine, 0.055 g; arginine, 0.088 g; histidine, 0.038 g; alanine, 0.054 g; aspartic acid, 0.369 g; glutamic acid, 0.139 g; glycine, 0.156 g; proline, 0.136 g; and serine, 0.060 g (USDA-ARS 2014).

The nutrient composition of the rhizome per 100 g edible portion (CINE 2007) was reported as follows: moisture, 80.5 g; energy, 75 kcal; protein, 1.9 g; fat, 0.2 g; carbohydrate, 16.4 g; fibre, 1.2 g; ash, 1 g; vitamin A, 3 µg RE (1.5 µg RAE); total carotene, 20 µg; vitamin C, 44 mg; Zn, 0.23 mg; Fe, 1.4 mg; and Ca, 39 mg. Another study reported that the rhizomes have thiamine, 0.16 mg; riboflavin, 0.22 mg; niacin, 0.4 mg; vitamin C, 44 mg; calcium, 45 mg; phosphorus, 100 mg; iron, 1.6 mg; potassium, 730 mg; sodium, 40 mg; magnesium, 25 mg; zinc, 0.2 mg; protein, 2.6 g; carbohydrate, 14.7 g; and fat, 0.1 g (Howard et al, 1962). Korean white lotus cultivars (Inchisa, Muan, Garam and Chungyang) and rhizomes were reported to possess high amounts of bioactive compounds: total phenols, between 7.95 and 4.21 mg of gallic acid equivalents (GAE)/g dry weight (DW); ascorbic acid, between 15.8 and 22.3 mg of ascorbic acid/g DW; and amino acids, between 15.05 % and 16.62 0 % DW (Park et al. 2009). Tryptophan was isolated from the aqueous extract of lotus rhizome (Jiang et al. 2010).

The ethanol extract of lotus rhizomes contained less total fatty acids and total phytosterols than did the ethanol extract of lotus seeds (Zhao et al. 2013a). The concentration of fatty acid and phytosterol in the triglyceride and stearyl-fatty acid ester (non-polar components) in lotus rhizomes (g/kg hexane extract) was determined as follows: palmitic (C16:0), 43.64 g; linoleic (C18:2), 53.68 g; linolenic (C18:3), 7.91 g: oleic (*cis*-C18:1), 14.27 g: elaidic (*trans*-C18:1), 1.17 g; stearic (C18:0), 8.34 g; arachidic (C20:0), 0.43 g; behenic (C22:0), 1.56 g; and total fatty acids, 131.01 g. The concentration of diglycerides, monoglycerides, free fatty acids and free phytosterol (polar components) in lotus rhizomes (g/kg hexane extract) was determined as follows: diglycerides (0.27 g 1-palmitoyl-2-linoleoylglycerol and 0.45 g 1-palmitoyl-3-linoleoylglycerol), monoglycerides (8.13 g 2-palmitoylglycerol and 7.11 g 1-linoleoylglycerol), free fatty acids (myristic (C14:0), 0.11 g; palmitic (C16:0), 6.80 g; linoleic (C18:2), 5.21 g; linolenic (C18:3), 1.51 g; oleic (*cis*-C18:1), 1.51 g; elaidic (*trans*-C18:1), 0.15 g; stearic (C18:0), 0.41 g; gondoic (C20:1), 0.02 g; arachidic (C20:0), 0.09 g; heneicosylic (C21:0), 0.02 g; behenic (C22:0), 0.34 g; tricosylic (C23:0), 0.08 g; lignoceric acid (C24:0), 0.45 g; and total fatty acids, 83.9116.02 g) and free phytosterols (campesterol, 4.51 g; isofucosterol, 0.65 g; β-sitosterol, 76.27 g; β-amyrin, 7.34 g; α-amyrin, 7.78 g; lanosterol, 12.68 g; and total phytosterol, 109.22 g).

The proximate composition of lotus rhizome flour (g/100 g flour) was determined as ash (1.10 g), the total nitrogen (1.36 g), total protein (8.48 g), water-soluble proteins (1.23 g), salt-soluble proteins (5.73 g), total salt-soluble proteins (6.064 g), total sugar (19.08 g), reducing sugars (0.168 g), non-reducing sugars (18.87 g) and free amino acids (0.78 g) (Shad et al. 2011). The temperature-dependent behaviour of solubility and swelling capacity of the rhizome flour showed a linear increase (1.2–13.84 %) in solubility but an exponential increase in swelling capacity with a gradual increase in the temperature (40–100 °C). Water absorption and oil holding capacities were found to be 2.56 and 2.03 %, respectively, while least gelation concentration, foaming volume increase, foaming stability, emulsifying capacity and emulsion stability were 18.0 %, 5.23 %, 4.97 %, 48.93 % and 96.43 %, respectively. The lotus rhizome was found to be a poor source of crude oil (2.68 g/100 g dry weight) with the following physicochemical properties: crude fat (2.68 g/100 g DW), acid value (16.66 mg KOH), saponification value (110.43 mg KOH) and unsaponifiable matter (0.026 g/100 g oil).

The amylose content was the highest (30.61 %) in lotus starch (Zhiong et al. 2007). The average particle size (diameter) was 50.27, 24.08 and 38.97 μm for lotus, kudzu and corn starches, respectively. Lotus starch exhibited a B-type X-ray diffraction pattern and kudzu starch exhibited a C-type pattern. Kudzu starch was characterised by a maximum viscosity immediately followed by a sharp decrease in viscosity, while the lotus starch was characterised by a plateau when the maximum viscosity was reached.

Lotus rhizome starches had small oval granules and large elongated granules (Man et al. 2012). Rhizome starches had higher swelling power, lower amylase content and gelatinisation temperature than seed starch. Rhizome starches showed a C-type pattern which changed from C to A type with gradually increasing crystalline degree during acid hydrolysis. The degree of order in starch external region was higher in rhizome than in seed. The external region structure of rhizome starches became more ordered during acid hydrolysis. Rhizome starches had higher rate of acid hydrolysis and lower rate of porcine pancreatic α-amylase hydrolysis than seed starches. Starch in rhizome of lotus cultivar Meirenhong exhibited C-type X-ray diffraction pattern, while starch in rhizome of cultivar Wawalian showed A-type pattern (Yu et al. 2013a). Starch granules in cv. Meirenhong showed oval-shaped granules, while starch granules in cv. Wawalian were elongated and oval in shape with relatively large size. Gelatinisation temperatures of starch in Meirenhong and Wawalian were 330.5 and 342.4 K, respectively, and the gelatinisation temperature range of Meirenhong was significantly wider than that of Wawalian. Starch in rhizome of cv. Meirenhong

showed lower pasting temperature, lower hot and cool viscosities, lower setback and higher peak viscosity and breakdown than those of cv. Wawalian in rapid viscosity analyser pasting profiles at 6 % starch concentration. Amylose molecules in lotus rhizome starch were large, with number-average and weight-average degrees of polymerisation (DPs) of 4170 and 8040, respectively, number-average chain length ($\overline{CL}_n$) of 540 and apparent DP distribution range of 520–42,000 (Suzuki et al. 1992). The $\overline{CL}_n$ of amylopectin was 22.3, and its distribution by gel-exclusion HPLC showed three peaks, at DP 14, 42 and 1900, and a shoulder at DP 63. The amylose content was 15.9 % determined by iodine affinity and 17.4 % determined by blue value. The onset of gelatinisation determined by photopastegraphy was at 58.5 °C. The amylogram of the starch resembled that of tapioca starch. The retrogradation tendency of lotus starch was slower than that of potato, lily and kudzu starches but faster than that of tapioca starch. During gelatinisation of lotus rhizome starch, the crystallinity changed from C type to A type via CA type and finally became amorphous structure (Cai et al. 2014). The amylose content, crystal degree, helix content, ratio of 1045/1022 cm^{-1} and peak intensity of crystalline lamellae of gelatinising starch significantly decreased after 70 °C. The amorphous content and ratio of 1022/995 cm^{-1} increased after 70 °C. The study elucidated that B-type allomorph was mainly arranged in the distal region of eccentric hilum, A-type allomorph was mainly located in the periphery of hilum end, and the centre of the starch granule was a mixed distribution of A- and B-type allomorphs. Lotus seed-resistant starch (LRS), a type of retrograded starch, is commonly known as resistant starch type 3 (RS3) (Zhang et al. 2014). Compared with native starch and high amylose maize starch (HAMS), LRS lacked the polarisation cross, and the irregularly shaped LRS granules had a rougher surface, B-type crystal structure and greater level of molecular order.

The petroleum ether extract of lotus rhizomes yielded steroids; the chloroform extract yielded alkaloids and steroids; the methanol and water extracts yielded alkaloids, steroids, reducing sugars and saponins (Mukherjee et al. 1998). The detection and quantification limitations of catechin were 23 ng and 50 ng, respectively, in lotus rhizome (Yan et al. 2009). The catechin level was 0.0025 % in the lotus rhizome and 0.011 % in the knot of the lotus rhizome. (±)-Gallocatechin and (–) catechin plus LB2 was a polysaccharide-protein complex with a molecular mass of 18.8 kDa isolated from lotus rhizome (Jiang et al. 2011). LB2 was identified as a polysaccharide sulphate containing α/β-pyranose and α-furanose. It was composed of mannose, rhamnose, glucose, galactose and xylose with a molar ratio 2:8:7:8:1.

The percentage of recovery of betulinic acid from lotus rhizome by HPTLC was found to be 98.36 % (Mukherjee et al. 2010c). The limit of detection and limit of quantification of betulinic acid were detected to be 0.4 and 2.30 µg per spot. From lotus rhizome, a new ursane triterpenoid ester, urs-12-en-3β-*O*-9*E*,12*E*-octadecadienoate, was identified along with the isolation of seven known compounds (palmitic acid, linoleic acid, 9*E*,12*E*,15*E*-octadecatrienoic acid, α-amyrin, β-sitosterol, betulinic acid and β-sitosterol-3-*O*-glucoside) (Chaudhuri and Singh 2009) and a new triterpenoid, 2α,24-diacetoxy-3β-hydroxyolean-12-en-28-oic acid, along with four known compounds (hyptatic acid-A (2α,3β,24-trihydroxyolean-12-en-28-oic acid), maslinic acid (2α,3β-dihydroxyoleane-12-ene-28-oic acid), betulin and lupeol) (Chaudhuri and Singh 2013).

Fifteen compounds were isolated from the total alkaloid extract of lotus stem (rhizome) and identified as asimilobine, isococlaurine, *N*-acetylnorarmepavine, crykonisine, velucryptine, pycnarrhine, liriodenine, nuciferine, nornuciferine, armepavine, *N*-methylasimilobine, coclaurine, *N*-norarmepavine (13), *N*-methylcoclaurine and lysicamine (Duan et al. 2013). Astragalin, rutin, isoquercetin, nuciferine, dauricine, isoliensinine and neferine were identified in lotus rhizomes (Zhao et al. 2014).

High-quality RNA was recovered from five different tissues of lotus as assessed by polyphenol oxidase (PPO) gene expression profiles (Zhang et al. 2013b). The relative expression lev-

els of the PPO gene based on RTPCR in five tissues of lotus were rhizome buds (2.66), young leaves (2.42), fresh cut rhizome (2.02), petals (1.80) and petiole (1.65), using housekeeping gene β-actin as an internal control. The ethanol extracts of lotus seeds from Vietnam (Ho Chi Minh City), raw rhizomes from Korea (Siheung) and dried rhizomes from Japan (Nigata) had the greatest specific flavonoid content (Zhao et al. 2014). The ethanol extracts of seeds from China (Hubei), raw rhizomes from Japan (Nigata) and dried rhizomes from Korea (Siheung) had the greatest specific alkaloid content.

Leaf Nutrients/Phytochemicals

Proximate nutrient composition of lotus leaf (g DW/100 g) was reported as moisture, 1.65 g; crude protein, 14.47 g; crude lipid, 2.29 g; crude ash, 9.36 g; carbohydrate, 10.23 g; chemicals (mg DW)/100 g K, 1345.25 mg; Ca, 1069.51 mg; P, 293.27 mg; Mg, 261.48 mg; Na, 12.4 mg; Fe, 4.32 mg; Zn, 1.76 mg; Cu, 0.26 mg; sucrose, 1646.56 mg; fructose, 210.70 mg; glucose, 110.14 mg; vitamin A, 714.61 mg; vitamin C, 679.59 mg; vitamin B1, 4.10 mg; and vitamin B2, 3.67 mg (Ha et al. 2010).

Scanning electron microscopy and chemical analysis of the chloroform extract of lotus leaves showed that the wax was composed of a mixture of aliphatic compounds, principally nonacosanol and nonacosanediols (Koch et al. 2006). Analysis of gas chromatography spectra of lotus leaf waxes showed a much lower proportion of the secondary alcohol nonacosan-10-ol (16.2 % by weight) compared with nonacosanediols (64.7 %). Gas chromatographic analysis of the extracted leaf waxes revealed nonacosan-10-ol (16.2 %), triacontan-7-ol (2.4 %), nonacosane-4, 10-diol (18.6 %), nonacosine-5, 10-diol (34.1 %), nonacosane-10, 13-diol (12.0 %), hentriacontane- 12, 15-diol (1.8 %), tritriacontane-9, 10-diol (0.7 %) and octadecanoic acid (0.7 %).

The first alkaloid isolated from lotus leaves was nuciferine (Arthur and Cheung 1959). Alkaloids were found in lotus leaves, petiole and cotyledons in the fruit but not in the edible rhizome (Tomita et al. 1961c). Roemerine and nuciferine were isolated as the tertiary, nonphenolic bases, and a new base, nornuciferine, as the tertiary phenolic base, from the leaves. Roemerine and nornuciferine were isolated from the petiole but not from nuciferine. The results indicated that the main alkaloids of lotus are all tertiary bases of the aporphine type. Roemerine, nuciferine and nornuciferine, a new aporphine-type tertiary phenolic base, were isolated from the leaves and petioles of domestic lotus (Tomita et al. 1961a). Besides the isolation of phenolic bases, nuciferine, roemerine and nornuciferine, another base, *dl*-armepavine, was isolated from the leaves (Tomita et al. 1961b). Aporphine-type alkaloid bases, roemerine, and nornuciferine, and benzyl-tetrahydro-isoquinoline-type base, armepavine, from the leaves, and roemerine and nornuciferine from the leaf petiole were isolated from an ancient lotus cultivar Ohga-hasu (Tomita and Frurukawa 1962). Alkaloids contained in the so-called primitive lotus 'gen-shi-hasu' were similar to domestic lotus: roemerine, nuciferine, nornuciferine and *dl*-armepavine (Kunitomo et al. 1964). Cleavage reaction of nuciferine and nornuciferine by metallic sodium in liquid ammonia afforded 2-methoxyaporphine and 2-hyrdoxyaporphine, respectively (Kunimoto and Kamimura 1964). Tertiary alkaloids anonaine, pronuciferine, *N*-nornuciferine, liriodenine and D-methylcoclaurine were isolated from the leaves besides the known roemerine, nuciferine, *O*-nornuciferine and dl-armepavine (Kunitomo et al. 1970). The structure of nornuciferine, an aporphine-type tertiary phenolic base isolated from the domestic lotus, was proven to be dl-1-methoxy-2-hydroxyaporphine (Kunitomo et al. 1971). Four new alkaloids, dehydroroemerine, dehydronuciferine, dehydroanonaine and *N*-methylisococlaurine, were isolated from *N. nucifera* leaves, besides the known roemerine, nuciferine, anonaine, pronuciferine, *N*-nornuciferine, nornuciferine, amepavine and *N*-methylcoclaurine (Kunitomo et al. 1973). Asimilobine and lirinidine, serotoninergic receptor antagonists, were isolated from lotus leaves (Shoji et al. 1987). Four alkaloids, i.e., 2-hydroxy-1-methoxyaporphine, pronuciferine, nuciferine

and roemerine, were identified in *Nelumbo nucifer*a and its alkaloid fraction by HPLC (Wang et al. 2008). The linear ranges of 2-hydroxy-1-methoxyaporphine, pronuciferine, nuciferine and roemerine were 0.110–0.658 μg (R^2 = 0.9995), 0.0210–0.126 μg (R^2 = 0.9995), 0.103–0.618 μg (R^2 = 0.9998) and 0.085 6–0.514 μg (R^2 = 0.9995), with the average recoveries of 101.5 %, 99.14 %, 99.21 % and 98.41 % for the alkaloid fraction of *N. nucifera* and 99.53 %, 100.5 %, 97.51 % and 100.1 % for *N. nucifer*a, respectively. (+)-1(R)-Coclaurine, (–)-1(S)-norcoclaurine, liensinine, neferine, isoliensinine and nuciferine together with quercetin 3-*O*-β-D-glucuronide (4) were isolated from lotus leaves (Kashiwada et al. 2005). *N*-Nornuciferine, *O*-nornuciferine, nuciferine and roemerine were identified in lotus leaves (Luo et al. 2005). From 4.0 g of the crude lotus leaf extract, 120 mg *N*-nornuciferine, 1020 mg nuciferine and 96 mg roemerine were obtained each with a purity of over 98 % (Zheng et al. 2010). Three alkaloids *N*-nornuciferine, *O*-nornuciferine and nuciferine were isolated from lotus leaf (Ma et al. 2010). 500 mg of crude lotus leaf extract furnished 7.4 mg of *N*-demethylarmepavine, 45.3 mg of nuciferine and 26.6 mg of roemerine with purities of 90 %, 92 % and 96 %, respectively (Xu et al. 2011b). The compounds isolated from lotus leaves included seven aporphines ((–)-nuciferine, (–)-nornuciferine, (–)-asimilobine,(–)-*N*-methylasimilobine, (–)-caaverine, (–)-anonaine (6) and (–)-roemerine), two oxoaporphines (lysicamine and liriodenine), one dioxoaporphine (cepharadione B), one dehydroaporphine (–7-hydroxydehydronuciferine), two steroids (β-sitostenone and stigmasta-4,22-dien-3-one) and two chlorophyll (pheophytin-a and aristophyll-C) (Wang et al. 2011). (–)-caaverine, cepharadione B and 7-hydroxydehydronuciferine were reported for the first time in lotus. Liriodenine in lotus leaves was extracted and quantified using ethanol and water-soluble solvents; liriodenine content obtained was 4.8 mg% by both methods (Mongkolrat et al. 2012).

N-methylasimilobine, a newly found potent acetylcholinesterase (AChE) inhibitor, along with two weakly active aporphine alkaloids, nuciferine and nornuciferine, was isolated from *Nelumbo nucifera* leaves (Yang et al. 2012). The following major alkaloids (–)-nuciferine, (–)-nornuciferine, (–)-caaverine, (–)-armepavine, (+)-norarmepavine, (+)-isoliensinine and (+)-pronuciferine were found in *Nelumbo nucifera* leaves (Do et al. 2013). In all samples, (–)-nuciferine (0.34–0.63 %), (–)-armepavine (0.13–0.20 %) and (+)-isoliensinine (0.06–0.19 %) were the most dominant alkaloids. The total alkaloid content varied from 0.72 to 1.41 %. From the methanolic extracts of lotus flower buds and leaves, a new alkaloid, *N*-methylasimilobine *N*-oxide, was isolated together with 11 benzylisoquinoline alkaloids (Nakamura et al. 2013). 2-Hydroxy-1-methoxyaporphin (2H1M), an alkaloid, was isolated from lotus leaves (Chen et al. 2012c). Major anti-inflammatory compounds identified from lotus leaves were nuciferine, *O*-nornuciferine, hirsutrin, hyperin, luteoloside and roemerine (Zhou et al. 2013a). From lotus leaves, liriodenine, lysicamine, (–)-anonaine, (–)-asimilobine, (–)-caaverine, (–)-*N*-methylasimilobine, (–)-nuciferine, (–)-nornuciferine, (–)-roemerine, cepharadione B and 7-hydroxydehydronuciferine were isolated (Lin et al. 2014). 100 mg of crude lotus leaf extracts yielded 6.3 mg of 2-hydroxy-1-methoxyaporphine (95.1 % purity), 1.1 mg of pronuciferine (96.8 % purity), 8.5 mg of nuciferine (98.9 % purity) and 2.7 mg of roemerine (97.4 %) (Ma et al. 2014).

Quercetin, myricetin, kaempferol 3-*O*-glucoside, quercetin 3-*O*-glucoside and luteolin 7-*O*-glucoside were isolated from aerial parts of *N. nucifera* (Wassel et al. 1996). From lotus leaf extract, the following compounds were isolated: a new megastigmane, nelumnucifoside, together with 12 megastigmanes ((*E*)-3-hydroxymegastigm-7-en-9-one, (–) –boscialin, (+) – dehydrovomifoliol, vomifoliol, 3-oxo-retro-α-ionol I, byzantionoside A, 5,6-epoxy-3-hydroxy-7-megastigmen-9-one, annuionone D, icariside B2, grasshopper ketone, 3*S*, 5*R*-dihydroxy-6*S*, 7-megastigmadien-9-one and (+)-epilioliolide); a new eudesmane sesquiterpene, eudesnelumboside; eight alkaloids ((6*R*, 6a*R*)-roemerine-Nβ-oxide,

liriodenine, pronuciferine, oleracein E, *trans*-*N*-coumaroyltyramine, *cis*-*N*-coumaroyltyramine, *trans*-*N*-feruloyltyramine and *cis*-*N*-feruloyltyramine); and 11 flavonoids (quercetin, kaempferol, luteolin, quercetin 3-*O*-glucopyranoside, kaempferol 3-*O*-glucopyranoside, chrysoeriol 7-*O*-glucopyranoside, taxifolin, epitaxifolin, 5,7,3′,5′-tetrahydroxyflavanone, (–)-catechin and elephantorrhizol) (Ahn et al. 2013).

The following compounds quercetin 3-*O*-α-arabinopyranosyl-(1 → 2)-β-galactopyranoside, rutin, (+)-catechin, hyperoside, isoquercitrin, quercetin and astragalin were isolated from water lotus leaf ethanol extract (Ohkoshi et al. 2007). Three flavonoid compounds hyperin, isoquercetin and astragalin were obtained from lotus leaves with over 97 % recovery (Tian et al. 2007). In the ethyl acetate lotus leaf fraction, quercetin 3-*O*-β-D-glucopyranoside and quercetin 3-*O*-β-D-glucuronopyranoside were found as its two major components, as well as quercetin 3-*O*-β-D-galactopyranoside as a minor compound (Jung et al. 2008). A total of 4.6 mg of isoquercitrin, 9.1 mg of hyperoside and 3.0 mg of astragalin with the purity of 95.8 %, 97.5 % and 98.3 %, respectively, were obtained from lotus leaf extract (Deng et al. 2009b). Six flavonoids, quercetin, rutin, quercetin 3-*O*-β-D-galactopyranoside (Qc-3-Gal), quercetin 3-*O*-β-D-glucopyranoside (Qc-3-Glc), quercetin 3-*O*-β-D-glucuronide (Qc-3-Gln) and quercetin 3-*O*-α-arabinopyranosyl-(1 → 2)-β-galactopyranoside (Qc-3-AraGal), were isolated from the methanol leaf extract (Goo et al. 2009). Among them, Qc-3-Glc and Qc-3-Gln were found to be major components in the methanol leaf extract. Five norsesquiterpenes ((*E*)-3-hydroxymegastigm-7-en-9-one, (3*S*,5*R*,6*S*,7*E*)-megastigma-7-ene-3,5,6,9-tetrol, dendranthemoside B, icariside B2 and sedumoside F1), four flavonoids (luteolin, quercetin 3-*O*-β-D-glucuronide, quercetin 3-*O*-β-D-glucoside and isorhamnetin 3-*O*-rutinoside), two triterpenes (alphitolic acid and maslinic acid) and one alkaloid (*N*-methylasimilobine) were isolated from the methanol lotus leaf extract (Kim et al. 2009). Seven flavonoids were isolated from lotus leaves and identified as catechin, quercetin, quercetin-3-*O*-glucopyranoside, quercetin-3-*O*-glucuronide, quercetin-3-*O*-galactopyranoside, kaempferol-3-*O*-glucopyranoside and myricetin-3-*O*-glucopyranoside (Lin et al. 2009a, b). From the ethyl acetate-*n*-butanol-water (4:1:5, v/v) extract of lotus leaves, 5 mg of quercetin-3-*O*-sambubioside [quercetin-3-*O*-β-D-xylopyranosyl (1 → 2)-β-D-glucopyranoside} with a purity of 98.6 % was obtained (Deng et al. 2009a). From lotus leaves, one new compound, 24(*R*)-ethylcholest-6-ene-5α-ol-3-*O*-β-D-glucopyranoside, along with 11 known compounds including aporphine alkaloids, diterpenes, a steroid glycoside and a flavonoid glycoside were isolated (Agnihotri et al. 2008). 10-Eicosanol and 7,11,15-trimethyl-2-hexadecanone were reported for the first time. Six compounds were detected and characterised in lotus leaf ethanol extract, one as catechin glycoside and five as flavonoid glycoside derivatives: miricitrin-3-*O*-glucoside, hyperin, isoquercitrin, quercetin-3-*O*-rhamnoside and astragalin (Huang et al. 2010b).

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From 150 mg of the crude lotus leaf sample, 6.1 mg of quercetin-3-*O*-β-D-glucuronide, 14.8 mg of myricetin-3-*O*-β-D-glucopyranoside and 20. 2 mg of astragalin were obtained with purities of 97.0 %, 95.4 % and 96.3 %, respectively (Xu et al. 2011c).

The polyphenols identified in lotus leaves consisted primarily of gallic acid, rutin and quercetin (Yang et al. 2011). Quercetin-3-*O*-β-D-glucuronide, hyperoside and isoquercitrin were the most dominant flavonoids in lotus leaves (Do et al. 2012). Twenty-five compounds were isolated from the 70 % ethanol lotus leaf extract and identified as 10-octacosanol, β-sitosterol, 1-undecanol, 1-eicosanol, daucosterol, 6′-hydroxy-4,4′-dimethoxychalcone, 3,7,8-trim ethoxy-1-hydroxy-xanthone, rhamnetin-3-*O*-β-D-glucopyranoside, chrysoeriol-7-*O*-β-D-glucoside, quercetin-3-*O*-β-D-glucopyranoside, quercetin-3-*O*-α-L-rhamnopyranosyl, hyperoside, quercetin-3-*O*-rutinoside, astragalin,

isorhamnetin-3-*O*-α-L-rhamnopyranosyl-(1 → 6)-[α-D-lyxopyranosyl-(1 → 2)-β-D-glucopyranoside], isorhamnetin-3-*O*-α-D-lyxopyranosyl-(1 → 2)-β-D-glucopyranoside, isorhamnetin-3-*O*-β-D-glucopyranoside, isorhamnetin-3-*O*-α-L-rhamnopyranosyl-(1 → 6)-β-D-glucopyranoside, quercetin, kaempferol, dehydronuciferine, roemerine, stigmast-7-en-3-*O*-β-D-glucopyranoside, stigmast-7-en-3β-ol and benzene-1,2-diol (Zhao et al. 2013b. Mature leaf pulp (771.79 mg/100 g FW (fresh weight)) and young leaves (650.67 mg/100 g FW) of lotus had higher total flavonoid amount than flower stamens and petals, but leaf stalks had lower (<40 mg/100 g FW) (Chen et al. 2012b). Young leaves, mature leaf pulps and mature leaf veins contained similar range of flavonoids in varying concentrations: myricetin 3-*O*-glucoside, quercetin 3-*O*-arabinopyranosyl-(1 → 2)-galactopyranoside, quercetin 3-*O*-rhamnopyranosyl-(1 → 6)-glucopyranoside (rutin), quercetin 3-*O*-galactoside (hyperoside), quercetin 3-*O*-glucoside (isoquercitrin), quercetin 3-*O*-glucuronide, kaempferol 3-*O*-galactoside, kaempferol 3-*O*-glucoside (astragalin), isorhamnetin 3-*O*-glucoside, kaempferol 3-*O*-glucuronide, diosmetin 7-*O*-hexose and quercetin; leaf stalks had similar flavonoids plus diosmetin. Thirteen flavonoids were simultaneously separated and identified from lotus leaf methanol–water extract (Chen et al. 2012c). From lotus leaves, 13 megastigmanes, including a new megastigmane, nelumnucifoside A and a new eudesmane sesquiterpene, nelumnucifoside B, eight alkaloids and 11 flavonoids were isolated (Ahn et al. 2013).

Flower Phytochemicals

The flavonoid kaempferol-3-galactorhamnoglycoside was isolated from lotus flower (Rahman et al. 1962). Two new isorhamnetin glycosides, designated as nelumboroside A and nelumboroside B, as well as known isorhamnetin glucoside and isorhamnetin rutinoside were isolated from the n-BuOH fraction of *N. nucifera* stamens (Hyun et al. 2006). Seven known flavonoids, kaempferol, kaempferol 3-*O*-β-D-glucuronopyranosyl methylester, kaempferol 3-*O*-β-D-glucopyranoside, kaempferol 3-*O*-β-D-galactopyranoside, myricetin 3′,5′-dimethylether 3-*O*-β-D-glucopyranoside, kaempferol 3-*O*-α-L-rhamnopyranosyl-(1 → 6)-β-D-glucopyranoside and kaempferol 3-*O*-β-D-glucuronopyranoside, along with β-sitosterol glucopyranoside, were isolated from lotus stamens (Jung et al. 2003). Thirteen flavonoids including kaempferol and seven of its glycosides, myricetin 3′,5′-dimethylether 3-*O*-β-D-glucopyranoside, quercetin 3-*O*-β-D-glucopyranoside and two isorhamnetin glycosides as well as four non-flavonoid compounds (adenine, myo-inositol, arbutin and β-sitosterol glucopyranoside) were isolated from the ethyl acetate-soluble fraction of lotus stamens (Lim et al. 2006). Polyphenols found in Korean traditional lotus liquor (Yunyupju) made from lotus blossom and leaves were identified as catechin, rutin, quercitrin, myricetin and quercetin (Lee et al. 2005). β-carotene concentrations in lotus stamens ranged from 6.50 to 58.50 μg/mL (Phonkot et al. 2010). The β-carotene of the four lotus varieties was 465.77–1150.80 mg%. Fifteen flavonoids comprising anthocyanins and flavonols were identified in lotus petals: delphinidin 3-*O*-glucoside, cyanidin 3-*O*-glucoside, petunidin 3-*O*-glucoside, peonidin 3-*O*-glucoside, malvidin 3-*O*-glucoside and quercetin 3-*O*-rutinoside, quercetin 3-*O*-galactoside, quercetin 3-*O*-glucuronide, kaempferol 3-*O*-robinobioside, kaempferol 3-*O*-galactoside, kaempferol 3-*O*-glucoside, kaempferol 3-*O*-glucuronide, isorhamnetin 3-*O*-rutinoside, syringetin 3-*O*-hexose and kaempferol 3-*O*-pentose (Yang et al. 2009). From 125 mg crude lotus petal sample, 5.0 mg syringetin-3-*O*-β-D-glucoside, 6.5 mg quercetin-3-*O*-β-D-glucoside, 12.8 mg isorhamnetin-3-*O*-β-D-glucoside and 32.5 mg kaempferol-3-*O*-β-D-glucoside were obtained (Guo et al. 2010). A new β-cyclogeraniol diglycoside, nuciferoside, with the chemical structure 1-hydroxymethyl-2,6,6-trimethyl-1-cyclohexene 9-*O*-β-D-glucopyranosyl-(1 → 6)-β-D-glucopyranoside, along with four known components, cycloartenol,

p-hydroxybenzoic acid, vanilloloside and 5′-*O*-methyladenosine, were isolated from the *n*-BuOH fraction of lotus stamens (Jung et al. 2010b).

A total of five anthocyanins and 14 flavones and flavonols were detected and quantified in108 lotus cultivars with red, pink, yellow, white and red/white pied petal colours (Deng et al. 2013). In general, the yellow, white and pied species hardly contained any anthocyanins; red cultivars contained more than pink cultivars. Among the five anthocyanins, malvidin 3-*O*-glucoside was the most abundant one in all the cultivars that contain anthocyanin. The 14 flavones and flavonols belonged to four groups based on their aglycones. Except for the yellow cultivars, kaempferol derivatives were the most abundant one. Flavones and flavonols, deemed as accessory pigments, appeared to contribute little to the yellow colour. Most of the cultivars could be sorted into three groups (A, B and C). Group A exclusively contained mostly red and several pink cultivars due to high content of total anthocyanins. Group B contained most of the yellow cultivars, small part of pink and pied colour cultivars and two white cultivars due to high content of flavones and flavonols. Group C contained most of the white cultivars due to low content of total anthocyanins, flavones and flavonols. Anthocyanins in lotus flower petals were identified as delphinidin 3-*O*-glucoside, cyanidin 3-*O*-glucoside, peonidin 3-*O*-glucoside and malvidin 3-*O*-glucoside (Li et al. 2014).

Flower tissues including flower petals, stamens, pistils and, especially, reproductive tissue fruit coats had more flavonoid compounds (15–17) than leaves (12) (Chen et al. 2012b). Total flavonoid content in flower stamens was 359.45 mg/100 g FW and 342.97 mg 100/g FW in flower petals, while leaf flower stalks had much less total flavonoid (less than 40 mg/100 g FW). Flower petals and stamens contained similar range of flavonoids, namely, myricetin 3-*O*-galactoside, myricetin 3-*O*-glucoside, quercetin 3-*O*-arabinopyranosyl-(1 → 2)-galactopyranoside, myricetin 3-*O*-glucuronide, quercetin 3-*O*-rhamnopyranosyl-(1 → 6)-glucopyranoside (rutin), quercetin 3-*O*-galactoside (hyperoside), quercetin 3-*O*-glucoside (isoquercitrin), kaempferol 3-*O*-robinobioside, quercetin 3-*O*-glucuronide, kaempferol 3-*O*-galactoside, isorhamnetin 3-*O*-rutinoside, kaempferol 3-*O*-glucoside (astragalin), syringetin 3-*O*-glucoside, isorhamnetin 3-*O*-glucoside and kaempferol 3-*O*-glucuronide. Flower pistils had almost similar range plus diosmetin 7-*O*-hexose but minus kaempferol 3-*O*-robinobioside. Flower stalks had almost similar range plus 16 kaempferol 7-*O*-glucoside, 17 diosmetin 7-*O*-hexose and diosmetin but without kaempferol 3-*O*-robinobioside and isorhamnetin 3-*O*-rutinoside. A total of five anthocyanins (anthocyanins delphinidin 3-*O*-glucoside, cyanidin 3-*O*-glucoside, petunidin 3-*O*-glucoside, peonidin 3-*O*-glucoside and malvidin 3-*O*-glucoside) and 20 non-anthocyanin flavonoids (3 myricetin glycosides [myricetin 3-*O*-galactoside, myricetin 3-*O*-glucoside, myricetin 3-*O*-glucuronide], 6 quercetin glycosides [quercetin 3-*O*-arabinopyranosyl-(1 → 2)-galactopyranoside, quercetin 3-*O*-rhamnopyranosyl-(1 → 6)-glucopyranoside, quercetin 3-*O*-galactoside,quercetin 3-*O*-glucoside, quercetin-3-*O*-glucuronide, quercetin], 5 kaempferol glycosides [kaempferol 3-*O*-robinobioside, kaempferol 3-*O*-galactoside, kaempferol 3-*O*-glucoside, kaempferol 3-*O*-glucuronide, kaempferol 7-*O*-glucoside], 3 isorhamnetins [isorhamnetin 3-*O*-rutinoside, isorhamnetin 3-*O*-glucoside, isorhamnetin 3-*O*-glucuronide], 2 diosmetin [diosmetin 7-*O*-hexose, diosmetin] and syringetin 3-*O*-glucoside) were identified and quantified in the petals of 12 lotus genotypes (Chen et al. 2013).

Fatty acid and sterol content of lotus bee pollen oil extracted by supercritical CO_2 at 30 MPa and 50 °C comprised of the following: fatty acid (myristic acid (14:0), 0.8 %; pentadecanoic acid (15:0), 1.32 %; palmitic acid (16:0), 44.78 %; palmitoleic acid (16:1), 0.38 %; margaric acid (17:0), 1.71 %; stearic acid (18:0), 2.84 %; oleic acid (18:1), 18.93; linoleic acid (18:2), 14.78 %; α-linolenic acid (18:3), 7.32 %; behenic acid (22:0), 1.43 %; SFA (saturated fatty acids), 52.89 %; MUFA (monounsaturated fatty acids), 19.31; and PUFA (polyunsaturated fatty acids), 22.19) and sterols (g/kg oil) (campesterol, 1.39 g; stigmasterol, 3.97; β-sitosterol, 2.45 g; and β-amyrin, 2.90 g) (Xu et al. 2011a). The yield of

oil was 7.18 g/kg; carotenoids, 377.86 mg/kg; squalene, 84.94 mg/kg; and sterols, 490.90 mg/kg dry bee pollen.

Aerial Plant Parts Phytochemicals

Alkaloids were found in the leaves, petiole and cotyledons in the fruit but not in the edible rhizome (Tomita et al. 1961c). All the alkaloids found were in a free state. Roemerine and nuciferine were isolated as the tertiary, non-phenolic bases, and a new base, nornuciferine, as the tertiary phenolic base, from the leaves. Roemerine and nornuciferine were isolated from the petiole but not nuciferine. After methanolic extraction, the phenolic content of each part of the plant, determined in terms of gallic acid equivalents per g of dried extract (GAE, mg/g extract), was found to follow the order of leaves (177.7) > deembryonated seeds (92.7) > stamens (83.4) > embryos (41.0) > rhizomes (21.6). For the flavonoid contents, determined as mg of (+)-catechin equivalent per g of dried extract (CE, mg/g extract), the order was leaves (125.6) > deembryonated seeds (82.9) > stamens (50.3) > embryos (18.9) > rhizomes (8.5) (Jung et al. 2008).

Total flavonoid content was highest in the leaves 2.06 E3mg/100 g FW, followed by flower petals, stamens, plumule 402.9–496 mg/100 g FW and seed kernel the lowest 0.67 mg/100 g FW (Li et al. 2014). Thirty-three flavonoids were found in lotus flowers, seeds and leaves: myricetin 3-*O*-galactoside (f1), luteolin 8-*C*-β-D-glucopyranoside (orientin) (f2), luteolin 6-*C*-β-D-glucopyranoside (isoorientin) (f3), myricetin 3-*O*-glucuronide (f4), myricetin 3-*O*-glucoside (f5), quercetin 3-*O*-arabinopyranosyl-(1 → 2)-galactopyranoside (f6), apigenin 8-*C*-β-D-glucopyranoside (vitexin) (f7), quercetin 3-*O*-α-L-rhamnopyranosyl-(1 → 6)-β-D-glucopyranoside (rutin) (f8), apigenin 6-C-β-D-glucopyranoside (isovitexin) (f9), quercetin 3-*O*-β-D-galactopyranoside (hyperoside) (f10), quercetin 3-*O*-glucuronide (f11), quercetin 3-*O*-β-D-glucopyranoside (isoquercitrin) (f12), kaempferol 3-*O*-galactoside (f13), kaempferol 3-*O*-robinobioside (f14), isorhamnetin 3-*O*-rutinoside (f15), kaempferol 3-*O*-β-D-glcuopyranoside (f16), kaempferol 3-*O*-glucuronide (f17), isorhamnetin 3-*O*-β-D-glucopyranoside (f18), isorhamnetin 3-*O*-glucuronide (f19), syringetin 3-*O*-glucuronide (f20), apigenin di-*C*-glucoside (f21), 6-*C*-glucosyl-8-*C*-pentosyl luteolin (f22), 6-*C*-pentosyl-8-*C*-glucosyl luteolin (f23), 6-*C*-glucosyl-8-*C*-xylosyl apigenin (f24), 6-*C*-xylosyl-8-*C*-glucosyl apigenin (f25), 6-*C*-glucosyl-8-*C*-arabinosyl apigenin (schaftoside) (f26), 6-*C*-arabinosyl-8-*C*-glucosyl apigenin (isoschaftoside) (f27), quercetin 3-*O*-neohesperidoside (f28), 6-*C*-glucosyl-8-*C*-rhamnosyl apigenin (f29), luteolin 7-*O*-rutinoside (f30), 6-*C*-rhamnosyl-8-*C*-glucosyl apigenin (f31), isorhamnetin 3-*O*-neohesperidoside (f32) and diosmetin 7-*O*-rutinoside (f33). Flower petals and stamens possessed the highest amounts of kaempferol glycoside, specially f11 and f17. Additionally f14 and f16 were the predominant compounds in petals. The petals contained f1, f4, f5, f7, f8, f10, f11, f14, f15, f16, f17, f18 and f19. The stamens contained f1, f4, f5, f7, f8, f10, f11, f12, f14, f15, f16, f17, f18 and f19. The pistil and tori contained f1, f4, f6, f8, f14, f15, f16, f17, f18 and f19. The flower stalks contained f1, f4, f6, f8, f10, f15, f18 and f19; the leaves contained f1, f4, f6, f11, f15, f16, f18 and f20. Lotus seed pods contained f4, f6, f10, f11, f14, f15, f16, f17, f18 and f19; seed coats contained f2, f3, f4, f7, f9, f11, f12, f13, f14, f15, f16, f17, f18 and f19. The seed kernels contained f9, f11, f12, f15, f16 and f18. Thirteen *C*-glycosyl flavones (newly isolated *C*-glycosides, f7, f9, f21, f22, f23, f24, f25, f26, f27, f29 and f31) and six *O*-glycosides (newly isolated *O*-glycosides, f20, f28, f30, f32 and f33) within plumules were detected.

The extracts of lotus rhizomes, seeds, flowers and leaves had been reported to have varied therapeutic potential (Mukherjee et al. 2009). Several bioactive compounds had been derived from these plant parts belonging to different chemical groups, including alkaloids, flavonoids, glycosides, triterpenoid, vitamins, etc., which all imparting their own therapeutic impact.

Pharmacological studies have demonstrated that lotus herb exhibits various pharmacological effects, such as anti-hyperlipidaemia, antiobesity, antioxidant, anti-HIV, antimicrobial and anti-hypoglycaemic activities.

Antioxidant Activity

Lotus Seed/Seedpod/Seedlings

Lotus seed water, ethyl acetate and hexane extracts could inhibit nitric oxide accumulation in LPS-activated RAW 264.7 cells (Yen et al. 2006). The extracts in the range of 0.01–0.2 mg/ml showed a dose-dependent inhibitory effect on the accumulation of nitric oxide upon decomposition of sodium nitroprusside (SNP). The potency of inhibitory activity was in the order ethyl acetate > water > hexane. The results of the comet assay indicated that the three extracts could inhibit DNA damage in macrophage RAW 264.7 cells induced by SNP. Further, the three extracts, at 0.2 mg/ml, showed 63 %, 59 % and 38 % inhibition of DNA damage in macrophage RAW 264.7 cells induced by peroxynitrite, respectively. All extracts tested were found to be potent peroxynitrite scavengers, capable of preventing the nitration of tyrosine. The data obtained suggested that lotus seed extracts might act as chemopreventers through reduction of excess amounts of nitric oxide. Lotus seeds possessed higher temperature tolerances than maize seeds (Ding et al. 2008). Germination percentage of maize (*Zea mays* 'Huangbaogu') seeds was zero after they were treated at 100 °C for 15 min and that of lotus seeds was 13.5 % following the treatment at 100 °C for 24 h. For lotus seeds, (1) activities of superoxide dismutase (SOD) and glutathione reductase (GR) of axes and cotyledons and of catalase (CAT) of axes increased during the early phase of treatment at 100 °C and then decreased and (2) activities of ascorbate peroxidase (APX) and dehydroascorbate reductase (DHAR) of axes and cotyledons and of CAT of cotyledons gradually decreased with increasing treatment time at 100 °C. The hydroalcoholic lotus seed extract exhibited strong free radical scavenging activity as evidenced by the low IC_{50} values in both DPPH (1,1-diphenyl-2-picryl hydrazyl) (6.12 μg/ml) and nitric oxide (84.86 μg/ml) methods; the values were found to be lower than those of rutin, the standard used (Rai et al. 2006). Total phenolic content in the extract was found to be 7.61 % (w/w). The Fr2 fraction from lotus seed epicarp exhibited high antioxidant activity as assessed by 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging, the b-carotene bleaching method and hydroxyl radical and hydrogen peroxide scavenging ability using the chemiluminescence method (Kredy et al. 2010). This antioxidant potential in terms of IC_{50} values was 5.48, 40 and 0.62 g (dry Fr2)/mL on DPPH radicals, hydroxyl radicals and hydrogen peroxide, respectively. The Fr2 also exhibited antioxidant property in the b-carotene bleaching assay. In total, it possessed high levels of flavonol compounds with high antioxidant potential. The DPPH free radical scavenging activities of lotus seed extract (LSE) increased in a concentration-dependent manner (Sung et al. 2011). Mouse embryonic fibroblast cells, damaged by oxidative stress, decreased their viability following increasing concentration of H_2O_2, but the cotreatment of ethyl acetate fraction of lotus seed extract and H_2O_2 resulted in an increase in cell growth, by about 25 %, compared to the cells treated with H_2O_2. The ethyl acetate fraction of LSE inhibited the cytotoxicity induced by H_2O_2 in a concentration-dependent manner. The results suggested that LSE inhibited the cytotoxicity induced by H_2O_2 and exerted a protective effect on mouse embryonic fibroblast cell against oxidative stress. Hexane extract of lotus seed oil showed 66 % inhibition of DPPH radical with IC_{50} of 15 μgml (Anitha and Arunkumar 2012). It also exhibited the highest ABTS assay activity with IC_{50} of 124 μg/ml.

Studies showed that 0.1 % procyanidins from lotus seed pod had a strong antioxidant activity in a soybean oil system, better than BHT at the same concentration; inhibited lipoxygenase activity by >90 % at a concentration of 62.5 mug/mL, with an IC_{50} value of 21.6 mug/mL; and had IC_{50} inhibitory value rate to *OH of 10.5 mg/L and a scavenging effect on O_2* of 17.6 mg/L

(Ling et al. 2005). DPPH and ABTS scavenging capacities of the ethyl acetate fraction of lotus seed (LS) were 94.6 and 91.9 % and those of the water fraction of lotus seedpod (LSP) were 94.5 and 95.2 % at 0.8 mg/mL (Kim and Shin 2012). The ethyl acetate fraction of LS and the water fraction of LSP also showed high ferric reducing ability of plasma (FRAP). The high antioxidant capacities of LS and LSP may be due to their flavonoid and proanthocyanidin contents. The *n*-butanol fraction of lotus receptacle showed the highest total phenolic content (607.6 mg/g gallic acid equivalents), total flavonoid content (862.7 mg/g rutin equivalents) and total proanthocyanidin content (331.0 mg/g catechin equivalents), accompanied with the highest antioxidant activity compared to other fractions in the 1,1-diphenyl-2-picrylhydrazyl (DPPH) and 2,2′-azino-bis-(3-ethylbenzthiazoline-6-sulphonic acid) (ABTS) radical scavenging assays (Wu et al. 2012). Among the five isolated flavone glycosides, hyperoside, isoquercitrin and quercetin-3-*O*-β-D-glucuronide demonstrated significant DPPH and ABTS radical scavenging activity, with IC_{50} values of 8.9, 5.2 and 7.5 for DPPH and 114.2, 112.8 and 172.5 μg/mL for ABTS, respectively.

The activity of superoxide dismutase (SOD), dehydroascorbate reductase (DHAR) and glutathione reductase (GR) was lower in lotus seedlings germinated under water (submerged hypoxic condition) in darkness (SD seedlings) than those found in seedlings germinated in air and darkness (AD seedlings) (Ushimaru et al. 2001). In contrast, ascorbate peroxidase activity was higher in SD seedlings, and the activity of catalase and monodehydroascorbate reductase (MDAR) in SD seedlings was nearly the same as in AD seedlings. When SD seedlings were exposed to air, the activity of SOD, DHAR and GR increased, while the activity of catalase and MDAR decreased. Seven electrophoretically distinct SOD isozymes were detectable in *N. nucifera*. The levels of plastidic Cu, Zn-SODs and Fe-SOD in SD seedlings were comparable with those found in AD seedlings, which may reflect the maintenance of green plastids in SD seedlings as well as in AD seedlings.

Lotus Leaf

A dose-dependent protective effect against reactive oxygen species (ROS)-induced cytotoxicity was observed when Caco-2 cells were treated with 10 mM H_2O_2 in combination with the methanol extract of the lotus leaf (0.1–0.3 mg/ml) (Wu et al. 2003). However, no significant effect was found when cotreating Caco-2 cells with 10 mM H_2O_2 and α-tocopherol. In-vitro assay revealed that lotus leaf extract exhibited scavenging activities on free radicals and hydroxyl radicals and metal binding ability as well as reducing power, which explained partly the mechanism behind the extract's ability to protect cells from oxidative damage. Moreover, the extract also exhibited concentration-dependent antioxidant activities against haemoglobin-induced linoleic acid peroxidation and Fenton reaction-mediated plasmid DNA oxidation. Lotus leaf methanol extract exhibited a pronounced activity in the 1,1-diphenyl-2-picrylhydrazyl (DPPH) scavenging assay with an IC_{50} of 90 μg/ml, compared with an IC_{50} of 30 μg/ml for the butylated hydroxytoluene (BHT) control (Hutadilok-Towatana et al. 2006). The same extract was also found to be the most potent in removing the superoxide anion (O^{2}) radical and in inhibiting the 2,2′-azo-bis-(2-amidinopropane) dihydrochloride (AAPH)-induced erythrocyte haemolysis and lipid peroxidation in a rat brain homogenate.

The ethyl acetate and n-butanol fractions of lotus leaf methanol extract exhibited greater capacity to scavenge DPPH radical, delayed low-density lipoprotein (LDL) oxidation and had higher antioxidative contents than the water fraction (Lin et al. 2009a). Among its constituents, quercetin and its glycosides quercetin-3-*O*-glucopyranoside, quercetin-3-*O*-glucuronide and quercetin-3-*O*-galactopyranoside exerted potent inhibition of LDL oxidation, whereas myricetin-3-*O*-glucopyranoside (7) showed stronger DPPH scavenging activity. Jeong et al. (2009) reported that radical scavenging activities and total polyphenols of the γ-irradiated lotus leaf ethanol extract were not observed to be significantly different. However, γ-irradiation significantly increased the Hunter colour L*-value at doses of

20 and 50 kGy, while the Hunter colour b*-values were decreased under the same conditions. Lotus leaf extract exhibited 2-diphenyl-1-picrylhydrazyl hydrate (DPPH) free radical scavenging activities increased in a concentration-dependent manner (Ha et al. 2010). Mouse embryonic fibroblast (MEF) cells, damaged by oxidative stress, decreased their viability following increasing concentration of H_2O_2, but the cotreatment of n-butanol fraction of the leaf extract and H_2O_2 resulted in an increase in cell growth, by about 25 %, compared to the cells treated with H_2O_2. At 100 μg/ml extract concentration, lotus leaf, flower and seed extracts showed 78 %, 78 % and 80 % DPPH free radical scavenging activity (Kim et al. 2011). The IC_{50} values (μg/ml) of the antioxidation effects were flower, 5 μg; seed, 5 μg; leaf, 29 μg; root, 150 μg; stem(rhizome), 162 μg; and vitamin C, 5 μg.

The amounts of phenolics, flavonoids and proanthocyanidins in the lotus leaf extracts from various areas in China varied widely, ranging from 354 to 487 mg/g gallic acid equivalents, from 172 to 236 mg/g rutin equivalents and from 124 to 179 mg/g catechin equivalents, respectively (Huang et al. 2010a). All of the extracts had strong antioxidant activity in comparison to the standard compounds butylated hydroxytoluene and vitamin C. Wild lotus samples from Baiyangdian Lake and Weishan Lake exhibited a stronger free radical scavenging effect and greater reducing power than the cultivated samples, but no such differences were observed in the inhibition of lipid oxidation.

Lotus Rhizome

Methanol extract of lotus rhizome powder showed the highest extract yield among all of solvents (Yang et al. 2007). Although acetone extract had the highest total phenolics content, methanol extract had the highest total phenolics recovery from lotus powder (20.1 mg catechin equivalents/100 g lotus powder). Extract of either methanol or acetone demonstrated the highest DPPH scavenging activity at both 66.7 and 133.3 mg/L. All extracts exhibited higher antioxidant activity coefficient (AAC) than that of ascorbic acid; furthermore, dichloromethane and petroleum extracts had comparable AAC with BHA by the beta-carotene bleaching assay. Lotus rhizome knot extract exhibited high antioxidative capacity, as measured by1-diphenyl-2-picrylhydrazyl and 2,2′-azino (3-ethylbenzothioazolino-6-sulfonate) and measured by electron spin resonance (ESR) trapping of the transient carbon-centred 1-hydroxyethyl radical (generated in a Fenton-type reaction) (Hu and Skibsted 2007). Whole rhizome, however, only showed a significantly high scavenging activity for small carbon-centred radicals, as measured by the ESR method. Total phenol content in the plant extract correlated with the antioxidant capacity, except for the scavenging of carbon-centred radical. Studies found that gamma radiation treatment significantly reduced microbial load, enhanced the DPPH scavenging activity and increased the storability of the irradiated lotus rhizome samples (Khattak et al. 2009). The treated samples were also acceptable sensorically. The extraction yield and phenolic contents increased with the increase of radiation dose.

The lotus rhizome showed the strongest antioxidant activity in both assays of lipid peroxidation and inhibition of lysis of erythrocytes induced by peroxyl radicals (Jiang et al. 2010). Of three fractions, L2 fraction showed the highest antioxidant activity and was further fractionated, and L2c showed the strongest activity in inhibiting haemolysis of erythrocytes, and on further purification, L2c-3 was purified and identified as tryptophan. Its inhibitory concentration of 50 % (IC_{50}) value in inhibiting haemolysis of erythrocytes was 156.3 μg/ml (i.e. 765.4 μM).

Lotus Flower

Ethanol lotus flower extract exhibited higher antioxidant activity in-vitro (lower IC_{50} value) than vitamin C (Gayathri et al. 2009). A methanol extract of lotus stamens showed strong antioxidant activity in the peroxynitrite (ONOO-) system and marginal activity in the DPPH and total reactive oxygen species (ROS) systems (Jung et al. 2003). After fractionation, the ethyl acetate fraction exhibited strong antioxidant

activity in all the model systems tested, and among its constituents, kaempferol exhibited good antioxidant activities in all the model systems tested. Compounds kaempferol 3-*O*-β-D-glucuronopyranosyl methylester and kaempferol 3-*O*-β-D-glucuronopyranoside showed scavenging activities in the DPPH and ONOO- tests, while compounds kaempferol 3-*O*-β-D-glucopyranoside and kaempferol 3-*O*-β-D-galactopyranoside were only active in the ONOO-test. Conversely, compound β-sitosterol glucopyranoside showed no activities in any of the model systems tested.

All isolated isorhamnetin glycosides, nelumboroside A, nelumboroside B, isorhamnetin glucoside and isorhamnetin rutinoside, from lotus stamens showed marked antioxidant activities in the DPPH and peroxynitrite (ONOO)– assays (Hyun et al. 2006). The DPPH antioxidant activities (IC_{50}) of methanol stamen solution of four lotus varieties were 68.30 6.30, 62.22 4.00, 31.60 3.40 and 40.90 1.50 g/mL, respectively, whereas those of the mixed-solvent solution were 2.21 0.06, 2.23 0.05, 1.29 0.02 and 1.83 0.07 mg/mL (Phonkot et al. 2008).

Lotus Liquor

The antioxidant activities of lotus liquor (Yunyupju) made from lotus blossom and leaves were dose dependent and reached a plateau (about 80 % inhibition) when the concentration of lotus liquor exceeded 25 μg in a modified linoleic acid peroxidation induced by haemoglobin (Lee et al. 2005). The concentrations to attain one absorbance unit at 700 nm were 23.6 μg for butylated hydroxytoluene (BHT) and 45.7 μg for lotus liquor. The scavenging activities of DPPH exerted by lotus liquor and α-tocopherol were obtained and the IC_{50} values were estimated at 17.9 μg for lotus liquor and 5.6 μg for α-tocopherol. The maximum scavenging activity on hydroxyl radicals (40 %) could be achieved when lotus liquor was more than 500 μg. Lotus liquor also exhibited potent superoxide radical scavenging activity, with value of 0.93 unit/mg as superoxide dismutase equivalents. The IC_{50} was estimated at 1.07 mg for lotus liquor.

Anticancer Activity

Oxoushinsunine, a cytotoxic alkaloid isolated from lotus receptacle, showed tumour inhibitory activity against nasopharynx carcinoma (Yang et al. 1972). Luteolin, alphitolic acid, maslinic acid and *N*-methylasimilobine, isolated from lotus leaves, exhibited considerable cytotoxicity against four human cancer A549 (non-small cell lung adenocarcinoma), SK-OV-3 (ovarian cancer), SK-MEL-2 (skin melanoma) and HCT15 (colon cancer) cell lines in-vitro using a SRB (sulforhodamine B) bioassay (Kim et al. 2009). Among Korean white lotus cultivar rhizomes, the highest contents of polyphenols (7.95 mg of GAE/g DW) and the highest levels of antioxidant [by 2,2-azino-bis(3-ethylbenzthiazoline-6-sulfonic acid) and 1,1-diphenyl-2-picrylhydrazyl assays, 54.27 and 21.98 μM Trolox equivalents/g DW, respectively] and antiproliferative activities on both human cancer cell lines (Calu-6 for human pulmonary carcinoma and SMU-601 for human gastric carcinoma, 59.75 % and 71.21 % cell viability, respectively) were found in the Chungyang cultivar (Park et al. 2009). Neferine possessed a potent growth-inhibitory effect on human osteosarcoma cells, but not on non-neoplastic human osteoblast cells (Zhang et al. 2012). The inhibitory effect of neferine on human osteosarcoma cells was largely attributed to cell cycle arrest at G1. The induction of G1 arrest was p21(WAF1/CIP1) dependent, but was independent of p53 or RB (retinoblastoma-associated protein). Neferine treatment led to an increased phosphorylation of p21 at Ser130 that was dependent on MAPK and JNK. Compounds liriodenine, nuciferine, nornuciferine, armepavine, *N*-norarmepavine and *N*-methylcoclaurine, from lotus rhizome, showed significant cytotoxic activities against HL-60 carcinoma cell line with inhibitory ratios of 51.36 %, 59.09 %, 52.51 %, 53.93 %, 51.43 % and 64.31 % at concentration of 1×10^{-5} mol/L, respectively (Duan et al. 2013). Neferine, from lotus embryo, induced autophagy in A549 human lung adenocarcinoma epithelial cells by inhibiting PI3K/Akt/mTOR pathway and reactive oxygen species hypergeneration (Poornima et al. 2013b). Neferine

inhibited human lung cancer A549 cells by inducing apoptosis in a dose-dependent manner with the hypergeneration of reactive oxygen species, activation of MAPKs, lipid peroxidation, depletion of cellular antioxidant pool, loss of mitochondrial membrane potential and intracellular calcium accumulation (Poornima et al. 2014). Furthermore, neferine treatment caused the inhibition of nuclear factor kappaB and Bcl2, upregulation of Bax and Bad, release of cytochrome C, activation of caspase cascade and DNA fragmentation. In addition, neferine could induce p53 and its effector protein p21 and downregulation of cell cycle regulatory protein cyclin D1 thereby inducing G1 cell cycle arrest. Neferine was also found to exert cytotoxicity on liver cancer cells HepG2 in a dose-dependent manner (Poornima et al. 2013a). The data suggested that mitochondrial-mediated ROS (reactive oxygen species) generation induced by neferine led to caspase-dependent apoptosis in HepG2 cells. In another study, neferine exhibited cytotoxicity against hepatocellular carcinoma Hep3B cells (Yoon et al. 2013). Neferine induced cell cycle arrest, endoplasmic reticulum (ER) stress and apoptosis, acting through multiple signalling cascades. The significant reduction of the migration in Hep3B cells and the capillary tube-like formation of HUVECs by neferine were also determined.

Oral administration of hydroethanolic extracts of pink and white lotus flowers exerted antitumor effect by modulating lipid peroxidation and augmenting antioxidant defence systems in Ehrlich ascites carcinoma bearing mice (Brindha and Arthi 2010b). Lotus white flower possessed potent antioxidant and antitumor activity when compared with lotus pink flowers. Flavonoid-enriched lotus leaf extract exhibited antiproliferative effect on MCF-7 human breast cancer cell line in-vitro and in-vivo (Yang et al. 2011). MCF-7 cells treated with the extract were arrested at the G_0/G_1 phase (approximately 86.54 %). In xenograft nude mice inoculated with MCF-7 cells, treatment with the extract effectively reduced tumour volume and tumour weight compared to control.

Antiviral Activity

The hot water extract of *N. nucifera* at a concentration of 125 μg/ml inhibited the activity of Moloney murine leukaemia virus reverse transcriptase in-vitro with a relative inhibitory ratio (IR) over 50 % (Suthienkul et al. 1993). The methanol extract exhibited an IR value of 54 %. The aporphine alkaloid, (−)-nuciferine HCl, was found to be active in-vitro against human poliovirus (Boustie et al. 1998). (+)-1(R)-Coclaurine (1) and (−)-1(S)-norcoclaurine (3), together with quercetin 3-*O*-β-D-glucuronide (4), were isolated from lotus leaves and identified as anti-HIV principles (Kashiwada et al. 2005). Compounds 1 and 3 demonstrated potent anti-HIV activity with EC_{50} values of 0.8 and <0.8 μg/mL, respectively, and therapeutic index (TI) values of >125 and >25, respectively. Compound 4 was less potent (EC_{50} 2 μg/mL). Also other liensinine (14), neferine (15) and isoliensinine, isolated from lotus leaves, also showed potent anti-HIV activities with EC_{50} values of <0.8 μg/mL and TI values of >9.9, >8.6 and >6.5, respectively. Nuciferine (12), an aporphine alkaloid, had an EC50 value of 0.8 μg/mL and TI of 36. Ethanol lotus seed extract significantly blocked Herpes simplex virus (HSV-1) multiplication in HeLa cells without apparent cytotoxicity (Kuo et al. 2005). The mechanisms of antiviral action of the extract appeared to be mediated, at least in part, through inhibition of immediate early transcripts, such as ICP0 and ICP4 mRNA and then blocking of all downstream viral products accumulation and progeny HSV-1 production.

The antioxidant components L2f-2, L2f-3 (micromolecular) and LB2 (macromolecular) from lotus rhizomes strongly inhibited HIV-1 RT (reverse transcriptase) and integrase (Jiang et al. 2011). L2f-2 was identified as (±)- gallocatechin, L2f-3 was identified as (−) catechin and LB2 was a polysaccharide-protein complex. LB2 inhibited HIV-1 RT HIV-1 RT with an IC_{50} value of 33.7 μM. It also exhibited the highest HIV-1 3′-processing inhibitory activity with an IC_{50} value of 5.28 μM. Both L2f-2 and L2f-3 upregulated the expression of IL-2 (interleukin-2) and downregulated IL-10, while LB2 exhibited posi-

tive regulation on IL-2, IL-4 and IL-10. Furthermore, L2f-3 and LB2 might inhibit HIV-1 directly by downregulating TNFα (tumour necrosis factor α).

Antiobesity/Antihyperlipidaemic/ Anticholesterolemic Activities

In-Vitro Studies

Nuciferine, from lotus leaves, dose-dependently inhibited the synthesis of cholesterol and cholesterol esterase activity in Bel-7402 cells and augmented low-density lipoprotein receptor expression to reduce blood lipid levels (Han et al. 2008).

Studies showed that incubation of preadipocytes with lotus leaf extract solution significantly decreased triglyceride accumulation during adipogenesis without affecting cell viability (Siegner et al. 2010). Compared to controls, adipocytes incubated with lotus leaf extract solution exhibited a significant increase in lipolysis activity. It was also demonstrated that a combination of lotus leaf extract and L-carnitine reduced triglyceride accumulation in human (pre)adipocytes by affecting different processes during the adipocyte life cycle. This combination might represent a treatment option for obesity-related diseases. Both methanol and successive water extracts of lotus petals had an effect on inhibition of lipid storage in adipocytes and on increasing lipolysis (Velusami et al. 2013). Lotus petal methanol extract exhibited concentration-dependent inhibitory effect on lipase activity with an IC_{50} value of 47 μg/mL. Lotus petal extracts showed marked agonist and antagonist activity towards serotonin (5-) and cannabinoid (CNR2) receptors, respectively, while it showed no effect towards melanocyte concentrating hormone (MCHR1) and melanocortin (MC4R) receptors. Overall, the methanol extract showed better activity than successive water extract. Lotus leaf extracts which contained abundant amounts of quercetin glycosides significantly elevated plasma high-density lipoprotein-cholesterol (HDLC) in mice (Ohara et al. 2013). They found that quercetin-3-*O*-glucuronide (Q3GA), a major quercetin metabolite after absorption from the digestive tract, enhanced ATP-binding cassette, subfamily A and member 1 (ABCA1) expression, in-vitro, via LXRα in macrophages. ABCA1 is a crucial cholesterol transporter involved in reverse cholesterol transport to produce high-density lipoprotein-cholesterol.

Animal Studies

Oral administration of aqueous extracts of lotus leaves (Kayo), leaves and stem of *Lonicera japonica* (nindo) and stems of *Akebia quinata* (mokutsu) to rats loaded with a high-fat diet containing 1.5 % cholesterol and 1.0 % cholic acid significantly decreased serum total cholesterol (TC), free cholesterol (FC) and phospholipid (Onishi et al. 1984). The overall effects in suppressing serum lipid elevation were in the order of Nindo > Mokutsu > Kayo. A decoction of *Nelumbo nucifera* was tested and found to cause a reduction of triglyceride and cholesterol (LaCour et al. 1995).

Studies showed that hepatic and serum total cholesterol levels were significantly lowered on day 40 in F1B hamster given lotus leaf extract extracts (200, 400 mg/kg/day) when compared with a control value of high-fat atherogenic diet-fed hamsters (Kim et al. 2005). But the HDL levels were not changed between control and treated lotus leaf groups.

Treatment of high-fat diet-induced obese mice with *N. nucifera* leaf extract for 5 weeks caused a concentration-dependent inhibition of the activities of α-amylase and lipase and upregulated lipid metabolism and expression of UCP3 mRNA in C2C12 myotubes (Ono et al. 2006). The extract prevented the increase in body weight, parametrial adipose tissue weight and liver triacylglycerol levels in the obese mice. UCP3 mRNA expression in skeletal muscle tended to be higher, when mice were administrated by the extract and made to exercise. The results suggested that *N. nelumbo* leaf extract impaired digestion, inhibited absorption of lipids and carbohydrates, accelerated lipid metabolism and upregulated energy expenditure and was beneficial for the suppression of obesity.

A 50 % ethanol leaf extract of *N. nucifera* stimulated lipolysis in the white adipose tissue (WAT) of mice via the β-adrenergic receptor (β-AR) pathway (Ohkoshi et al. 2007). Dietary supplementation of the extract resulted in a significant suppression of body weight gain in A/J mice fed a high-fat diet. Of the compounds isolated from the leaf extract, quercetin 3-*O*-α-arabinopyranosyl-(1 → 2)-β-galactopyranoside, (+)-catechin, hyperoside, isoquercitrin and astragalin exhibited lipolytic activity, especially in visceral adipose tissue. The flavonoid-enriched *N. nucifera* leaf extract supplement effectively ameliorated the high-fat diet-induced lipid metabolic disorders in hamster such as the significant increases of body weight, plasma lipid derivatives (triglyceride, total cholesterol and lipoproteins), lipid peroxidation and liver damage markers (plasma aspartate aminotransferase and alanine aminotransferase), as did silymarin and simvastatin (Lin et al. 2009b). Moreover, the flavonoid-enriched supplement alleviated the high-fat diet-induced accumulation of lipids in liver, the findings showing distinguishing mechanisms from the effects of silymarin and simvastatin. Lotus leaf water extract significantly inhibited hyperlipidaemia and atherosclerosis in rabbits fed with high-cholesterol diet (Lee et al. 2010). In rabbits fed with high-cholesterol diet (HCD) plus 0.5 or 1.0 % of lotus leaf extract, the inhibitory level of triglyceride was 30 and 46.6 %, and low-density lipoprotein-cholesterol (LDL-C) was 45.4 and 45.9 % compared with the HCD-fed rabbits. The extract significantly reduced severe atherosclerosis, foam cell formation and smooth muscle cell proliferation and migration in the aorta. In the thiobarbituric acid-reacting substance assay, the concentration of the extract higher than 0.05 mg/mL, the inhibitory percentage was about 80 % and inhibited oxidative LDL up to 60 %.

Administration of a flavonoid-enriched lotus leaf extract to C57BL/6 mice fed with a high-fat diet, reduced body weight, body lipid accumulation and activities of fatty acid synthase (FAS), glutamic oxaloacetic transaminase and glutamic pyruvic transaminase (Wu et al. 2010). Lotus extract also suppressed the expression of FAS, acetyl-CoA carboxylase and HMGCoA reductase and increased the phosphorylation of AMP-activated protein kinase in the liver. The results suggested that lotus leaf extract targeted lipid-regulated enzymes and may be effective in attenuating body lipid accumulation and preventing obesity. Studies by Du et al. (2010) found that oral administration of hot water lotus leaf extract with taurine supplementation showed antiobesity and hypolipidaemic effects in high-fat diet-induced obese male Sprague–Dawley rats, which was more effective than lotus leaf hot water extract alone. The combined supplementation elicited better blood lipid profiles compared to lotus leaf hot water extract alone. Lotus leaf alkaloid inhibited 3T3-L1 preadipocyte differentiation and ameliorated high-fat diet (HFD)-induced obesity and body fat accumulation in rats (Xie et al. 2011). Furthermore, it reduced the body weight, Lee's index, adipose tissue weight and plasma lipid levels in HFD-induced obese rats. Oral administration of lotus leaf extract to rats fed a high-fat diet significantly decreased body weight, total cholesterol and triglyceride contents in liver tissues and serum levels of total lipids, total cholesterol and triglycerides compared to untreated rats fed a high-fat diet (Lee and Lee 2011). Liu et al. (2013) demonstrated that lotus leaf flavonoids (NLF) could effectively ameliorate hyperlipidaemia and inhibit the key enzymes related to type 2 diabetes mellitus in high-fat diet-induced hyperlipidaemic rats. In-vitro, NLF showed high inhibitory activity against porcine pancreatic lipase, α-amylase and α-glucosidase with IC_{50} values of 0.38, 2.20 and 1.86 mg/mL, respectively.

In-vitro treatment with lotus ethanol seed extract resulted in inhibition of lipid accumulation and decreased expression of peroxisome proliferator-activated receptor gamma (PPARγ), glucose transporter 4 (GLUT4) and leptin in cultured human adipocytes (You et al. 2014a). In addition, the extract had a beneficial effect, reducing adipose tissue weights, ameliorating blood lipid profile and modulating serum leptin level in rats fed a high-fat diet. Administration of ethanol lotus rhizome extract resulted in a significant decrease in relative weights of adipose tis-

sues in rats fed a high-fat diet (You et al. 2014b). Consumption of a high-fat diet resulted in an increase in serum total cholesterol (TC) and triglyceride (TG) levels; however, administration of lotus extract resulted in a decrease in the levels of TC and TG. Administration of the extract also resulted in a decrease in the level of serum leptin and insulin and in hepatic thiobarbituric acid reactive substance content, elevated by a high-fat diet and caused an increase in superoxide dismutase activity and hepatic glutathione content. The results suggested that lotus root exerts antioxidant and antiobesity effects and could be used as a functional and nutraceutical ingredient in combating obesity-related diseases.

Administration of Jiang-Zhi-Ning (a traditional Chinese medicine containing fleeceflower root, Fructus crataegi, Folium nelumbinis and Semen cassiae) extract and effective fraction significantly reduced contents of serum total cholesterol (TC), triglyceride (TG), low-density lipoprotein-cholesterol (LDL-C), coronary index and atherogenic index in hyperlipidaemic rats as well as significantly increased contents of high-density lipoprotein-cholesterol (HDL-C), in rats (Chen et al. 2011). Moreover, they significantly enhanced the activity of serum total nitric oxide synthase (NOS) and increased contents of nitric oxide. They also caused significant reductions in contents of endothelin-1 and malondialdehyde as well as significant increase in superoxide dismutase (SOD) activity and total antioxidant capacity (T-AOC) in the hyperlipidaemic rats. In-vitro, they restored and enhanced the vitality of HUVECs with a concentration-dependent manner as well as content of NO in the culture media of HUVEC. They caused reductions in the contents of endothelin-1 and malondialdehyde in HUVECs. They also caused an increase in the vitality of SOD and T-AOC in HUVECs. Furthermore, they enhanced LDL-RmRNA expression andCYP7A1 mRNA with in a concentration-dependent manner. Finally, they caused reductions in the contents of cholesterol in Bel-7402. They also increased intercellular content of total bile acid as well as lowered extracellular contents of TBA in the cells in a concentration-dependent manner. Studies found that lotus leaf extract had potential as an antiobesity agent by inhibiting pancreatic lipase and adipocyte differentiation (Ahn et al. 2013). Among its constituents, the alkaloids *trans-N*-coumaroyltyramine and *cis-N*-feruloyltyramine significantly inhibited pancreatic lipase, whereas alkaloids (6R, 6aR)-roemerine-Nβ-oxide and liriodenine showed strong inhibitory effect on adipocyte differentiation.

Antidiabetic Activity

Lotus rhizome extract exhibited hypoglycaemic effect in streptozotocin-induced diabetic rats (Mukherjee et al. 1995c). The LD_{50} of the extract was found to be 2 g/kg. The extract (300 mg/kg and 600 mg/kg, orally) caused a reduction of blood glucose levels in streptozotocin-induced diabetic rats by 53 % and 55 %, respectively, at the end of 12 h.

The crude protein of lotus seeds caused a significant decrease (44.80 %) in the blood glucose level of diabetic albino rats after 2 weeks of treatment (Ibrahim and El-Eraqy 1996). Oral administration of lotus rhizome ethanolic extract significantly markedly reduced the blood sugar level of normal, glucose-fed hyperglycaemic and streptozotocin-induced diabetic rats, when compared with control animals (Mukherjee et al. 1997b). The extract improved glucose tolerance and potentiated the action of exogenously injected insulin in normal rats. When compared with tolbutamide, the extract exhibited activity of 73 and 67 % of that of tolbutamide in normal and diabetic rats, respectively. A methanol extract of the lotus stamens exerted an inhibitory effect on rat lens aldose reductase (RLAR) which had been shown to play an important role in the complications associated with diabetes (Lim et al. 2006). Among the isolated flavonoids, those harbouring 3-*O*-α-L-rhamnopyranosyl-(1 → 6)-β-D-glucopyranoside groups in their C rings, including kaempferol 3-*O*-α-L-rhamnopyranosyl-(1 → 6)-β-D-glucopyranoside and isorhamnetin 3-*O*-α-L-rhamnopyranosyl-(1 → 6)-β-D-glucopyranoside, exhibited the highest degree of rat lens aldose

reductase inhibitory activity in-vitro, with IC_{50} values of 5.6 and 9.0 μM, respectively.

Studies by Pan et al. (2009) demonstrated that neferine, from lotus embryo, had effects similar to rosiglitazone in significantly decreasing fasting blood glucose, insulin, triglycerides and tumour necrosis factor-α (TNF-α) and enhancing insulin sensitivity in insulin-resistant rats. Streptozotocin-induced diabetic rats treated with lotus seed ash at a concentration of 200 mg/kg body weight orally for 30 days exhibited significant hypoglycaemic activity (Mani et al. 2010). The hypoglycaemic activity of the ash was comparable with gliclazide. The presence of trace elements in appreciable amounts in the seeds may play a direct or indirect role on insulin secretion or its action in a synergetic manner. Lotus leaf methanolic extract (NNE) increased insulin secretion from β cells (HIT-T15) and human islets in-vitro (Huang et al. 2011a). NNE enhanced the intracellular calcium levels in β cells and could also enhance phosphorylation of extracellular signal-regulated protein kinases (ERK)1/2 and protein kinase C (PKC). In-vivo studies showed that NNE possessed the ability to regulate blood glucose levels in fasted normal mice and high-fat diet-induced diabetic mice. Of its active constituents, quercetin did not affect insulin secretion, but catechin significantly and dose dependently enhanced insulin secretion. Orally administered catechin significantly reversed the glucose intolerance in high-fat diet-induced diabetic mice. The findings suggested that NNE and its active constituent catechin were useful in the control of hyperglycaemia in non-insulin-dependent diabetes mellitus through their action as insulin secretagogues. Administration of lotus flower extract at a dose of 250 mg/kg significantly decreased the levels of fasting blood glucose (FBG), total cholesterol (TC), triglycerides (TG), low-density lipoprotein (LDL) and blood urea nitrogen (BUN) but increased high-density lipoprotein (HDL) in streptozotocin-induced diabetic rats compared to untreated diabetic controls (Sakuljaitrong et al. 2013). However, the extract did not alter creatinine in diabetic-treated rats compared to diabetic controls. Also the extract did not produce any signs or symptoms of toxicity or mortality. The findings indicated that lotus flower extract had non-acute toxicity but possessed hypoglycaemic and hypolipidaemic activities.

Among several compounds extracted from antidiabetic plants, nuciferine from *N. nucifera* was found to stimulate insulin secretion in isolated beta INS-1E cells by blocking potassium-adenosine triphosphate channels, thus contributing to the antidiabetic effects of *Nelumbo nucifera* (Nguyen et al. 2012). Studies showed that lotus plumule polysaccharide (LPPS) administration on non-obese diabetic (NOD) female mice for 15 weeks significantly increased pancreatic islet cell numbers and slightly enhanced the basal insulin secretion ability compared to the control group (Liao and Lin 2013a). LPPS administration improved serum lipid profiles in the diabetic mice via relatively increasing serum high-density lipoprotein-cholesterol, but decreasing low-density lipoprotein-cholesterol and total cholesterol levels. All four lotus leaf compounds, 2-hydroxy-1-methoxyaporphine, pronuciferine, nuciferine and roemerine, showed the effects of improving insulin-stimulated glucose consumption in differentiated 3T3-L1 adipocytes compared with the control group (Ma et al. 2014). 2-hydroxy-1-methoxyaporphine and pronuciferine exhibited the most potent glucose consumption-stimulatory activity at the concentration of 2 μg/mL.

Anti-inflammatory Activity

Kaempferol 3-*O*-glucoside and luteolin 7-*O*-glucoside from lotus aerial parts exhibited anti-inflammatory activity (Wassel et al. 1996). Methanol lotus rhizome extract at doses of 200 and 400 mg/kg and betulinic acid at doses of carrageenin and serotonin induced rat paw oedema in rats (Mukhjee et al. 1997a). The effects produced were comparable to that of phenylbutazone and dexamethasone, two prototype anti-inflammatory drugs. Studies showed that kaempferol, constituent of lotus extract, when administered to rat tissues, attenuated the NF-κB nuclear binding activity (Kim et al. 2007).

Kaempferol augmented GSH (glutathione) levels in a dose-dependent manner and inhibited ROS generation through the inhibition of iNOS and TNF-α expression in aged rat gingival tissues, via the modulation of the NF-κB and mitogen-activated protein kinase (MAPK) pathways.

N. nucifera leaf extract demonstrated anti-inflammatory effects by inhibiting the production of NO in RAW 264.7 cell activated by lipopolysaccharide (Kwon et al. 2012). The inhibition of NO production was achieved by the inhibition of expression of iNOS protein. Additionally, the extract inhibited interleukin IL-6, one of cytokines related to inflammatory reaction. Administration of methanolic seed extracts of red and white lotus varieties at 400 mg/kg and 600 mg/kg to albino rats exerted anti-inflammatory effects in the carrageenin-induced inflammation as well as in COX-2 enzyme inhibition assay (Chakravarthi and Gopakumar 2010). Studies found that the purified components, F1 and F2 from lotus plumule polysaccharide, exhibited potent anti-inflammatory effects on LPS-induced inflamed RAW264.7 macrophages in a dose-dependent and preventive manner (Liao and Lin 2012). Both F1 and F2, especially F2, exhibited strong anti-inflammatory effects in the presence of LPS by inhibiting toll-like receptor (TLR)-2 and/or TLR-4 expressions in murine primary splenocytes in normal, inflammatory and repair situations (Liao and Lin 2013b). The results further suggested that F2, a glycoprotein with low molecular weight of 25.7 kDa, may serve as a promising lead for the development of selective TLR antagonistic agents for inflammatory diseases.

Nuclear-factor-kappaB (NF-κB) inhibitors with anti-inflammatory ability were identified in various organs of lotus plant (Zhou et al. 2013a). Seventeen such compounds were found, ten NF-κB inhibitors were found abundantly in lotus embryo plumule (LP), most of which were isoquinoline alkaloids or flavone C-glycosides. LP extracts were considered to have the best anti-inflammatory ability compared to extracts from leaves and rhizome. The major compounds identified were higenamine, lotusine, 4′-methylcoclaurine, isoliensinine, liensinine, neferine, armepavine, 4′-methyl-*N*-methylcoclaurine, apigenin-6-C-α-L-glucopyanosyl-8-C-β-D-glucopyranoside and apigenin-6-C-α-L-arabofuranosyl-8-C-β-D-glucopyranoside from lotus plumule; b-sitosterol from rhizome; nuciferine, *O*-nornuciferine, hirsutrin, hyperin, luteoloside and romaine from leaves; β-sitosterol from rhizome; and apigenin-6-C-α-L-arabofuranosyl-8-C-β-D-glucopyranoside and an unknown compound from seeds. Lotus leaf extract significantly reduced the inflammatory effects of lipopolysaccharide (LPS) in murine macrophage cell line RAW264.7 (Liu et al. 2014). Its active constituents, quercetin and catechin, significantly also decreased the LPS-elevated protein expression of iNOS, COX-2 and phospho-JNK. Besides, the mRNAs and levels of IL-6 and TNF-α also decreased by quercetin and catechin treatment in LPS-induced RAW264.7 cells. The results showed that lotus leaf extract and its major components quercetin and catechin exhibited anti-inflammatory activities by inhibiting the JNK- and NF-κB-regulated pathways and could therefore be a useful anti-inflammatory agent.

Central Nervous System (CNS) Activity (Sedative, Anxiolytic)

Nuciferine exhibited depressant properties on the CNS in rodents, as well as weak anti-inflammatory, analgesic, antitussive, antiserotonin and adrenergic blocking activities (Macko et al. 1972). Lotus rhizome methanolic extract caused a reduction in spontaneous activity; decreased exploratory behavioural pattern by the head dip and Y-maze test; reduced muscle relaxant activity by rotarod, 30° inclined screen and traction test; and potentiated the pentobarbitone-induced sleeping time in mice significantly (Mukherjee et al. 1996c).

The methanol extracts of *Nelumbo nucifera* seed embryos significantly inhibited locomotor activity in mice (Sugimoto et al. 2008). The chloroform partitioned extracts strongly inhibited locomotor activity in mice, and its main alkaloid, neferine, dose dependently inhibited locomotor activity in mice. Neferine induced hypothermia in mice and apparently potentiated thiopental-

induced sleeping time. An anxiolytic, diazepam decreased locomotor activity and rectal temperature and enhanced sleep elicited by thiopental, similar to neferine. In addition, neferine and diazepam showed anti-anxiety effects in the elevated plus maze test. Neferine did not affect muscle coordination by the rotarod test. Neferine did not affect strychnine- nor picrotoxin-induced seizure. The results suggested that neferine had several central nervous system effects and that neferine may participate in the efficacy of the sedative effects of embryos of *N. nucifera* seeds. Results of studies showed that lotus seed extract ameliorated scopolamine-induced amnesia in rats by inhibiting acetylcholinesterase activity and inducing choline acetyltransferase expression (Oh et al. 2009). The i.p. administration of neferine 25–100 mg/kg elicited anti-immobility effects in mice (Sugimoto et al. 2010). The molecular dose effects of neferine in the forced swimming test were almost equal to those of the typical antidepressants maprotiline and imipramine. The antidepressant effect was found to be mediated by serotonin1A (5-HT1A) receptor and was likely to be linked to serotonergic neurotransmission.

Compounds cycloartenol, *p*-hydroxybenzoic acid, vanilloloside and nuciferoside, isolated from lotus stamens, exhibited good and noncompetitive inhibition against acetylcholinesterase (AChE) with IC_{50} values of 11.89, 20.07, 4.55 and 3.20 microM and K_i values of 15.71, 25.44, 7.76 and 5.76 μM, respectively (Jung et al. 2010b). Cycloartenol, *p*-hydroxybenzoic acid and nuciferoside also possessed butyrylcholinesterase (BChE) inhibitory activities with IC_{50} values of 13.93, 62.29, 205.78 and 83.06 μM, respectively. The selectivity index (SI) values of 1, 2, 3 and 5, calculated from IC_{50} values of BChE and AChE, were 1.2, 3.1, 45.7 and 26.0. However, all isolated compounds lacked BACE1 inhibition up to 100 μM. The data suggested that *N. nucifera* stamen-derived compounds could potentially exert their primary anti-Alzheimer effects as AChE inhibitors rather than BACE1 inhibitors.

Neferine, liensinine, isoliensinine, nelumboferine and *O*-methylneferine, isolated from lotus embryos, inhibited mice locomotor activity indicating that they all possessed sedative activity (Nishimura et al. 2013). The efficacy of liensinine, isoliensinine and nelumboferine was more potent than neferine and *O*-methylneferine. Compounds isolated from lotus leaves 6′-hydroxy-4,4′-dimethoxychalcone, rhamnetin-3-*O*-β-D-glucopyranoside, quercetin-3-*O*-β-D-glucopyranoside, quercetin-3-*O*-α-L-rhamnopyranosyl, quercetin-3-*O*-rutinoside and isorhamnetin-3-*O*-α-L-rhamnopyranosyl-(1 → 6)-[α-D-lyxopyranosyl-(1 → 2)-β-D-glucopyranoside] showed inhibitory activities against beta amyloid (1–42) by A-beta aggregation method with inhibition rates of (63.99)%, (79.61)%, (49.96)%, (101.19)%, (88.41)% and (72.48)%, respectively (Zhao et al. 2013b). Of the alkyl 4-hydroxybenzoates isolated from lotus seeds, methyl 4-hydroxybenzoate and ethyl 4-hydroxybenzoate enhanced 5-HT-stimulated inward current ($I_{5\text{-HT}}$) in *Xenopus* oocytes, but butyl 4-hydroxybenzoate reduced it (Youn et al. 2010). The results indicated that butyl 4-hydroxybenzoate was an inhibitor of the 5-HT_3A receptors expressed in *Xenopus* oocytes.

N-methylasimilobine, a potent acetylcholinesterase (AChE) from *N. nucifera* leaves, inhibited 50 % of AChE activity at the concentrations of 1.5 μg/mL when the IC_{50} value of physostigmine standard was 0.013 μg/mL (Yang et al. 2012). The mode of AChE inhibition by *N*-methylasimilobine was reversible and noncompetitive.

Cognitive-Enhancing Activity

The methanol extract of *N. nucifera* rhizome elicited in significant improvements of memory functions and neurogenesis in the dentate gyrus of Wistar rats (Yang et al. 2008). In the passive avoidance test, the retention time of extracted-treated rats was significantly longer than that of controls. In addition, cell proliferation and cell differentiation increased significantly in the dentate gyrus. The results suggested that *N. nucifera* rhizome extract may improve learning and memory by enhancing neurogenesis in the dentate

gyrus of the hippocampus. Hydroalcohol lotus extract exhibited a weak inhibition of acetylcholinesterase with IC_{50}value of 185.55 μg/mL, compared to physostigmine (IC_{50} 0.076 μg/mL) used as a standard (Mukherjee et al. 2007).

Neferine, from lotus embryo, exerted significant improvement in cognitive impairment in scopolamine-induced amnesia animal models and moderate inhibitory activities in cholinesterases (ChEs)- and β-site APP cleaving enzyme 1 (BACE1) assays (Jung et al. 2010a). Additionally, it exhibited notable scavenging activities against 1,1-diphenyl-2-picrylhydrazyl (DPPH), 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), NO (nitric oxide) and O^{2-} (superoxide) radicals, as well as $ONOO^{-}$ (peroxynitrite). Neferine also demonstrated dramatic inhibitory activity against lipid peroxidation and protein nitration in cell-free antioxidant assays and moderate inhibitory activity of NO generation with exceptional suppression of NF-κB activation in cell-based assays. The results demonstrated that the anti-amnesic effect of neferine may be mediated via antioxidant and anti-inflammatory capacities, as well as inhibition of ChEs and BACE1. The administration of lotus rhizome extract significantly ameliorated the scopolamine-induced reduction of Ki67- and doublecortin-immunoreactive cells in the hippocampal dentate gyrus of rats (Yoo et al. 2011). In addition, the administration of the extract significantly restored the scopolamine-induced reduction of brain-derived neurotrophic factor (BDNF) in hippocampal dentate gyrus homogenates. The results suggested that lotus rhizome extract could ameliorate the scopolamine-induced reductions of cell proliferation, neuroblast differentiation and BDNF levels.

Lotus plant extract was one of several plants used in Indian Ayurvedic system of medicine for improving cognitive function that showed IC_{50} values <100 μg/ml for acetylcholinesterase inhibitory activity (Mathew and Subramanian 2014). Allantoin, an active compound in lotus, exerted memory-enhancing effects in mice (Ahn et al. 2014). Subchronic administration of allantoin (1, 3 or 10 mg/kg, for 7 days) significantly increased the latency time measured during the passive avoidance task in scopolamine-induced cholinergic blockade and normal naïve mice. Allantoin treatment (3 or 10 mg/kg, for 7 days) also increased the expression levels of phosphorylated phosphatidylinositide 3-kinase (PI3K), phosphorylated protein kinase B (Akt) and phosphorylated glycogen synthase kinase-3β (GSK-3β). Also, allantoin significantly increased the neuronal cell proliferation of immature neurons in the hippocampal dentate gyrus region. The results suggested that allantoin may have therapeutic potential for the cognitive dysfunctions observed in Alzheimer's disease.

Convulsant Activity

Nornuciferine derivatives administered intraperitoneally to mice as hydrobromide or hydrochloride provoked intense clonic convulsions (Burkman and Cannon 1972). Unlike apomorphine, they did not induce emesis in dogs. *N*-Propyl nuciferine was the most effective convulsant agent.

Analgesic Activity

Kaempferol 3-*O*-glucoside and luteolin 7-*O*-glucoside from lotus aerial parts exhibited analgesic activity (Wassel et al. 1996). Methanol seed extract of red and white lotus, fed to albino rats, elicited considerable analgesic effect in the acute pain (tail flick) model in a concentration-dependent fashion (Chakravarthi and Gopakumar 2009). The higher dose group of white lotus seed (600 mg/kg) exhibited more pronounced activity than other extracts.

Cosmeceutical/Antityrosinase Activity

Lotus plant parts were found to have whitening effect as measured by tyrosinase inhibition assay and DOPA-oxidase inhibition assay, and anti-wrinkle effect as measured by elastase inhibition

assay (Kim et al. 2011). DOPA-oxidase inhibition effect (whitening effect) of *N. nucifera's* leaf, seed and flower extract was 59 %, 57 % and 50 %, respectively. *N. nucifera's* leaf, seed and flower extract showed 56 %, 49 % and 54 % elastase inhibition (antiwrinkle effect) at 200 μg/ml, while adenosine indicated 26 % inhibition. Lotus plant parts were found to have whitening effect as measured by tyrosinase inhibition assay and DOPA-oxidase inhibition assay and antiwrinkle effect as measured by elastase inhibition assay (Kim et al. 2011). DOPA-oxidase inhibition effect (whitening effect) of *N. nucifera's* leaf, seed and flower extract was 59 %, 57 % and 50 %, respectively. *N. nucifera's* leaf, seed and flower extract showed 56 %, 49 % and 54 % elastase inhibition (antiwrinkle effect) at 200 μg/ml, while adenosine indicated 26 % inhibition. Water cream including *Nelumbo nucifera's* root, leaf, flower and stem extract did not cause significant skin irritation. Methanolic extracts from the flower buds and leaves of sacred lotus were found to show inhibitory effects on melanogenesis in theophylline-stimulated murine B16 melanoma 4A5 cells (Nakamura et al. 2013). Among the constituents isolated, nuciferine, *N*-methylasimilobine, (–)-lirinidine and 2-hydroxy-1-methoxy-6a,7-dehydroaporphine showed potent inhibition of melanogenesis. In addition, 3–30 μM nuciferine and *N*-methylasimilobine inhibited the expression of tyrosinase mRNA, 3–30 μM *N*-methylasimilobine inhibited the expression of TRP-1 mRNA and 10–30 μM nuciferine inhibited the expression of TRP-2 mRNA.

Hepatoprotective Activity

Ethanol lotus seed extract showed potent DPPH free radical scavenging effects with a median inhibition concentration of 6.49 g/ml (Sohn et al. 2003). Treatment of hepatocytes with the extract inhibited both the production of serum enzymes and cytotoxicity by carbon tetrachloride (CCl_4). The genotoxic and cytotoxic effects of aflatoxin B1 (AFB1) were also inhibited by the extract in dose-dependent manners. These hepatoprotective effects of lotus seed extract against CCl_4 and AFB1 might result from its potent antioxidative properties. In-vitro studies showed that neferine efficiently inhibited cultured hepatic stellate (HSC-T6) cell activation and induced apoptosis by increasing Bax and caspase 3 mRNAs expression via the mitochondrial pathway (Ding et al. 2011).

Administration of hydroalcoholic lotus seed extract to Wistar rats at 100 and 200 mg/kg body weight for 4 days prior to carbon tetrachloride treatment caused a significant dose-dependent increase in the level of superoxide dismutase and catalase and a significant decrease in the level of thiobarbituric acid reactive substances (TBARS), when compared to CCl_4-treated control in both liver and kidney (Rai et al. 2006). These changes observed at 100 mg/kg body weight treatment were comparable to those observed for standard vitamin E at 50 mg/kg treatment. Armepavine, a lotus compound, exerted anti-hepatic fibrogenic effects in-vitro and in-vivo (Weng et al. 2009). It dose dependently attenuated tumour necrosis factor-α (TNF-α)- and lipopolysaccharide (LPS)-stimulated α-SMA protein expression and AP-1 activation by HSC-T6 cells without adverse cytotoxicity in bile duct-ligated (BDL) rats. It significantly reduced plasma AST and ALT levels, hepatic α-SMA expression and collagen contents and fibrosis scores as compared with vehicle treatment. The results suggested that armepavine both in-vitro and in-vivo has antifibrotic effects in rats, possibly through anti-NF-κB activation pathways. Oral administration of lotus root hot water extract with taurine supplementation exerted antioxidant and hepatic protective effects in high-fat diet-induced obese male Sprague–Dawley rats (Du et al. 2010). Activities of serum glutamate oxaloacetate transaminase, glutamate pyruvate transaminase and thiobarbituric acid reactive substance content were reduced, and hepatic antioxidant enzymes were reduced by lotus root extract. An ethanolic lotus leaf extract at doses of 300 and 500 mg/kg exhibited hepatoprotective activity against CCl_4-induced liver toxicity in rats and antioxidant activity at 100 mg/

kg that was comparable with that of a standard treatment comprising 100 mg/kg of silymarin, a known hepatoprotective drug (Huang et al. 2010b).

Lotus germ oil treatment of mice with chronic hepatotoxicity induced by carbon tetrachloride increased significantly the activities of antioxidant enzymes, such as superoxide dismutase (SOD), catalase (CAT) and the concentration of glutathione (GSH) in a dose-dependent manner (Lv et al. 2012). Also the lipid peroxidation product malondialdehyde and serum levels of hepatic enzyme biomarkers (alanine aminotransferase and aspartate aminotransferase) were decreased. In addition, lotus germ oil could inhibit the conversion of super-coiled pBR322 plasmid DNA to the open circular form and apoptosis of hydrogen peroxide-induced PC-12 cells.

After 3 weeks of feeding, the hepatomegaly and hepatic triglyceride accumulation was markedly alleviated in the lotus polyphenol-diet-fed db/db mice relative to the control mice (Tsuruta et al. 2011, 2012). Although the lipolytic enzyme activity was not changed, the activities of lipogenic enzymes, such as fatty acid synthase and malic enzyme, were significantly lower in the lotus polyphenol-diet-fed db/db mice. Further, the presence of B-type proanthocyanidin polymers with polymerisation degree up to 9 was detected in the polyphenolic lotus root extract. It was suggested that condensed tannins contained in lotus root could alleviate hepatic steatosis by suppressing the lipogenic enzyme activity in the livers of db/db mice. They also found that the serum levels of adiponectin, which had been reported to have a protective effect against non-alcoholic fatty liver disease (NAFLD), were significantly higher in the Lotus group than in the control group of the *db/db* mice. Additionally, the hepatic expression of such inflammatory genes as tumour necrosis factor-alpha and monocyte chemoattractant protein-1 was markedly suppressed by the Lotus diet. They speculated that the development and progression of NAFLD were prevented by suppressing the expression of lipogenic and inflammatory genes as a result of the higher serum adiponectin level in the Lotus diet-fed *db/db* mice. Nuciferine supplementation in hamsters ameliorated high-fat diet-induced dyslipidaemia as well as liver steatosis and hepatic injury (Guo et al. 2013). The beneficial effects of nuciferine were associated with altered expression of hepatic genes involved in lipid metabolism. Tang et al. (2014) showed that the polyphenol-rich lotus leaf extract inhibited alcohol-induced steatohepatitis by multiple ways including reducing hepatic lipid synthesis, oxidative stress and anti-inflammation and enhancing fatty acid oxidation and transport responses in C57BL/6 J mice.

Pulmonoprotective Activity

Administration of isoliensinine, a constituent of lotus embryo, markedly suppressed the increase in hydroxyproline content and abated pulmonary fibrosis histological injury induced by bleomycin in mice (Xiao et al. 2005). Isoliensinine enhanced serum superoxide dismutase activity and decreased the bleomycin-elevated malondialdehyde level in a concentration-dependent manner. Moreover, isoliensinine also significantly inhibited the overexpression of TNF-α and TGF-β1 induced by bleomycin. The results indicated that isoliensinine possessed a significant inhibitory effect on bleomycin-induced pulmonary fibrosis, probably due to its antioxidant and/or anti-inflammatory activities and its inhibition of overexpression of TNF-α and TGF-β1 induced by bleomycin. Neferine, from lotus embryo, significantly inhibited amiodarone-induced pulmonary fibrosis in adult Kunming mice modulated by its properties of anti-inflammation, surfactant protein-D inhibition and restoring increased CD4+CD25+ regulatory T cells which may regulate Th1/Th2 imbalance by suppressing Th2 response (Niu et al. 2013).

Renoprotective Activity

Studies showed that (*S*)-armepavine, from lotus, administered in the established phase of autoimmune crescentic glomerulonephritis (ACGN) in mice, was capable of markedly decreasing glomerular crescents in the kidney and improving

proteinuria and renal dysfunction (Ka et al. 2010). These therapeutic effects were associated with (1) early systemic negative modulation of T/B cells; (2) intra-renal regulation of combined NF-κB activation and mononuclear leukocytic infiltration, thereby preventing glomerular crescent formation; and (3) protection from apoptosis in both the spleen and kidney.

Spasmolytic/Anti-arrhythmic/ Hypotensive/Bradycardic Activities

Nn-9 a non-crystalline alkaloid isolated from lotus embryo exerted hypotensive effects in animals (Chen et al. 1962). In anesthetised cats, i.v. injections of 1–2 mg/kg lowered, after a delay of 1/2–1 min, the blood pressure by about 50 % from the original level, lasting 2–3 h. In dogs, the blood pressure returned to normal in 1/2 h. This dosage was ineffective in rabbits. Pretreatment with Nn-9 also lessened the hypotensive action of histamine. Nn-9 appeared to act primarily through histamine release. The alkaloids asimilobine and lirinidine, isolated from lotus leaves, inhibited the contraction of isolated rabbit aorta induced by serotonin; the pA_2 values were 5.78 and 7.36, respectively (Shoji et al. 1987).

Studies found that neferine from lotus embryo possessed antiarrhythmic action (Li et al. 1989). It exerted an inhibitory effect on the slow transmembrane Na^+ and/or Ca^{2+} current of myocardium. Neferine decreased the amplitude of action potential and the maximal upstroke velocity in rabbit sinoatrial nodes and in the clusters of cultured cardiac myocytes from neonatal rats in a concentration-dependent manner. In subsequent studies, neferine at 1–10 mg/kg i.v. dose dependently decreased the monophasic action potential amplitude, prolonging the monophasic action potential duration in anaesthetised cat's heart (Li et al. 1990). It also decreased left ventricular pressure (LVP), dP/dt, prolonged sinus cycle length and reduced arterial blood pressure in a dose-dependent manner. These effects were similar to those of quinidine and different from tetrandrine. Liensinine, an alkaloid from lotus embryo, was shown to have antiarrhythmic action; its mechanism may be related to blockade of Ca^{2+}, Na^+ influx (Wang et al. 1992). Liensinine 3 mg/kg i.v. temporarily inhibited all parameters of haemodynamics in anesthetised or pithed rats. The dose-dependent inhibitory effects of liensinine (1–30 mg/kg) on LVP, +dp/dtmax and SAP (slow action potential) in anesthetised rats were slightly stronger than those of quinidine 3 mg/kg. Liensinine 1–30 mg/kg dose dependently produced these actions. The magnitude of inhibitory effect of liensinine on all haemodynamic parameters nearly corresponded to these of verapamil 1 mg/kg. Liensinine 1–100 μmol/L reduced the contractile force of isolated left atria and the spontaneously beating rate of isolated right atria of rabbits in concentration-dependent manner. Liensinine 10–100 μmol/L was also shown to concentration dependently decrease the action potential amplitude (APA) and the maximal velocity of phase 0 depolarisation (Vmax) and prolong the sinus cycle length (SCL) of SAP in isolated sinoatrial node pacemaker cells of rabbits (Wang et al. 1993). Moreover, liensinine 1–100 μmol/L was found to inhibit the slow inward current of canine cardiac Purkinje fibre in concentration-dependent manner. Liensinine 3 and 100 μmol/L reduced the peak value of slow inward current by 14 % and 88 %, respectively. The results suggested that liensinine possessed calcium antagonistic effects.

Studies by Morales et al. (1997) demonstrated the hypotensive and bradycardic properties of (±)-norarmepavine, a lotus alkaloid. In rat's aorta, (±)-norarmepavine (10 mg/kg i.v.) decreased the mean arterial pressure and heart rate by 45 % and 21 %, respectively. It showed a negative chronotropic effect on rat-isolated atria, decreasing the spontaneous frequency by about 54 %. Aortic rings contracted with KCl 70 mM were relaxed in a concentration-dependent manner by (±)-norarmepavine, (±)-coclaurine and (±)-norcoclaurine. The two earlier alkaloids exhibited an efficacy similar to verapamil, relaxing the aortic rings by 100 %. (±)-Norcoclaurine exhibited a lower efficacy. The rank order of potency was verapamil > (±)-norarmepavine > (±)-norcoclaurine > (±)-coclaurine.

Neferine alkaloid isolated from lotus embryo exhibited antiarrhythmic effect in experimental arrhythmic models (Qian 2002). In guinea pig papillary muscles and atria, neferine reduced the force of contraction, decreased the amplitude and upstroke velocity Vmax of action potential and prolonged action potential duration (APD50 and APD 90) and effective refractory period. Neferine also suppressed the contractility of rabbit papillary muscles, prolonged functional refractory period and inhibited automaticity, positive staircase and post-rest potentiation. Neferine, isolated from the seed embryo, increased the basal cAMP concentration in rabbit corpus cavernosum tissue in a dose-dependent manner (Chen et al. 2008). The accumulation of cAMP induced by prostaglandin E1 (PGE1, a stimulator of cAMP production) was also augmented by neferine in a dose-dependent manner. It was found that neferine with its spasmolytic activity could enhance the concentration of cAMP in rabbit corpus cavernosum tissue, probably by inhibiting phosphodiesterase activity. Neferine, from lotus embryo, induced a concentration-dependent decrease in current amplitude according to the voltage steps and tail currents of human ether-à-go-go-related gene (HERG) K^+ channels in a dose-dependent manner with an IC_{50} of 7.419 μM (Gu et al. 2009) in human embryonic kidney (HEK293) cells. It had no effect on the generation and trafficking of HERG protein. A blocked-off HERG channel was one mechanism of the antiarrhythmic effects by neferine.

Antithrombotic/Antiplatelet Activity

Neferine was shown to significantly inhibit rabbit platelet aggregation induced by ADP, collagen, arachidonic acid (AA) and platelet-activating factor (PAF) with IC_{50} of 16, 22, 193 and 103 μmol/L, respectively (Yu and Hu 1997). Neferine was found to increase vascular 6-keto-PGF1 alpha and platelet cAMP levels in dose-dependent manner, but inhibit AA-stimulated TXA2 release from platelets. The results suggested that the mechanism of neferine on platelet aggregation is related to regulation of TXA2/PGI2 and cAMP/cGMP balance. Studies found neferine could dose dependently inhibit human or rat platelet aggregation induced by ADP, collagen and epinephrine both in-vitro and in-vivo (Qian 2002). Neferine, from lotus embryo, significantly and dose dependently inhibited collagen-, thrombin- and U46619-induced platelet aggregation in mice-washed platelets, or ADP-induced platelet aggregation in mice platelet-rich plasma (Zhou et al. 2013b). Neferine treatment decreased platelet dense granule secretion initiated by collagen, thrombin and U46619. Also, Neferine markedly and dose dependently promoted the dissociation of platelet aggregates preformed by various agonists including collagen, thrombin, U46619 or ADP. Neferine could significantly reduce the area of mice platelet adhesion to the collagen and inhibited thrombosis in-vitro. In collagen–epinephrine-induced acute pulmonary thrombus mouse model, neferine, at 6 mg/kg, significantly attenuated thrombus formation.

Immunomodulatory Activity

N. nucifera ethanolic extracts significantly suppressed phytohemagglutinin-activated human peripheral blood mononuclear cell (PBMC) proliferation (Liu et al. 2004). The inhibitory action of lotus extract did not involve direct cytotoxicity. The suppressant effects of lotus extract on proliferation of activated PBMC appeared to be mediated, at least in part, through inhibition of early transcripts of PBMC, especially those of important interleukin IL-2, interferon-gamma (IFN-gamma) and cyclin-dependent kinase (cdk) 4 mRNA expression and arrest of cell cycle progression in the cells. Oral administration of MRL/MpJ-lpr/lpr mice with similar disease features to human systemic lupus erythematosus with (S)-armepavine (from lotus) for 6 weeks prevented lymphadenopathy and elongated life span of MRL/MpJ-lpr/lpr mice (Liu et al. 2006). It appeared to be mediated by inhibition of splenocyte proliferation, suppression of interleukin-2

(IL-2), interleukin-4, interleukin-10, and interferon-gamma (IFN-gamma) gene expressions, reduction of glomerular hypercellularity and immune complexes deposition and decrease of urinary protein and anti-double-stranded DNA autoantibody production. It was suggested that (S)-armepavine may be an immunomodulator for the management of autoimmune diseases like systemic lupus erythematosus. Also, they found that (S)-armepavine inhibited phytohemagglutinin-activated human peripheral blood mononuclear cell (PBMC) proliferation and cytokine production in a major way by blocking membrane-proximal effectors such as IL-2-inducible T-cell kinase (Itk) and phospholipase Cgamma (PLCgamma) in a PI-3K-dependent manner (Liu et al. 2007).

Studies found that the extract of lotus rhizome and seed stimulates defence system by modulating several immunological parameters (Mukherjee et al. 2010b). Total leukocyte count and lymphocyte count increased significantly, but the neutrophil count was decreased in both extract-treated animal groups compared to the control. A dose-dependent potentiation of delayed type hypersensitivity reaction induced by sheep red blood cells was observed from the extracts. The percentage of neutrophil adhesion to the nylon fibre was increased in rhizome-treated groups (63.22 and 62.91 %) compared to the seed-treated group (54.86 and 54.23 %). A potential phagocytic response was seen on treatment of the extracts, and significant changes were observed in the formation of formazone crystals. In separate studies, lotus rhizome extract stabilised erythrocyte membrane significantly at 10 (42.05 %) and 100 μg/mL (44.31 %) (Mukherjee et al. 2010a). The extract showed 38.66 % (100 μg/mL) and 69.66 % (10 μg/mL) degranulation against compound 48/80 (C 48/80) in mast cells. The extract at 1 and 5 μg/mL inhibited lipopolysaccharide (LPS)-induced activation of macrophages by decreasing the expression of costimulatory molecules. The extracts also inhibited the nitrite concentration at 1 and 5 μg/mL compared to LPS-treated group.

Cardiovascular Protective Activity

Isoliensinine, extracted from lotus embryo, inhibited angiotensin II-induced proliferation of porcine coronary arterial smooth muscle cells in-vitro (Xiao et al. 2006). Its antiproliferative effect was related to the decrease of the overexpression of growth factor platelet-derived growth factor (PDGF)-β and basic fibroblast growth factor (bFGF), proto-oncogene c-fos, c-myc and hsp70. Polyphenol-rich water extract of lotus leaves was found to inhibit both proliferation and migration of vascular smooth muscle cells (VSMC) and thus may serve as a potential anti-atherogenic agent (Ho et al. 2010). 1.0 % of lotus leaf extract reduced neointima formation conspicuously and inhibited smooth muscle cell proliferation and MMP-2 secretion in the blood vessel of rabbits fed with a high-cholesterol diet. Neferine, from lotus embryo, inhibited nitric oxide production induced by lysophosphatidylcholine in human umbilical vein endothelial cells (HUVECs) by modulating dimethylarginine dimethylaminohydrolase (DDAH) – asymmetric dimethylarginine (ADMA) pathway via its antioxidant properties (Peng et al. 2011). Animal studies showed that administration of lotus leaf extract elicited cardioprotective effect in isoproterenol (ISO)-induced myocardial infarction in rats (Subashini et al. 2012). Oral pretreatment with the extract (400 mg/kg) to ISO-induced rats daily for a period of 21 days showed a significant decrease in the levels of lipid peroxidative products and improved the antioxidant enzyme activities. This amelioration was supported by histopathological findings.

Oral administration of lotus leaf extract for 4 weeks to rats after balloon injury reduced the intimal thickening by suppressing vascular smooth muscle cells (VSMC)'s proliferation through inhibition of extracellular signal-regulated kinase 1/2 phosphorylation and their migration by reducing the expression of MMP-2 and MMP-9 through inhibition of JNK1/2 phosphorylation (Karki et al. 2013). The results

suggested that lotus leaf could be considered to have therapeutic value in the prevention of atherosclerosis.

Aldose Reductase Inhibitory Activity

Among several solvent fractions of lotus leaf extract, the ethyl acetate and *n*-butanol fractions, having prominent total phenolic content (TPC) and total flavonoid content (TFC)C values, showed significant antioxidant effects in the DPPH and TEAC assays (Jung et al. 2008). Moreover, the ethyl acetate fraction exhibited superior inhibitory effects in the total reactive oxygen species (ROS), rat lens aldose reductase (RLAR) and advanced glycation end products (AGE) assays, with IC_{50} values of 9.4, 2.4 and 28.2 μg/ml, respectively. Also, two of its key antioxidant flavonoids, quercetin 3-*O*-β-D-glucopyranoside and quercetin 3-*O*-β-D-glucuronopyranoside, may play important roles in the antioxidant and RLAR inhibitory effects of *N. nucifera* leaves. The hydroalcoholic extract of lotus plant exhibited aldose reductase inhibitory activity with an IC_{50} value 59.78 μg/mL, and its alkaloidal extract was more inhibitory with an IC_{50} of 28.82 μg/mL (Gupta et al. 2014).

Diuretic Activity

The methanol extract of lotus rhizomes induced significant diuresis in rats (Mukherjee et al. 1996b). Dose-dependent effects were observed in urine volume and electrolyte excretion. There was a significant increase in natriuretic and chlorouretic activity, but kaliuresis was less than natriuresis.

Antipyretic Activity

The methanolic lotus rhizome extract, in doses of 200, 300 or 400 mg/kg (p.o.), produced significant dose-dependent lowering of normal body temperature and yeast-induced elevation of body temperature (pyrexia) in rats (Mukherjee et al. 1996a). The effect produced was comparable with the standard antipyretic drug, paracetamol (150 mg/kg, i.p.). The ethanol lotus stalk extract at a dose of 200 mg/kg was found to produce significant lowering of normal body temperature up to 3 h, and at 400 mg/kg, it caused significant lowering of body temperature up to 6 h after its administration (Sinha et al. 2000). In the model of yeast-induced elevation of body temperature, the extract showed dose-dependent lowering of body temperature up to 4 h at both the doses, and the results were comparable to that of paracetamol, a standard antipyretic agent.

Antihemorrhagic Activity

The antihemorrhagic principle in nelumbins receptaculum, dried receptacle of *Nelumbo nucifera*, was identified as quercetin [2-(3, 4-dihydroxy)-3, 5, 7-trihydroxy-4*H*-1-benzopyran-4-one] (Ishida et al. 1988).

Antiallergic Activity

Flow cytometric analysis revealed that Fc epsilon RI expression on human basophilic KU812F human basophilic KU812F cell surface was suppressed in a concentration-dependent manner when the cells were cultured with kaempferol extracted from a methanolic extract of flavonoid-rich lotus stamens (Shim et al. 2009). Moreover, RTPCR analysis showed that the mRNA levels for Fc epsilon RI alpha- and gamma-chains were reduced as the result of kaempferol treatment in a concentration-dependent manner. Kaempferol showed its suppressive effects on intracellular Ca^{2+} concentration and histamine release from anti-Fc epsilon RI alpha-chain antibody-stimulated cells in a concentration-dependent manner. These observations indicated that kaempferol may exert antiallergic effect via downregulation of Fc epsilon RI expression and degranulation.

Antiestrogenic/Antisteroidogenic Activity

The petroleum ether lotus seed extract administered to mice exhibited antiestrogenic, antiprogestational and contraceptive activity at a dose of 3 mg/kg body weight (Mazumder et al. 1992). Oral administration of lotus seed petroleum ether extract to sexually immature female rats and mature male rats on alternate day for 15 days caused a remarkable delay in sexual maturation in prepubertal female rats as evidenced from age of vaginal opening and first estrus (cornified smear) and a significant reduction in the sperm count and motility in mature male rats (Gupta et al. 1996). In both the cases, treatment resulted in accumulation of cholesterol and ascorbic acid and reduction in D5-3b-hydroxysteroid dehydrogenase and glucose-6-phosphate dehydrogenase activity in the ovary and testis of female and male rat, respectively. The results indicated suppression of steroidogenesis in both ovary and testis by lotus seed extract.

Oral administration of lotus seed ethanol extract to female albino rats elicited in significant decline in weights of reproductive organs (ovary, uterus, vagina) (Mutreja et al. 2008). Glycogen levels in the reproductive organs were decreased significantly, but the cholesterol levels were increased; no changes in haematological parameters were found. The extract prolonged the oestrous cycle. The results suggested that lotus seed exhibited antiestrogenic activity without altering the general physiology of the female rats.

Antidiarrhoeal Activity

Rats treated with lotus rhizome methanol extract significantly inhibited castor oil-induced diarrhoea and PGE-induced enteropooling (Mukherjee et al. 1995b). It also showed significant reduction in gastrointestinal motility following charcoal meal in rats. The results obtained confirmed the efficacy of lotus rhizome extract as an antidiarrhoeal agent. Lotus rhizome extract in graded doses (100, 200, 400 and 600 mg/kg body wt.) reduced not only the frequency of defecation, wetness of faecal dropping and PGE2-induced enteropooling but also the propulsive movements of charcoal meal significantly in rats (Talukder and Nessa 1998). Aqueous lotus fruit extract was found to have strong significant anti-rotaviral activity with a 50 % inhibitory concentration (IC_{50}) <300 μg/ml (Knipping et al. 2012). A combination of *Glycyrrhiza glabra* and lotus showed synergy in their antiviral activities and interventions of lotus, and combination may be useful in the treatment of diarrhoea caused by rotavirus infection.

Anti-dermatitis Activity

Oral administration of lotus leaf extract to NC/Nga mice with atopic dermatitis induced by repeated epicutaneous application of 2,4-dinitrochlorobenzene (DNCB) on the dorsal skin resulted in the suppression of clinical severity score, transepidermal water loss, scratching behaviour and blood IgE level (Karki et al. 2012). Histopathologic analyses revealed that thickening of the epidermis and mast cell degranulation were significantly reduced in lotus-treated mice. The results suggested that lotus leaf extract may be a useful natural resource for the management of atopic dermatitis.

Antimalarial Activity

Antimalarial activity was observed for lotus leaf alkaloids (*R*)-roemerine and *N*-methylasimilobine with IC_{50} = 0.2 and 4.8 μg/mL for the D6 (chloroquine-sensitive) clone of *Plasmodium falciparum*, respectively, and 0.4 and 4.8 μg/mL for the W2 (chloroquine-resistant) clone, respectively (Agnihotri et al. 2008). An analysis of the structure–activity relationship revealed that the substituents in position C-1 and C-2 of aporphine alkaloids were crucial for the antimalarial activity.

Radioprotective/Photoprotective Activity

Pretreatment of Swiss albino mice with lotus seed pod procyanidins (LSPCs) 200 mg/kg by intragastric (i.g.) for 15 days before gamma irradiation was found to be the most effective dose in preventing radiation sickness, reducing radiation-induced mortality, increasing mean survival time and elevating radiation median lethal dose (LD_{50}) from 8.9 to 10.5 Gy, indicating a dose-modifying factor (DMF) of 1.18 (Duan et al. 2010). Further, administered LSPCs at a dose of 200 mg/kg could effectively maintain spleen index close to normal; stimulate endogenous spleen colony forming units; promote the levels of red blood cells (RBC), white blood cells (WBC), platelets and haemoglobin in peripheral blood and prevent spleen and skin damage in irradiated mice; reduce the level of radiation-induced micronucleated polychromatic erythrocytes in bone marrow, maintain the polychromatic erythrocytes (PCE) and normochromatic erythrocytes (NCE) ratio (P/N ratio); and significantly decrease bone marrow chromosomal damage. Alternatively, pretreatment with LSPCs (200 mg/kg) significantly decreased the lipid peroxidation (LPO) level and elevated the activities of endogenous antioxidant enzymes in liver after irradiation. The results indicated that LSPCs possessed potent whole body radioprotective activity, and it may be used as a radioprotector.

Lotus leaf extract (10, 100 and 1000 μg/ml) possessed strong protective effect against UVB-induced phototoxicity in the mitochondria model (Huang et al. 2013). The in-vivo test showed that LLE lotus leaf extract exerted significant protective effects on the level of superoxide dismutase, catalase and glutathione peroxidase, as well as the contents of hydroxyproline and malondialdehyde in mouse skin.

Antimicrobial Activity

The methanol lotus rhizome extract inhibited the in-vitro growth of the following fungi-tested *Candida albicans, Aspergillus niger, Aspergillus fumigatus* and *Trichophyton mentagrophytes* (Mukherjee et al. 1995d). Antibacterial activity in-vitro was documented for lotus rhizome extracts against *Staphylococcus aureus, Escherichia coli, Bacillus subtilis, Bacillus pumilus* and *Pseudomonas aeruginosa* (Mukherjee et al. 1995a). Kaempferol 3-*O*-glucoside and luteolin 7-*O*-glucoside from lotus aerial parts showed significant activity against six bacteria and *Candida albicans* (Wassel et al. 1996). Lotus pollen essential oil significantly inhibited growth of *Salmonella typhimurium* and *Escherichia coli* in-vitro (Sittiwet 2009). The MICs and MBCs were 10–40 and 20–80 ml/L, respectively. The hydroethanolic extract of both white and pink lotus flowers showed almost similar antimicrobial activities (Brindha and Arthi 2010a). MIC for white flower extract against *Escherichia coli* and *Staphylococcus aureus* was found to be 430 μg and 450 μg, respectively, and pink flower showed 480 μg and 490 μg, respectively.

The pink flower extract showed moderate in-vitro inhibitory activity against *Aspergillus niger* and *Monascus purpureus*, while the white flower extract had weaker activity. Hexane extract of lotus seed oil strongly inhibited growth in-vitro of diarrheal bacteria *Shigella* sp., *Staphylococcus aureus* and *Klebsiella* sp. and in a moderate way *Salmonella* sp and weakly against *Escherichia coli* (Anitha and Arunkumar 2012). It also inhibited fungal dermatophytes *Malassezia furfur, Trichophyton mentagrophytes* and *T. rubrum*.

Antiosteoporotic Activity

Im et al. (2013) found that water and ethanol lotus seed extracts protected L6 rat skeletal muscle cells from antimycin-induced mitochondria-mediated cell death. The extracts reduced cellular apoptosis; preserved the mitochondrial membrane potential; protected mitochondrial ATP production; inhibited p53, Bax, and caspase 3 activities; and induced Bcl-2 production.

Prebiotic Activity

Studies showed that prebiotics such as lotus seed-resistant starch, especially P-LRS3, could stimulate the growth of *Bifidobacterium adolescentis* (Zhang et al. 2013a). Compared with glucose and high amylose maize starch (HAMS) media, bifidobacteria had a higher tolerance to gastrointestinal conditions in lotus-resistant starches LRS3 and P-LRS3 media. The rough surface of lotus-resistant starch and the short chain fatty acids produced during fermentation might influence the proliferation of bifidobacteria. Lotus seed-resistant starch was more effective than either glucose or HAMS in promoting the proliferation of bifidobacteria (Zhang et al. 2014).

Anthelmintic Activity

Aporphine alkaloids from lotus leaves, liriodenine, lysicamine, (–)-anonaine, (–)-asimilobine, (–)-cadaverine, (–)-*N*-methylasimilobine, (–)-nuciferine, (–)-nornuciferine, (–)-roemerine, 7-hydroxydehydronuciferine and cepharadione B killed *Hymenolepis nana* or reduced their spontaneous movements (oscillation/peristalsis) but had no larvicidal effect or ability to halt spontaneous parasite movement for 72 h of *Anisakis simplex* (Lin et al. 2014). The above compounds showed greater lethal anthelmintic efficacy on *H. nana* than against *A. simplex.*

Insecticidal/Larvicidal Activity

The hexane, chloroform, ethyl acetate, acetone, methanol and aqueous lotus leaf extracts and synthesised silver nanoparticles using aqueous lotus leaf extract showed moderate larvicidal effects against fourth instar larvae of *Anopheles subpictus* and *Culex quinquefasciatus* (Santhoshkumar et al. 2011). Maximum efficacy was observed in crude methanol, aqueous and synthesised silver nanoparticles against the larvae of *A. subpictus* (LC_{50} = 8.89, 11.82 and 0.69 ppm; LC_{90} = 28.65, 36.06 and 2.15 ppm) and against the larvae of *C. quinquefasciatus* (LC_{50} = 9.51, 13.65 and 1.10 ppm; LC_{90} = 28.13, 35.83 and 3.59 ppm), respectively. Of nine plant extracts tested ,the highest larvicidal activity was observed after 24 h in the leaf methanol extract of *N. nucifer*a, seed ethyl acetate and methanol extract of *P. nigrum* against the fourth instar larvae of *Anopheles stephensi* (LC_{50} = 34.76, 24.54 and 30.20 ppm) and against *Culex quinquefasciatus* (LC_{50} = 37.49, 43.94 and 57.39 ppm), respectively (Kamaraj et al. 2011). Lotus leaf ethyl acetate extract caused 100 % mortality of *A. stephensi* and *C. quinquefasciatus* after 48 h exposure. The maximum repellent activity was observed at 500 ppm in methanol extracts of *N. nucifera*, ethyl acetate and methanol extract of *P. nigrum* and methanol extract of *Trachyspermum ammi.* Lotus leaf extracts were found to have insecticidal (adulticidal) activity (Santhoshkumar et al. 2011). In adults of *Haemaphysalis bispinosa*, parasitic mortality of 80, 74, 72 and 100 % was observed in lotus crude leaf hexane, ethyl acetate, acetone and methanol extracts, respectively. Maximum efficacy was observed in lotus leaf methanol extract against the adults of the Acarina *H. bispinosa* and the hematophagous fly *Hippobosca maculata* with LC_{50} and LC_{90} values of 437.14 and 200.81 ppm, respectively.

Drug Interaction/Cytochrome Inhibitory Activity

Studies showed that nuciferine inhibited cytochrome P450 1A2 (CYP1A2) activity in-vitro and caused changes in the pharmacokinetic parameters of phenacetin after oral administration to Wistar rats (Hu et al. 2010). Studies revealed that the alcoholic lotus leaf extract and its alkaloid fraction strongly inhibited human cytochrome CYP2D6 with an IC_{50} value of 12.05 µg/mL and 0.966 µg/mL, respectively, and weakly inhibited other isoenzymes (CYP2C9, CYP2C19, CYP2E1 and CYP3A4) (Ye et al. 2014a). The flavonoid fraction was found to weakly inhibit CYP2D6. The three aporphine alkaloids isolated from the alkaloid fraction, nuciferine, *N*-nornuciferine and 2-hydroxy-1-methoxyaporphine significantly inhibited

CYP2D6 with IC_{50} values of 3.78, 3.76 and 3.15 μM, respectively.

Mutagenic/Antimutagenic Activity

The nitrite-treated methanol extract of *Nelumbo nucifera* flowers exhibited the high mutagenicity on *Salmonella typhimurium* TA 98 and TA 100 strains (Wongwattanasathien et al. 2010). All dichloromethane extracts of flowers including lotus decreased the mutagenicity induced by the product of 1-aminopyrene nitrite model on both tester strains.

Toxicity Studies

None of the lotus leaf alkaloid compounds were cytotoxic to Vero cells up to a concentration of 23.8 μg/mL (Agnihotri et al. 2008). The results from both acute and subchronic oral toxicity studies suggested that the oral lethal dose of lotus stamen extract for male and female rats was in excess of 5000 mg/kg, and the no-observed-adverse-effect level (NOAEL) of the extract for both male and female rats was considered to be 200 mg/kg/day (Kunanusorn et al. 2011).

Pharmacokinetic Studies

Nornuciferine was found to be metabolised by rat and rabbit liver microsomes to lysicamine (Smith and Sood 1971). Rat, rabbit and guinea pig liver microsomes also dealkylated *N*-alkylated analog of nornuciferine. 2-Hydroxy-1-methoxyaporphin (2H1M), an alkaloid from *Nelumbo nucifera*, one of the herbal component of the Chinese Traditional Medicine Jiang-Zhi-Ning (JZN), was identified as the constituent showing the major pharmacodynamic effect (Chen et al. 2011, 2012a). The major metabolites of 2H1M after intragastric administration of JZN to beagle dogs were analysed and identified as *N*-demethyl-2-hydroxy-1-methoxyaporphine-2-*O*-glycuronic acid, 2-hydroxy-1-methoxyaporphine-2-*O*-glycuronic acid and 2-hydroxy-1-methoxyaporphine-2-*O*-sulphate. Following a single oral and intravenous administration of total bisbenzylisoquinoline alkaloids from lotus seed embryo in rats, liensinine, isoliensinine and neferine were detected in rat plasma (Huang et al. 2011b). The lower limit of quantification can reach 0.03 μg/ml for the three compounds. Studies found that neferine had no effect on amiodarone plasma pharmacokinetics when it was co-administered intragastrically with amiodarone, an antiarrhythmic agent (Wan et al. 2011). Studies in Caco-2 cells demonstrated that liensinine, neferine and isoliensinine, from lotus embryo, were substrates of P-glycoprotein, whereas MRP2 cell was not involved in the transport process, suggesting that P-glycoprotein might be responsible for the absorption and distribution of the 3 alkaloids (Yu et al. 2013b).

After administration of neferine to rats, one-compartmental pharmacokinetic parameters indicated that nuciferine had rapid distribution, extensive tissue uptake and poor absorption into systemic circulation (Gu et al. 2014). The values of absolute bioavailability were (3.8)%, (4.2)% and (3.9)% after oral administration of 2.0, 5.0 and 10.0 mg/kg nuciferine and intravenous administration of 0.2 mg/kg nuciferine in rats. The results suggested that nuciferine was distributed into the brain, liver and adipose tissue after intravenous administration. A total of 37 in-vivo components were identified in rats after oral administration of a lotus leaf flavonoid extract, including quercetin-3-*O*-glucuronide, quercetin-3-*O*-glucoside, quercetin-3-*O*-galacoside, quercetin and kaempferol, as well as their methylation, glucuronidation and sulfonation metabolites (Ye et al. 2014b).

Traditional Medicinal Uses

Nelumbo nucifera is a medical plant used in traditional Chinese medicine, and every part is utilised and officially listed in the Chinese Pharmacopoeia as:

- Lianzi, Semen Nelumbinis, the dried mature seeds used as a sedative and tonic.
- Lianzixin, Plumula Nelumbinis, the dried embryos from the mature seeds used as a sedative and haemostatic.
- Lianfang, Receptaculum Nelumbinis, the dried receptacles used as a haemostatic.
- Lianxu, Stamen Nelumbinis, the dry stamens collected when the lotus flowers bloom used as an adstringent.
- Heye, Folium Nelumbinis, the dry leaves used as a haemostatic.
- Oujie, Nodus Nelumbinis rhizomatis, the dry nodes of lotus rootstock used as a haemostatic (Tang and Eisenbrand 1992). After charring the receptacles, leaves and rootstocks are also used against bleeding. According to Chinese traditional knowledge, medicinal uses of different part of lotus plants are common in the treatment of diarrhoea, tissue inflammation and haemostasis (Yu and Hu 1997).

Nelumbo nucifera leaf has been used for summer heat syndrome as home remedy in Japan and China, and it has recently been used to treat obesity in China (Ono et al. 2006). Embryo of lotus seeds is used in traditional Chinese drug called 'Lian Zi Xin', which primarily helps to overcome nervous disorders, insomnia, high favours (with restlessness) and cardiovascular diseases (e.g. hypertension, arrhythmia) (Chen et al. 2007). Jiang-Zhi-Ning (JZN), a TCM, is composed of four Chinese herbs, i.e. fleeceflower root, Fructus Crataegi, Folium Nelumbinis and Semen Cassiae is used to strengthen blood circulation of coronary artery, arrhythmia and hyperlipidaemia (Chen et al. 2011). Lotus leaf is known to be effective for 'overcoming body heat' and stopping bleeding and is commonly used as a traditional curing plant for the treatment of haematemesis, epistaxis, haemoptysis, haematuria and metrorrhagia in traditional Chinese medicine (Lee and Lee 2011). The herb of lotus (*Nelumbo nucifera*) leaves is the traditional Chinese medicine He Ye, which is commonly used to treat sunstroke, assuage thirst and cure both diarrhoea and fever in China (Ye et al. 2014a, b). In traditional Korean medicine, lotus (*Nelumbo nucifera* Gaertn) roots have been used as an antidiabetic and an antiproliferative remedy (Park et al. 2009).

In folk medicines, seeds are used in the treatment of tissue inflammation, cancer, skin diseases and leprosy; used as poison antidote, antiemetic and cooling agent; and generally prescribed to children as diuretic and refrigerant (Chopra et al. 1986; Liu et al. 2004). The fruits and seeds of lotus are astringent and used to treat hyperdipsia, dermatopathy, halitosis, menorrhagia, leprosy and fever (Nadkarni and Nadkarni 1982). Seed powder mixed with honey is useful in treating cough, while roots with ghee (melted fresh butter), milk and gold promote strength, virility and intellect. Its rhizomes are used for treating pharyngopathy, pectoralgia, spermatorrhoea, leucoderma, small pox, diarrhoea, dysentery and cough (Mukherjee et al. 1997a, b; Ou 1989). The stem is used in indigenous Ayurvedic medicines as a diuretic and anthelmintic and to treat strangury, vomiting, leprosy, skin diseases and nervous exhaustion. Young leaves with sugar are useful to treat rectal prolapse, and the leaves boiled with *Mimosa pudica* in goat's milk can be used to treat diarrhoea. *Nelumbo nucifera* has been used for the treatment of several disorders including skin disease, cough, inflammation, fever and many other disorders (Mukherjee et al. 2010b; Ou 1989). The leaves are used as an effective drug for haematemesis, epistaxis, haemoptysis, haematuria, metrorrhagia, fever and inflammatory skin conditions (Ou 1989).

Nelumbo nucifera seed has been used as an antiobesity agent in traditional Chinese herbal medicine (Pan et al. 2009). Hyperlipidaemia in rodents can be treated with lotus leaves (La Cour et al. 1995; Onishi et al. 1984). Leaves also possess diuretic and astringent properties and help to treat fever, sweating and strangury and as styptic (Chinese Materia Medica 1977).

The Chinese administer the rhizomes for diarrhoea and dysentery; the Cambodians make a tea for menorrhagia (Burkill 1966). The Chinese used the embryo to reduce high fever and in the treatment of cholera, haemoptysis and spermatorrhoea. In Malayan medicine, it is highly esteemed as a tonic and taken as tea for fever. The Malays

used pounded petals for syphilis. They are astringent and taken for diarrhoea and vomiting in Java. The Chinese used them in facial cosmetic. In India, they are used for fever and in the Philippines for dysentery. The stamens are astringent and diuretic and used by the Chinese. They are also used in cosmetics. In India, they are employed as an astringent and cooling medicine. In Indonesia and India, the juice from the petioles and peduncles is used for treating diarrhoea.

In Vietnam, the seeds are used to treat dysentery, spermatorrhoea, leucorrhoea, palpitation, insomnia, general debility and anorexia (NIMM 1999). The plumules are useful in the therapy of permanent mild fever, insomnia, thirst and haemoptysis. The leaves are beneficial in treating bloody stools, haematuria, gingival and subcutaneous haemorrhage. The stamens are effective for metrorrhagia, haemoptysis, spermotorrhoea and insomnia. The achnes in decoction are used for treating dysentery and aphonia. The receptacle in decoction is useful as haemostatic in treating bloody stools, urination, leucorrhoea and hypertension. Rhizome decoction is employed as haemostatic in treating bloody stools, haematuria, haematemesis, epistaxis and metrorrhagia. NIMM (1999) also reported that in India, a nutritious flour made from the rhizome is given to children affected by diarrhoea, dysentery and dyspepsia. A paste made of powdered rhizome is applied for tinea and other dermatoses.

Other Uses

The lotus is a very beautiful and attractive plant cultivated in many parts of the world as an ornamental and as cut flower used as centrepieces for parties or as religious offerings in India and Thailand. The dried stalked seed receptacle is also used in dried floral arrangements. In India, the fibre of the stem is used for making the wicks of sacred lamps.

It is commonly planted in fields or ponds with nutrient-rich mud and can extract nutrients from old pond mud efficiently. Water levels of ponds can be increased as lotus plant grows. Fish can be stocked when water levels reach 30 cm and harvested 4–5 months after planting the lotus. Additionally, lotus shoots provide substrate for growth of epiphytic algae that are consumed by tilapia fish. Lotus rhizomes knot, as a waste from food production, will be a potential material for extracting antioxidants (Hu and Skibsted 2007). In India, the fibres from the stem are used as lamp wicks (Burkill 1966). A Thai cigarette may be wrapped in lotus petal to impart a dainty appearance.

Studies by Thongtha et al. (2014) found that phosphorus in domestic wastewater was removed from the initial concentration of 1.038 mg/L to 0.094 and 0.048 mg/L by *N. nucifera* and *Cyperus alternifolius,* respectively, within 5 days. Domestic wastewater is a source of phosphorus contamination that causes eutrophication when it contaminates aquatic environments.

Lotus leaf extract inhibited algal bloom more effectively than the stem (rhizome) extract (He et al. 2013). At 25 g/L, the leaf extract exhibited highest inhibition rate of 71.33 % and 88.14 % against the algae *Microcystis aeruginosa* and *Scenedesmus quadricauda*, respectively, while the inhibition rate for the rhizome extract was 49.78 % and 52.14 %, respectively.

Comments

Lotus is revered as a sacred religious flower in Hinduism and Buddhism. Lotus flower is the national flower of India and is legendary in folklore and religious mythology. In Japan, Moriyama City's prefectural flower is the lotus. The lotus flower is the national flower of Vietnam and the golden lotus logo of Vietnam's Airline.

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Mirabilis expansa

Scientific Name

***Mirabilis expansa* (Ruiz & Pav.) Standl.**

Synonyms

Allionia expansa (Ruiz & Pav.) Kuntze, *Calyxhymenia expansa* Ruiz & Pav., *Oxybaphus expansa* (Ruiz & Pav.) Vahl

Family

Nyctaginaceae

Common/English Names

Chago, Mauka

Vernacular Names

Bolivia: Mauka
Ecuador: Miso, Pega-Pega, Taso
Peru: Chago, Arricón, Yuca, Inca, Cushipe, Chaco
Spanish: Arracacha De Toro, Arricón, Camotillo, Chagos, Cushpe, Mauka, , Pega-Pega, Shallca Yuca, Yuca De La Jalca, Yuca Inca

Origin/Distribution

Mauka is indigenous to the Andes in South America, distributed naturally in the area of La Paz (Bolivia), to the North of Quito (Ecuador) and in Cajamarca (Peru); however, it was also found in Venezuela and Chile (Popenoe et al. 1989; Bermejo and León 1994; Flores 2003). Its wild ancestors are found in Peru, Bolivia, Ecuador and Colombia.

Agroecology

Mauka is found in the cold, windy altitudes above 2700–3500 m in the Andes where other crops like potato cannot survive the harsh ecological conditions (Popenoe et al. 1989; Bermejo and León 1994). The area is characterised by mean annual temperature of 13 °C and with maxima of 25 °C and minima of 5 °C and an annual precipitation of 680 mm and intensive sunshine. However, in Cajamarca, it thrives at 600–1000 mm per year. It thrives well on fertile,

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
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moist, deep, loose alluvial soils with abundant organic matter (Flores 2003).

Edible Plant Parts and Uses

The lower stem parts, swollen roots cooked and leaves are edible (Popenoe et al. 1989; Facciola 1990; Bermejo and León 1994). The stem and swollen roots are usually boiled or fried as vegetables. Freshly harvested, they contain an astringent principle which can be removed by drying them in the sun. Traditionally, the dried and sun-sweetened tubers are chopped, boiled and mixed with honey or brown sugar and toasted grain in Bolivia. The combined ingredients afford a hearty meal, and the cooking water makes an especially flavourful drink. In Ecuador, mauka is processed in two ways, salty and sweet (*de sal* or *de dulce*). For salty mauka, the tubers are cleaned, cooked and peeled and then eaten immediately or used as an ingredient of soups and stews. To make sweet mauka, the stems and roots are layered with barley or mauka stems in a pit dug in the ground for about several weeks to a month, by which time the starches have largely hydrolysed to sugars. Both salty and sweet forms are commonly mixed with syrup or molasses and eaten with tomatoes and fish (particularly sardines or tuna). The leaves are also eaten as a cooked leafy vegetable or used raw in salads and chilli sauces.

Plate 1 Mauka tuberous root (Frank Van Keirsbilck)

Plate 2 Mauka foliage (Frank Van Keirsbilck)

Botany

Mirabilis expansa is a low, compact, herbaceous perennial, growing to 1 m high. The swollen stems below ground are white, salmon coloured or yellow. They are commonly smooth and fleshy, about 5 cm in diameter and 50 cm in length. Young tuberous roots are yellow and older ones white (Plate 1). The aerial portion is made up of a mass of foliage formed from the basal shoots. The aerial stems are cylindrical, with short distinct internodes, pale green or with reddish markings with opposite ovate or cordate, pubescent, petioled leaves (Plate 2), 8 cm by 3 cm wide often with reddish edges. The inflorescences are terminal racemes, 3–6 cm long covered with viscid hairs. Flowers apetalous, calyx tubular with 5-cleft purple, white or white-purple mottled perianth; stamens 5–6 as long as perianth; filaments are connate at the base; style 1 with a capitate stigma. Fruit is hard, capsule like and indehiscent. Seeds are small and dark brown.

Nutritive/Medicinal Properties

Chemical composition of mauka roots (per 100-g dry matter) was reported as: energy 427 kcal, moisture 61.94 %, fibre 4.83 %, protein 7.41 %, ash 4.49 %, starch 67.71 %, carbohydrates 80.46 %, Ca 0.61 %, P 0.09 %, Mg 0.09 %, Na

0.03 %, K 1.27 %, Cu 6 ppm, Fe 50 ppm, Mn 7 ppm and Zn 62 ppm (Klásková and Fernandéz 2011).

Bermejo and León (1994) reported that Bolivian maukas contained 7 % protein content, 2 760-mg Ca and 590-mg P (in dry matter) in the underground parts and a 17 % protein content in the foliage. They also reported that analysis of three cultivars of chago from Cajamarca in Peru showed 4–5 % protein, 157 46-mg Ca and 117-mg P per 100-g edible portion. Chago was found to be low in Fe and Na.

Popenoe et al. (1989) reported both the swollen stems and the roots of mauka to be rich in carbohydrates (87 % per dry weight basis) with 7 % protein (an appreciable amount for a root crop) and little fibre. Based on an evaluation of three separate ecotypes, mauka was found to be richer than the other Andean tubers in Ca, K and P. The leaves were found to contain about 17 % protein with higher level of digestibility than that of the other forages grown in the upland Andes.

ME1, a type 1 ribosome-inactivating proteins (RIP), was cloned and sequenced from storage roots of *Mirabilis expansa* (Vepachedu et al. 2003, 2005). The full-length cDNA sequence of ME1 had 1129 nucleotides with an open reading frame of 951 nucleotides representing 317 amino acids. ME1 showed very close similarities to MAP and MAP-4 from *Mirabilis jalapa*. ME1 was produced in large quantities in Mauka storage roots. RIPs are toxic proteins synthesised by many plants and some bacteria, which specifically depurinate the 28S RNA and thus interrupt protein translation. RIPs hold broad interest because of their potential use as plant defence factors against pathogens. ME1 was shown to depurinate a variety of partially denatured nucleic acids, randomly removing adenine residues from single-stranded regions and, to a lesser extent, guanine residues from wobble base pairs in hairpin stems (Park et al. 2004). Exposure to ME1 in-vitro completely abolished the infectivity of partially denatured RNA transcripts of the potato spindle tuber viroid, suggesting that RIPs may target invading nucleic acids before they reach host ribosomes in-vivo.

Ribosome-inactivating protein (RIP) isolated from *M. expansa* showed substantial inhibitory activity against fungal growth (Vepachedu et al. 2003). RIP from *M. expansa* was targeted to the surface of fungal cells and transferred into the cells where they caused ribosome depurination and subsequent fungal mortality. Two novel type I ribosome-inactivating proteins (RIPs) were found in the storage roots of *Mirabilis expansa* and named ME1 and ME2 (Vivanco et al. 1999). The two proteins were found to be similar in size (27 and 27.5 kD), and their isoelectric points were determined to be greater than pH 10.0. ME2 showed high similarity to the *Mirabilis jalapa* antiviral protein, a type I RIP. ME1 and ME2 were active against several fungi, including *Pythium irregulare*, *Fusarium oxysporum solani*, *Alternaria solani*,*Trichoderma reesei* and *Trichoderma harzianum*, and an additive antifungal effect of ME1 and ME2 was observed. Antibacterial activity of both ME1 and ME2 was observed against *Pseudomonas syringae*, *Agrobacterium tumefaciens*, *Agrobacterium radiobacter* and others.

Other Uses

The whole plant is used as animal feed especially for guinea pigs and pigs (Popenoe et al. 1989). Animals consume it fresh or dried. In feeding pigs and guinea pigs, the raw tubers, leaves and stems are often mixed with corn and weedy vegetation, while cavies are fed the green foliage or hay.

Comments

The plant is propagated from seeds or stem cuttings.

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Nymphaea odorata

Scientific Name

***Nymphaea odorata* Aiton**

Synonyms

Castalia minor (Sims) DC. ex Small, *Nymphaea odorata* var. *minor* Sims, *Nymphaea odorata* var. *odorata*, *Nymphaea odorata* f. *odorata*, *Nymphaea odorata* subsp. *odorata*, *Nymphaea odorata* var. *rosea* Pursh, *Nymphaea odorata* var. *stenopetala* Fernald, *Nymphaea parkeriana* Lehm.

Family

Nymphaeaceae

Common/English Names

American White Water Lily, Beaver Root, Fragrant Water Lily, Sweet-Scented Water Lily, Tuberous Water Lily, White Water Lily

Vernacular Names

French: Nymphéa Odorant, Nymphéa Tubéreux
German: Wohlriechende Seerose
Swedish: Doftnäckros

Origin/Distribution

The species is native to North America (USA and Canada), Central America and the Caribbean (Grin 2014). The species occurs from Puerto Rico to Alaska and from California to Quebec (Kartesz 1999).

Agroecology

Nymphaea odorata grows in shallow ponds, lakes and their margins, ditches, swamps, slow streams from sea level to 1700 m elevation. The species grows rooted in mucky or silty sediments in water up to 6–7 feet deep and can survive in both acid and alkaline waters. *N. odorata* plants

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs*,
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can be established from seeds in up to 90 cm water and the seedlings grow as submerged aquatics until they switch abruptly to the production of floating leaves (Richards and Cao 2012).

Edible Plant Parts and Uses

Young leaves are used in soups and stews and tubers are also edible (Fernald et al. 1958; Tanaka 1976; Kunkel 1984; Facciola 1990). Flower buds pickled or eaten as cooked vegetable.

Botany

An aquatic perennial herbaceous plant with floating leaves and branched creeping, fleshy rhizomes. The rhizomes are attached by cluster of adventitious roots arising below the leaf bases; they bear circular leaf scars on the upper surface; the rhizomes are brown externally, greyish-white internally, spongy and are densely covered with short black hairs. Leaves are circular (10–35 cm across), cleft at the base, with entire, undulating margin, shining green and waxy above, reddish or purplish and more or less hairy on under surface, petiole slender and cylindrical attached to centre of lower leaf surface (Plate 1). Flowers solitary up to 25 cm across, on a grooved peduncle, floating on water surface or raised, with 4 green sepals and 15–40 white or pinkish, lanceolate petals with acute apices, 55–120 yellow stamens (Plate 1). Fruit an ovoid berry-like capsule, 1–2 cm across and containing many seeds (2–3 mm long).

Nutritive/Medicinal Properties

The following compounds were identified from fractionation of the ethanol extract of *N. odorata*: nymphaeoside A (1), icariside E(4) (2), kaempferol 3-*O*-α-L-rhamnopyranoside (afzelin, 3), quercetin 3-*O*-α-L-rhamnopyranoside (4), myricetin 3-*O*-α-L-rhamnopyranoside (myricitrin, 5), quercetin 3-*O*-(6″-*O*-acetyl)-β-D-galactopyranoside (6), myricetin 3-*O*-β-D-galactopyranoside (7) and myricetin 3-*O*-(6″-*O*-acetyl)-β-D-galactopyranoside (8) (Zhang et al. 2003). Compounds 3, 4 and 7 showed marginal inhibitory effect against fatty acid synthase with IC_{50} values of 45, 50 and 25 μg/mL, respectively.

Five plant growth inhibitory allelochemicals from *N. odorata* were identified as gallic acid, myricitrin, myricetin, 1,2,3,4,6-pentagalloyl-D-glucose and 2,3,4,6-tratragalloyl-D-glucose (Elakovich et al. 1999).

The crude leaf extract of *N. odorata* exhibited weak larvicidal activity against the larvae of the malaria vector, *Anopheles gambiae*, of 10 and 20 % (at 5 % w/v) and 20 and 30 % (at 10 % w/v) both at 12 and 24 h incubation, respectively (Oladimeji et al. 2008). The crude leaf extract and fractions were inactive against the bacterial and fungal isolates tested.

Studies by Deoda et al. (2012) reported that extracts of the leaf and bulbs exhibited better antilithiatic activity than the stem extract of the *Dolichos lablab* bean extracts.

Traditional Medicinal Uses

The root has been reported to be alterative, anodyne, antiseptic, astringent and demulcent (Grieve 1971; Lust 1974; Mill 1985; Bown 1995). A tea made from the roots is used in the treatment of tuberculosis, chronic bronchial complaints, diarrhoea, dysentery, gastrointestinal inflammation, gonorrhoea, vaginal discharge, inflamed glands, mouth sores and to stop bleeding (Bown 1995; Foster and Duke 1998). A poultice made from the roots is used in the treatment of swellings, boils, tumours, inflamed skin and vaginitis (Bown 1995; Foster and Duke 1998).

Moerman (1998) recorded the following ethnomedicinal uses of the plant by American natives: The Chippewa use pulverized roots for mouth sores; the Mimac use leaves as cold remedy, the juice of root is taken for coughs and poultice of boiled roots applied to swellings. The Ojibwe use the root as cough medicine and for tuberculosis. The Okanagan-Colville place stems directly onto tooth for toothache. The Penobscot apply leaves as poultice on limb swellings. The Potawatomi used poultice of pounded roots for unspecified ailments.

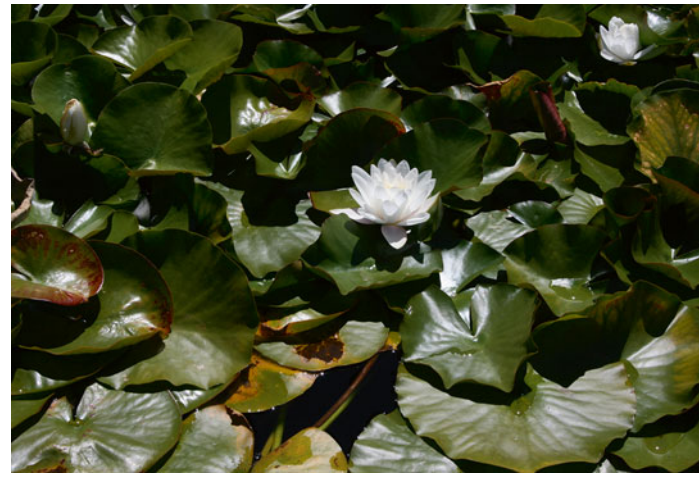

Plate 1 White water lily flower and leaves

Nymphaea odorata is an old herbal recipe used in the treatment and/or management of ocular, skin, gastrointestinal and urino-genital ailments amongst many others (Oladimeji et al. 2008). *Nymphaea odorata* has been traditionally deemed to be employed as antiseptic, astringent, demulcent, kidney stone, deobstruent, discutient and vulnerary (Deoda et al. 2012). Roots are used for coughs, mouth sores and for tuberculosis.

Other Uses

N. odorata is a common and popular ornamental for ponds.

Comments

A declared aquatic or terrestrial noxious weed and/or noxious-weed seed in some states in the USA. Dense infestations may also accelerate the natural siltation process in the shallow bodies of water.

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Nymphaea x rubra

Scientific Name

***Nymphaea x rubra* Roxb. ex Andrews (see origin/distribution)**

Synonyms

Castalia rubra (Roxb. ex Andrews) Tratt.

Family

Nymphaeaceae

Common/English Names

Red Water Lily, Red Indian Lily, Mini Water Lily, Dwarf Lily, Red Lily of the Nile

Vernacular Names

Burmese: Krani, Kyar-Ni
French: Lotus Rouge, Nenuphar Rouge
German: Rote Seerose
India: Mokua, Ronga Bhet, Ronga Seluk, Seluk (Assamese), Lal Shapla (Bengali), Kokaa (Hindu), Tharo Angangba (Manipur), Lal Kamal, Raktakamal (Marathi), Li'ne Aluk (Mising, Assam), Alagandha, Alipriya, Alohita, Kumuda, Raktakamal (Sanskrit) Atti (Tamil), Ranga Podum (Tai-Khamyang, Assam), Erra Kaluva, Thaamara (Telugu), Nilofar (Urdu)
Japanese: Hime-Suiren
Portuguese: Ninfeia Vermelha
Spanish: Nenufar Rojo
Vietnamese: Bông Súng Đỏ

Origin/Distribution

The species is reported to be indigenous to the Indian subcontinent, naturalised in tropical Asia and cultivated in the Caribbean and elsewhere (USDA-ARS 2015). However, Conrad (1905) in his monograph of the genus *Nymphaea* expressed his doubts whether true *Nymphaea rubra* existed in India.

Recent studies by Dkhar et al. (2013) using molecular cloning and sequencing of ITS (internal transcribed spacer) region confirmed *Nymphaea rubra* to be a hybrid produced through a cross between *N. lotus* and *N. pubescens* with the latter representing the maternal parent. Based

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs*,
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on these evidences and its inability to form seeds in nature, they proposed that the Indian red water lily be referred to as *Nymphaea x rubra*, nomenclaturally signifying it to be a natural hybrid. Observations from previous cytological (Gupta 1980) and reproductive (Mitra and Subramanyam 1982; Venu et al. 2003) studies also supported the hybrid origin of *N. rubra*. Mitra and Subramanyam (1982) reported the *N. rubra* to be propagated vegetatively and failed to set fruit in nature. As a result of its failure to set fruit/seed, they questioned the treatment of *N. rubra* as a true species and rather suggested it as an apomict evidence strongly pointed to the origin of *N. rubra* through hybridization or more appropriately an allopolyploidization event involving *N. pubescens* and *N. lotus* followed by chromosome duplication thereby explaining the difference in the ploidy level of this plant species.

Agroecology

Nymphaea x rubra is a hydrophyte, found in rivers and ponds in still or slow-flowing fresh waters in tropical and subtropical areas. It thrives in full sun and water of pH 6–8.

Edible Plant Parts and Uses

The flowers of the plant are used for ornamental purposes, while rhizomes, young leaves and peduncle are used as food and vegetable (Devi et al. 2015). The species is gaining an importance in the local markets of Northeast India as food material.

Rhizome is used as vegetable (Pathak and Sarma 2013), the tuber is eaten as a vegetable (Mohan and Kalidass 2010). The young peduncles are eaten as vegetable. In India, the fried seeds are eaten as puffed grains. The petioles, fruit and roots are cooked as vegetables; seeds are eaten raw or roasted; fruit and rootstock are eaten raw (Pegu et al. 2013; Patiri and Borah 2007).

Botany

Nymphaea x rubra is a perennial herbaceous aquatic plant with pinkish, corm-shaped rhizomes rooted in the sediment and producing slender stolons. Leaves are simple, orbicular with dentate or serrated margin, floating, 20–50 cm in diameter, sub-peltate, > 0.5 cm from base of sinus, reddish purple and pubescent on abaxial surface and glossy lime green or reddish tint on adaxial surfaces, on long petioles arising from the submerged rhizomes. Submerged leaves are cordate or sagittate with reddish tint. The flower is showy, fragrant, bisexual, actinomorphic, polymerous, hypogynous up to 15 cm across and solitary on emergent, dark-red peduncle above water. The calyx is aposepalous with four red oblong–lanceolate, caducous sepals. The corolla is apopetalous; 20–25 mm, elliptic to oblanceolate; its red to purple petals have length thrice longer than breadth, and many are seriately and spirally arranged (Plate 1). The androecium is polyandrous, stamens are 40 to > 50, many are seriately and spirally arranged, the filaments are petaloid and dark-red purple, and anthers are cream coloured. The ovary is globose, enveloped in a fleshy torus, multi-carpellate, syncarpous and multi-loculed. The fruit, if formed, is a globose berry containing numerous ellipsoid seeds.

Nutritive/Medicinal Properties

The proximate nutrient content of various parts of *N. rubra* plant had been determined and found to be quite high (Devi et al. 2015). The maximum amount of protein was recorded as 23.88 % of total dry weight. Proximate nutrient composition (per 100 g) of edible tuber was reported as: moisture 81.33 %, crude protein 8.31 g, crude lipid 5.05 g, crude fibre 3.74 g, ash 3.80 g, N-free extractives 79.09 %, energy 1650 kJ/100 g, Na 34.1 mg, K 734 mg, Ca 354 mg, Mg 104 mg, P 76.3 mg, Zn 1.64mg, Mn 1.34 mg, Fe 28.14 mg, Cu 1.12 mg, starch 13.52 g, niacin 5.88 mg and

Plate 1 Flowers and leaves of red water lily

ascorbic acid 14.43 mg (Mohan and Kalidass 2010). Tuber was reported to have an in-vitro protein digestibility of 5.78 % and in-vitro starch digestibility of 18.23 %. Antinutritional factors in the edible tubers per 100 g comprised total free phenolics 0.2 g, tannins 0.11 g, hydrogen cyanide 0.04 mg, total oxalate 0.42 g, amylase inhibitor 1.01 AIU/mg soluble starch and 0.56 trypsin inhibitor TIU/mg protein. Tubers were reported to be soaked to remove antinutrients and cooked before consumption (Mohan and Kalidass 2010).

Polysaccharides were purified from *N. rubra* carpels and found to have a degree of polymerisation (DP) value of 359.8 kDa (Cheng et al. 2012). The hydrolyzed polysaccharides had 51.3 % total sugar content, 2.35 % reducing sugar and total protein content of 5.28 %.

Antioxidant Activity

Among different concentration tested, methanol extract of *N. rubra* rhizome at 1000 µg/mL exhibited potent scavenging activity in all models, viz. DPPH, hydroxyl radical, superoxide and ABTS radical cation scavenging activity and reducing power (Daffodil and Mohan 2014). The total phenolics and flavonoids in the methanol extract were found to be 0.36 g/100 g and 0.67 g/100 g, respectively.

Antidiabetic Activity

The ethanolic extract of dried *N. rubra* flowers and one of its fraction, i.e. chloroform, showed significant antihyperglycemic activity on streptozotocin (STZ)-induced diabetic rats, neonatally STZ-treated rats and high-fructose-, high-fat-fed insulin-resistant rats (Rahuja et al. 2013). They lowered blood glucose level of STZ-induced diabetic rats and improved glucose tolerance post-sucrose load in normal rats. The chloroform fraction was also observed to enhance 2-deoxy-(3H) glucose uptake by skeletal muscle cells (L-6) in concentration-dependent manner. It also inhibited the process of adipogenesis and increased the expression of glucose transporter protein-4 (GLUT-4), insulin receptor substrate (IRS) and phosphatidyl inositol-3-kinase (PI-3 K). The ethanol extract of *Nymphaea rubra* flowers ameliorated TNF-α-induced insulin resistance in the rat skeletal muscle cell line (L6 myotube) (Gautam et al. 2014). It enhanced the GLUT4-mediated glucose transport in a dose-dependent manner and also increases the tyrosine phosphorylation of both IR-β and IRS-1 and the IRS-1-associated PI-3 kinase activity in TNF-α-treated L6 myotubes. It was concluded that *N. rubra* reversed the insulin resistance by the inhibition of c-jun NH2-terminal kinase and nuclear factor-κB.

Immunomodulatory Activity

Studies showed *N. rubra* polysaccharides (NR-PS) to have immunomodulatory effect affecting the maturation and function of rat dendritic cells derived from rat bone marrow haematopoietic cells (Cheng et al. 2012). NR-PS exhibited stimulatory effects on rat dendritic cells and promoted the secretion of T_H1 cytokines.

Anthelmintic Activity

The petroleum ether, methanol and chloroform extract of *N. rubra* rhizome exhibited dose-dependent anthelmintic activity against test earthworm, *Pheretima posthuma* (Behera et al. 2010). The methanolic extract showed remarkable anthelmintic activity; at a dose of 5 mg/ml, it took 28 min for paralysis and 62 min for worm death; at 10 mg/ml it took 17 min for paralysis and 51 min for worm death; at 20 mg/ml it took 8 min for paralysis and 27 min for worm death. The standard albendazole at 10 mg/ml took 38 min for paralysis and 64 min for worm death.

Traditional Medicinal Uses

The flower is astringent and cardiac tonic and is employed in palpitations of the heart, while the rhizomes are used for dysentery and dyspepsia (Khare 2007). Roots are administered for vomiting by rural people of Nagaon district, Assam (Sarma and Saikia 2010). The Tai-Khamyang of Assam pulverised the dried roots to powder and applied the powder in diseased area for 6–7 days for piles (Sonowal and Barua 2011). In Manipur, north-eastern India, crushed rhizome powder is mixed with honey and used as therapy for bleeding nose, piles and dysentery and as cardiotonic (Yumnam et al. 2012).

Other Uses

Red water lily is used as an ornamental plant in aquatic landscaping and also in the aquarium trade. The cut flowers are used for religious purposes in India.

Comments

The plant is propagated vegetatively by division of rhizome.

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Victoria amazonica

Scientific Name

***Victoria amazonica* (Poepp.) Sowerby**

Synonyms

Euryale amazonica Poepp. (basionym); *Nymphaea victoria* R. H. Schomb. ex Lindl., nom. inval.; *Victoria amazonica* Planch. ex Casp.; *Victoria regia* Lindl.; *Victoria regia* var. *randii* hort. ex Conard, nom. inval.; *Victoria regina* R. H. Schomb

Family

Nymphaeaceae

Common/English Names

Amazon Water Lily, Amazon Water Platter, Giant Amazon Water Lily, Giant Water Lily, Royal Water Lily, Victoria Lily, Water Maize

Vernacular Names

Brazil: Vitória-Regia, Aguapé-Assú, Cará-D'água, Forno-D'água, Forno-De-Jaçanã, Jaçanã, Milho-D'água, Mururê, Nanpé, Rainha-Dos-Lagos, Rainha-Dos-Nenúfare, Victória-Regia (Portuguese) Irupé (Guarani), Uapé, Aguapé (Tupi)
Chinese: Wang Lin
Czech: Viktorie Amazonská, viktorie královská
Estonian: Amasoonase Viktooria
French: Victoria d'Amazonie
German: Amazonas-Riesenseerose, Amazonas Wasserlilie, Königliche Seerose, Viktoria
Lithuanian: Gigantiškoji viktorija
Polish: Wiktoria Królewska
Spanish: Abatiyú, Agoapé, Aguapé, Hoja *De* Sol, Iguapé, Irupé, Maíz De Agua, Maruru, Ninfa Real, Plato De Agua, Loto Gigante
Swedish: Jättenäckros
Upper Sorbian: Wodowa krasnica

Origin/Distribution

The species is native to the shallow waters of the lakes and waterways in the Amazon River Basin, the Guianas and the Pantanal in South America. Its aquatic tropical home spans Brazil, Colombia, Peru and Guyana.

Agroecology

Victoria amazonica is tropical aquatic. The plant roots are best anchored in organically rich loams at the bottom of the bayous. Plants will remain perennial as long as water temperatures remain at

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
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least 24 °C and thrive in calm shallow waters (<2 m), full sun, slightly alkaline to neutral pH. Pollination by scarab beetles happens at night.

Edible Plant Parts and Uses

In the Brazilian Amazon, *Victoria amazonica* seeds and rhizomes are important items consumed by riverine inhabitants (Piedade and Junk 2000). The root, stem and seed of the Victoria lily are all edible, and the species is also used in traditional medicine (Castner et al. 1998).

The root, stem and seeds are edible. Dried seeds taste like popcorn. Indigenous Brazilians make flour from the seeds (Les 2003).

Botany

Victoria amazonica is a rhizomatous aquatic, strongly aculeate, herbaceous perennial (Plate 1) with short, thick, tuberous rhizome, which is brown externally and white inside and turning purple when cut; rhizome bears numerous cylindrical adventitious roots abounding in air cavities. Leaves are borne on a submerged aculeate, terete petiole 6 m long radiating from the submerged rhizome; they are huge, orbicular, peltate, floating, entire and full green adaxially with the edge turn upwards forming a rim (5–10 cm high), and the basal surface is a coppery colour with a prominent network of flattened ribs radiating from the petiole and cross ribs, all bearing sharp prickles (Plates 1–3) (Anonymous 1850; Allen 1854). Kunii et al. (2006) reported that the maximum value in leaf diameter was 2.35 m (4.34 m^2 in area) with a mean value of 1.6–1.7 m. Each plant has 10–15 floating leaves and the total leaf area per plant differed considerably (minimum value 12.1–17.2 m^2, maximum value 27.6–31.2 m^2). Flower solitary on an aculeate, terete pedicel arising from the rhizome, longer than leaf petiole, pear-shaped in bud (Plates 2–3). The flower is epigynous, fragrant, 30–50 cm across, hemicyclic, dichlamydeous, bisexual with vespertine anthesis (Rosa-Osman et al. 2011) and pollinated by scarab beetles. The calyx, consisting of four large and four small spiny sepals (Kunii et al. 2006), is coriaceous, fleshy and green becoming reddish purple. Petals are numerous, inserted on the throat and torus of the calyx; outer ones are completely reflexed. The petals remained expanded, erect and white all night and the next morning; by the evening of the second day, the petals had turned variegated white pink or red. Stamens are numerous, inserted with the petals on the torus in about three rows; the stamens, including the outer staminodia (infertile

Plate 1 Aquatic, rhizomatous plant with seven or more large, orbicular leaves with upturned rims

Plate 2 Huge leaves at the apex of long radiating submerged petioles arising from the rhizome

Plate 3 Young leaf with coppery basal surface and flower bud enclosed by four reddish-purple, spiny sepals

stamens) petaloid, middle fertile stamens and inner staminodia (termed paracarpels by earlier authors), were erect and formed an approx. 12-mm tunnel into the floral chamber (Seymour and Matthews 2006). The filaments are subulate, erect, outer filaments petaloid, connective long-appendiculate, filaments of the sterile stamens of the innermost whorl with fleshy appendages; anthers introrse. Carpels are numerous, crescent or horseshoe shaped up to the time of anthesis, and then postgenital fusion occurs forming the ovary. The ovary is globose below and concave campanulate at the top, with many locules containing numerous anatropous ovule; style is wanting, and stigmas are forming radiating lines on the top of the ovary. The fruit is fleshy, campanulate and irregular dehiscent with pseudo-syncarpy (Rosa-Osman et al. 2011), prickly 11 cm across. Seeds are many and ellipsoid globose with horny testa and aril that acts in the water dispersion.

Nutritive/Medicinal Properties

Two anthocyanins were isolated from *Victoria amazonica* leaves and identified as delphinidin 3-*O*-(2″-*O*-galloyl-β-D-galactopyranoside) and cyanidin 3-*O*-(2″-*O*-galloyl-β-D-galactopyranoside) (Strack et al. 1992). Four esters, together with free benzyl alcohol, were found as the main components of the fragrance of *Victoria* (Kite et al. 1991). The compounds were methyl 2-methylbutyrate, methyl tiglate, benzyl 2-methylbutyrate and benzyl tiglate. A number of other methyl and benzyl esters were found but at much lower concentrations. Fifteen compounds were isolated from the methanol leaf extract including stigmasterol, vanillic acids and aristophyll (Chang et al. 2014).

Na, K, Rb, Cs, AG, Zn, Y, Nb, Se, F, Br, Cl, I and Ni increased with age; Li, Cu, Be, Mg, Sr, Cd, Hg, Ce, Si, Ti, Zr, V, Cr, Fe and Al decreased with age; and Ba, B, Ga, Sc, La, P, Bi and S exhibited no consistent relationship to various growth stages (Cowgill and Prance 1982). However, Ca, Sn, Pb, As, Mo, Mn and Co were low in concentration in young plants, increased in the pre-flowering stage and then declined with the stage of the plant. *V. amazonica* accumulated Na in excess of that encountered in its terrestrial relatives. It contained rare earths lanthanum (La) and cerium (Ce) in normal amounts. Rare earths of higher atomic numbers were not detectable. Mg, Ca, Al, Si, S, Fe, Mn, Li and Ce were significantly more concentrated in the damaged leaf sections than in undamaged leaves of the mature plants with unopened buds (Cowgill and Prance 1989). In the case of pre-flowering plants, Na, Mg, Ca, Al, Si, S, Cl, Fe and Mn were more prevalent in the damaged tissue than in the unattacked leaves of the same plants. In the former case, Na, K, Cl and P are rapidly lost when damage occurs, while plants that have had a chance to recover from the damage, as in the case of the pre-flowering plant leaves, begin to make up the difference in elemental concentration between the damaged and undamaged leaves. Mineralogical investigation showed that the amount of calcite ($CaCO_3$), the calcium oxalates weddellite and whewellite and the siliceous minerals – low-form cristobalite opal, low-form tridymite opal and quartz – was higher in the recently injured leaves than in those that had been injured some time previously or than in the uninjured leaves.

The plant extract has folkloric medicinal use for rheumatism, inflammation and haemorrhoids when mixed with andiroba oil (Duke et al. 1994).

Other Uses

V. amazonica is used as an aquatic ornamental in botanical gardens and parks.

Comments

The plant is depicted in the Guyanese coat of arms.

Protogyny has been studied in *Victoria amazonica* (Prance 1974, 1980). The flowers will open following a dark period of 30 min, begun not earlier than 4 p.m. (Gessner 1960). The plants are often pollinated by scarab beetles (Prance and Arius 1975; Prance 1980).

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Diuris semilunulata

Scientific Name

***Diuris semilunulata* Messmer**

Synonyms

None recorded

Family

Orchidaceae

Common/English Names

Donkey Orchid, Late Leopard Orchid, Spotted Double-Tail Orchid

Vernacular Names

None recorded

Origin/Distribution

This orchid is native to Australia.

Agroecology

This orchid grows on well-drained, moist soils among grass and shrubs in sclerophyll forest; south from Nerriga, southern Tablelands and in Victoria.

Edible Plant Parts and Uses

Starch tubers of *Diuris* spp. including this species are edible but bland and glutinous and eaten by the aborigines (Cribb and Cribb 1987; Low 1989, 1991).

Botany

Diuris semilunulata is a terrestrial, perennial, geophytic herb. Roots are filamentose with small, naked, ovoid or cylindrical, often paired, tubers. It has 15–25 cm long and 3–4 mm wide, linear, basal, grass-like, alternate or whorled leaves, that is, conduplicate, with 2 leaves in a tuft (Plate 1). Scape is 20–35 cm high with 3–5-flowered, loose raceme. Flowers are hermaphroditic, orange, heavily blotched and suffused with brown and purple. Dorsal sepal is ovate, 6–10 mm long, 7–10 mm wide and erect. Lateral sepals are linear

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
DOI 10.1007/978-3-319-26062-4_10

to oblanceolate, 12–18 mm long, 2–4 mm wide, crossed and recurved beneath the labellum. Petals are divergent, ovate to obovate and 5–11 mm long by 4–9 mm wide; claw is 5–9 mm long. Labellum is 4–8 mm long; lateral lobes are narrowly to broadly, cuneate, 5–8 mm long and 2–7.5 mm wide; margins are crenulate; mid-lobe is cuneate, 5–7 mm wide and ridged along midline; and callus is with two 3–6 mm long raised ridges. Its fruit has a non-fleshy, dehiscent capsule, containing between 30 and 500 minute light-dark coloured, winged seeds.

Nutritive/Medicinal Properties

No information on its nutritive value and medicinal properties had been published.

Other Uses

This orchid is mainly grown by orchid enthusiasts and some small commercial orchid growers.

Comments

This orchid is propagated from seeds and from the underground tubers.

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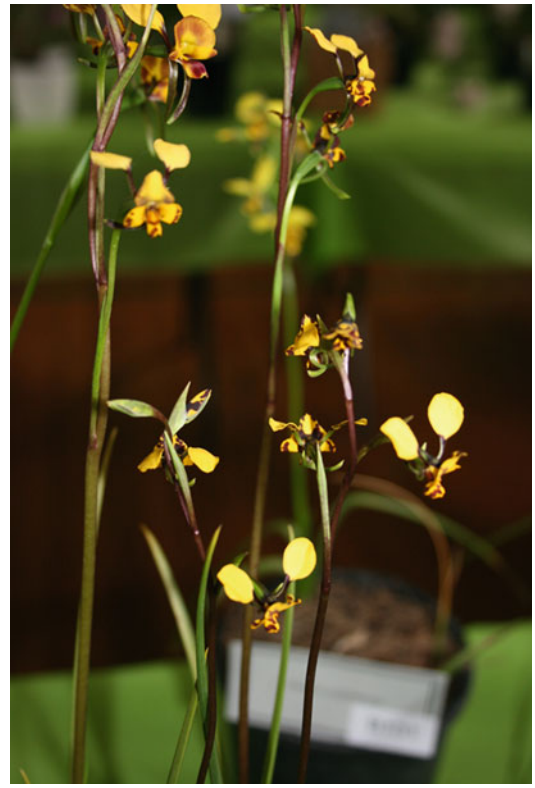

Plate 1 Flowers of *Diuris semilunulata*

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Diuris sulphurea

Scientific Name

***Diuris sulphurea* R.Br.**

Synonyms

Diuris latifolia Rupp., *Diuris oculata* F. Muell. ex Lindl., *Diuris sulphurea* f. *immaculata sulphurea* Gand., *Diuris sulphurea* f. *tasmanica* Gand.

Family

Orchidaceae

Common/English Names

Hornet Orchid, Tiger Orchid, Yellow Tiger Orchid Tiger Orchid, Hornet Orchid

Vernacular Names

None recorded

Origin/Distribution

This orchid is native to Australia.

Agroecology

This orchid is commonly found in well-drained moist soil in semi-shaded sites on slopes of the foothills in open sclerophyll forest and health in South Australia, Tasmania, Victoria, New South Wales and Queensland.

Edible Plant Parts and Uses

Starchy root tubers are edible but bland and glutinous and eaten by the aborigines (Anonymous 2010, 2011; Cribb and Cribb 1987; Low 1989, 1991).

Botany

Diuris sulphurea is a terrestrial, perennial, geophytic herb. Roots are filamentose with small, naked, ovoid or cylindrical, often paired, tubers. It has 15–25 cm long and 3–4 mm wide, linear, basal, grass-like, alternate or whorled leaves, that is, conduplicate, with 1–3 leaves in a tuft (Plates 1

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
DOI 10.1007/978-3-319-26062-4_11

and 2). Scape is 30–60 cm high with 1–6-flowered racemose inflorescence. Its flowers are bright yellow with prominent dark markings on the labellum and dorsal sepal, 3–4 cm across and stalked (Plate 3). Dorsal sepal is ovate, 8–20 mm long, 7–15 mm wide and obliquely erect. Lateral sepals are linear to lanceolate, 10–25 mm long, 1–3 mm wide, deflexed, parallel or crossed. Petals are divergent, ovate, 5–18 mm long and 5–12 mm wide; apex is obtuse or notched; and claw is 3–10 mm long and dark coloured. Labellum is 7–15 mm long; lateral lobes are broad cuneate, 3–6 mm long and 2.5–4.5 mm wide; margins are entire or crenulate; and callus is with 3–5 mm long single ridge. Column is with stamen and style nearly free; anther is dorsal and basifixed; stigma has large scutiform; and ovary is elongate, ribbed and glabrous. Capsule is dehiscent, thin walled and glabrous erect containing numerous light-dark-coloured, winged seeds.

Plate 1 Long scape with a few flowered raceme

Nutritive/Medicinal Properties

No information on its nutritive value and medicinal properties had been published.

Plate 2 Basal linear, grass-like conduplicate leaves

Plate 3 Bight yellow flowers with prominent dark-coloured markings

Other Uses

This orchid is mainly grown by orchid enthusiasts and some small commercial orchid growers.

Comments

This orchid is propagated from seeds and from the underground tubers.

Selected References

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Pridgeon AM, Cribb PJ, Chase MW, Rasmussen FN (eds) (2001) Genera Orchidacearum: Volume 2 Orchidoideae (Part one). Oxford University Press, Oxford/New York, 438 pp

Pterostylis curta

Scientific Name

***Pterostylis curta* R.Br.**

Synonyms

None recorded

Family

Orchidaceae

Common/English Names

Blunt Greenhood

Vernacular Names

None recorded

Origin/Distribution

The species is indigenous to Australia.

Agroecology

The species is commonly found in sclerophyll forest in coastal southeast Queensland, New South Wales, Victoria, southeast South Australia, Tasmania and Lord Howe Island. The species prefer moist and well-drained sites in the wild, but the range of forest types they occur in is broad, from grassy woodlands to riparian forests to subtropical rainforest, and even in exotic pine plantations. They occur in semi-shade to full shade.

Edible Plant Parts and Uses

The tubers are edible and eaten by the aborigines (Anonymous 2010; Steenbeeke 2001).

Botany

Pterostylis curta is a terrestrial perennial herb, 10–30 cm high, arising from small round tubers to form large colonies. Leaves are in ground-hugging rosette of 2–6, shortly petiolate, dark green, ovate to elliptic or oblong and 1.5–10 cm long by 8–30 mm wide, with entire or wavy mar-

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
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Plate 1 *Pterostylis curta* with ground-hugging rosette of leaves

Plate 2 Long scape with single flower

Plate 3 Close up of flowers

gins (Plates 1 and 2). Scape is 30 cm with a single erect flower, that is, 35 mm long, white and green with brown suffusions in the galea. Central sepal and petals are united into a galea (hood) over the column and labellum (lip) (Plates 2 and 3). Galea is mostly upright; top, shortly curved; and tip, tinged green brown and pointed. Lateral sepals are erect, loosely embracing the hood, leaving a broad V-shaped lateral gap; free points are linear tapered, about10 mm long, divergent and recurved. Labellum is oblong-obovate, brown and twisted.

Nutritive/Medicinal Properties

No information on its nutritive value and medicinal properties had been published.

Other Uses

This orchid is mainly grown by orchid enthusiasts and some small commercial orchid growers.

Comments

The plant is readily propagated from the tubers.

Selected References

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Pterostylis pedunculata

Scientific Name

***Pterostylis pedunculata* R. Br.**

Synonyms

None recorded

Family

Orchidaceae

Common/English Names

Maroonhood

Vernacular Names

None recorded

Origin/Distribution

The species is indigenous to Australia.

Agroecology

This orchid occurs in moist sheltered habitats in sclerophyll forest of coastal and near-coastal districts, in Queensland, New South Wales, Victoria, Tasmania and Lord Howe Island. It thrives on moist soil in leaf litter in fern gullies and moist to wet forests in dappled to full shade.

Edible Plant Parts and Uses

The starchy tubers are edible and eaten by aborigines (Steenbeeke 2001; Anonymous 2011).

Botany

Pterostylis pedunculata is a terrestrial perennial herb, 25 cm high, arising from small round tubers to form large colonies. It has a ground-hugging rosette of 2–6, shortly petiolate, thick, dark green, ovate to oblong, 10–65 mm long by 6–18 mm wide leaves, with entire or wrinkled margins (Plates 1 and 2). Scape is 20–25 cm with a single erect flower, that is, 15 mm long, white and green with reddish-brown to black suffusions in the galea. Central sepal and petals

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
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Plate 1 *Pterostylis pedunculata* plant habit

Plate 2 Ground-hugging rosette of leaves

are united into a galea (hood) over the column and labellum (lip) (Plates 2, 3 and 4). Apex of galea is horizontal. Dorsal sepal is acute to subacute. Lateral sepals are erect, loosely embracing the hood, leaving a broad V-shaped lateral gap; free points are filiform, 15–30 mm long, divergent and recurved. Petals are narrow and acute. Labellum is ovate, 4–7 mm long by 3 mm wide, dark reddish brown, straight and apex obtuse.

Nutritive/Medicinal Properties

No information on its nutritive value and medicinal properties had been published.

Plate 3 Scape with single flower

Plate 4 Close-up of flower

Other Uses

This orchid is mainly grown by orchid enthusiasts and some small commercial orchid growers as ornamental pot orchids.

Comments

The plant is readily propagated from the small tubers.

Selected References

Anonymous (2011) *Pterostylis pedunculata*. http://www.yarraranges.vic.gov.au/Residents/Yarra_Ranges_Plant_Directory/Lower_Storey/Orchids/Pterostylis_pedunculata

Jones DL (1993) Orchidaceae. In: Harden GJ (ed) Flora of New South Wales, vol 3. New South Wales University Press, Kensington. 775 pp

Steenbeeke G (2001) List of plant species from northern NSW that may be used as food plants. http://brg.cma.nsw.gov.au/uploads/MurriFoodPlants.pdf

Oxalis tuberosa

Scientific Name

***Oxalis tuberosa* Molina**

Synonyms

Acetosella crenata (Jacq.) Kuntze, *Acetosella tuberosa* (Molina) Kuntze, *Oxalis arracatcha* hort. ex Zucc., *Oxalis arracacha* G. Don, *Oxalis chicligastensis* R. Knuth, *Oxalis crassicaulis* Zucc., *Oxalis crenata* Jacq., *Oxalis melilotoides* var. *argentina* Griseb., *Xanthoxalis crassicaulis* (Zucc.) Small, *Xanthoxalis tuberosa* (Molina) Holub

Family

Oxalidaceae

Common/English Names

Kao, Oca, Oka, New Zealand Yam, Papa Roja, Quiba Yam

Vernacular Names

Arabic: Hhummâd
Argentina: Miquichi
Aymara: Apiña, Apilla, Kawi
Bolivia: Apiña, Apilla
Brazil: Azedinha, Batata-Baroa, Mandioquinha
Chile: Cubia
Columbia: Hibia, Huasisai, Ibi, Ibia, Ibiasoca
Danish: Oka
Dutch: Peruaanse Klaverzuring
Ecuador: Oca
Finnish: Oka
French: Oca D'amérique, Oxalide Crénelée, Oxalide Tubéreuse, Oxalis Tubéreux, Surelle Tubéreuse, Truffette Acide
German: Knollen-Sauerklee, Oka, Peruanischer Sauerklee
Italian: Ossalide Crenata, Trifoglio Tuberose
Mexico: Papa Colorada, Papa Extranjera, Papa Roja
New Zealand: Yam
Peru: Apiña, Oca, Oqa
Polynesia: Yam
Quechuan: O'qa, Okka, Uqa
Spanish: Aleluya Tuberosa, Cubio, Ibia, Oca
Swedish: Oca
Turkish: Yabani Kuzu Kulagi
Venezuela: Cuiba, Ciuva, Macachin, Miquichi, Oxalida, Quiba, Ruba, Timbo

Origin/Distribution

Oxalis tuberosa is indigenous to the Andes in South America (Arbizu and Tapia 1994). The area of greatest diversity both of cultivated and

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
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wild forms is found in the central region of Peru (latitude 10°S) and northern Bolivia (latitude 20°S). Oca is grown in greatest abundance in the highlands of Ecuador, Peru, Columbia and Bolivia, although it is found as far north as Venezuela and as far south as Chiloe Island in Chile (Popenoe et al. 1989). Of all Andean root and tuber crops, oca is presently second only to potato in area planted within the Central Andean region. Oca was introduced into Europe in the last century but did not establish as a permanent vegetable crop. In recent decades, oca has established as a popular commercial vegetable crop in New Zealand, where it called yam (Popenoe et al. 1989).

Earlier results of studies with nuclear-encoded, chloroplast-expressed glutamine synthetase suggested that *Oxalis picchensis* might be a progenitor of oca (Emshwiller and Doyle 2002). Subsequent AFLP (amplified fragment length polymor phism) data of this species, as well as different populations of wild, tuber-bearing *Oxalis* found in Lima Department, Peru, were relatively divergent from *O. tuberosa* (Emshwiller et al. 2009). Results from all analytical methods suggested that the unnamed wild, tuber-bearing *Oxalis* found in Bolivia and *O. chicligastensis* in NW Argentina were the best candidates as the genome donors for polyploid *O. tuberosa*.

Agroecology

Oca is widely grown as a staple crop in the Andean highlands due to its tolerance of marginal soil, acidities between pH 3.5–7.8, high altitude, harsh climate and ease of propagation (Popenoe et al. 1989; Arbizu and Tapia 1994). In its native range, it is cultivated from 2800 to 4000 m altitudes. In New Zealand, it is grown near sea-level. Oca flourishes in a climate of low cool temperatures from 4 to 18 °C and mean annual precipitation of 570–2000 mm uniformly distributed throughout the growing season. It tolerates light frost but its top growth is severely damaged by sub-zero temperatures. Temperatures above about 28 °C cause the plant to wilt and its leaves to die and tuber production reduced. It thrives best in light, well-drained and rich soil in full sun. Oca requires day length shorter than 12 h to stimulate tuber formation; longer day length periods promote foliage growth.

Edible Plant Parts and Uses

Oca tubers are boiled, baked, roasted, fried, mixed fresh with salads, added to stews and soups and pickled in vinegar or served as a sweet, either plain or candied (Arbizo and Tapia 1994; King and Gerhoff 1987; Popenoe et al. 1989; Bradbury and Emshwiller 2011). In the Andes, a few genotypes types are eaten raw. In Mexico, oca is commonly sprinkled with salt, lemon and hot pepper, and eaten raw. It is also made into bottled preserves (often in vinegar). Ocas that are consumed fresh belong to the category wayk'u (boiling) or misk'i (sweet, delicious). Aymara speakers refer to ocas for processing as *luk'i* and those for fresh consumption as *q'eni*. In the Andes, Oca is first sun-dried for a few days, to make it sweeter and then parboiled, roasted or prepared as *pachamanca* (meat roasted in a hole in the ground). The dried, frozen tuber is called *khaya.* If it is washed after freezing, a whiter product called *okhaya* is obtained which is considered to be of superior quality. The flour of the latter is used to make porridges and desserts. Bitter varieties are almost always converted into dry products (*cavi* or *caya*), during which the bitterness disappears to leave bland-tasting products that can be stored without refrigeration. The bitterness can also be removed by soaking and repeatedly freeze-drying the tubers. Oca tubers also have potential for producing superior quality starch for the food industry or alcohol.

Sensory evaluation studies in New Zealand found that for raw oca, panellists preferred bright red tubers, but size was also important (Sangketkit et al. 2000). Flesh colour, bitterness and mealiness were important variables which described the overall acceptability of steamed oca, while only flesh colour and bitterness were important variables for baked oca. Cultivars which had flesh colour described as 'bright yellow', flavour as 'no bitter taste' and a 'very slightly mealy' tex-

ture were more preferred. Cultivars with higher yellow/blue (b^*) and chroma (c^*) values for cooked tuber skin and flesh colours were more acceptable. Martin et al. (2005) found that cultivars with red skin, bright yellow flesh colour, a slightly mealy texture and a sweet taste were preferred.

Botany

Oca is a compact, perennial, tuberous herb, erect becoming decumbent or prostrate towards maturity, usually 20–30 cm high, with cylindrical, succulent stems that vary in colour from yellow and green to a purplish red (Plates 1–2). Under long days, the stolons grow as above-ground stems; under short days, they penetrate the soil and form tubers. The tubers are claviform-ellipsoid and cylindrical, 3–15 cm long by 3 cm wide, stubby-looking, with buds on the whole surface, and variegated in colour: white, yellow, red and purple. Leaves trifoliate on 2–9 cm long petioles, leaflets, heart-shaped, clover-like and green. Inflorescence with 4–5 small flowers. Calyx with five pointed green sepals. Corolla with five obovate, clawed petals fused at the base and with radiating purple striations at the basal part. Stamens ten. Flowers are tristylous: short-styled flowers with two tiers of stamens above the style; mid-styled flowers with a tier of stamens both above and below the styles and long-styled flowers with two tiers of stamens below the styles.

Plate 1 Variously coloured oca tubers (CIP)

Plate 2 Harvested *pinkish-red* oca tubers

Nutritive/Medicinal Properties

The nutritional composition (dry weight basis) of oca tubers was reported as protein 3.0–8.4 %, carbohydrate 83.0–88.8 %, fat 0.5–0.6 %, ash 1.9–3.5 %, fibre 4.0–5.1 %, moisture 80.2–84.6 %, energy 368–374 cal/100 g (King and Gershoff 1987). They also contained all of the essential amino acids (mg/g protein): lysine 57–59 mg, threonine 44–47 mg, valine 26–48 mg, isoleucine 36–468 mg, leucine 53–60 mg, phenylalanine + tyrosine 57–69 mg, tryptophan 5.5–8.0 mg and methionine + cystine 25–34 mg.

Nutrient values (ppm, dry weight basis) of oca tubers reported by Duke (1994 onwards): carbohydrate 138–852 ppm, protein 7–62, fat 6–37, fibre 5–49, ascorbic acid 370–2284, Ca 40–247, Fe 8–49, P 340–2099, riboflavin 0.3–4.3, thiamine 0.5–3.1, b-carotene 0.2, energy 630–3890 kilocal.

The main proteins in tubers of 23 different oca accessions were quite acidic with isoelectric points pH 4.7–4.9 and relative molecular weight of 17–18 KD (Stegemann et al. 1988). The proteins were rich in aspartic and glutamic acid (one third of all amino acids, asp:glu ratio of 1:2) with a considerable share of essential ones: histidine and lysine (7.5–9 %); leucine, isoleucine and valine (3.5–4 %); threonine (5 %); and arginine (4.5–7 % in most except 15 % in accession CTO-140).

Oca tuber was reported to have a nutritional value equivalent to or better than potato; on average, oca contained 84.1 % moisture, 1.1 % protein and 0.6 % lipid (Popenoe et al. 1989). Fourteen percent of its nutrient content comprised carbohydrates with sucrose as the major sugar (Gross et al. 1989). Chemical composition of oca tubers contains protein 6.84 %, lipid 0.72 %, soluble fibre 0.29 %, insoluble fibre 6.85 %, total sugar 23.28, starch 56.82 %, mineral residues 4.48 % and moisture 86.23 % (Valcárcel-Yamani et al. 2013). Chemical composition of oca contains starch 99.21 %, amylose 27.60 %, mineral residues 0.15 % and moisture 10.93 %. Oca starch granules were ellipsoid, oval, conical, pear-shaped and prismatic forms: ellipsoids and oval granules with lengths up to 54.30 μm. The physical, chemical and functional characterization of starches from Andean tubers oca, mashua and ulluco suggested that these starches could be used in food systems and other industrial applications, in products that require easy cooking, hot high viscosity, stability under refrigeration and do not need to be frozen. The absence of protein in the isolated starches indicated the utility of these starches for preparing syrups with high glucose content. The starches were found to cook easily and to have a high degree of swelling and solubility, high viscosity, low stability to stirring and cooking or mechanical action and a low tendency towards retrogradation. These starches showed high clarity, but with high syneresis when subjected to freeze-thaw cycle. Oca starch granules were oval-shaped with granular sizes between 20 and 55 μm, amylose content of 18.4 %, amylopectin with average chain length of 22.4 and β-amylolysis limit of 64.5 %, B-type X-ray diffraction pattern, gelatinisation enthalpy of 14.6 J/g and peak temperature of the endothermic DSC (differential scanning calorimetry) transition was 55.9 °C (Santacruz et al. 2002). Santacruz et al. (2003) found that oca starch gel stored at 4 °C showed a high increase in G' during the first day of storage. A decrease in pH from 6.5 to 4.0 produced a loss of structure in the starch gel, as was showed by the reduction of G'. Storage at freezing temperature (−20 °C) produced higher changes in G' than refrigeration conditions.

Hernández-Lauzardo et al. (2004) reported that oca starch possessed an apparent amylose content of 33 %, similar to maize starch used as control, with a granule size between 25 and 50 μm with oval and elliptical shapes and A-type X-ray diffraction pattern. The gelatinization temperature of oxalis starch was 64.0 °C, that was lower than the one determined in maize starch (73.0 °C), with an enthalpy value of 12.2 J/g, which was similar to that of maize starch. Both oxalis and maize starch pastes behaved as weak viscoelastic systems with the elastic modulus (G') predominating over the viscous character (G''). Heating (gelatinization) caused a more pronounced enhancement in the structure of the maize starch pastes than in that of oxalis starch pastes. They concluded that due to its physicochemical, functional and rheological properties, oxalis starch could be suitable for testing its use in the cosmetic and food industry.

Total phenolic content of oca tubers ranged from 0.71 to 1.32 mg/g with the purple coloured varieties having higher content and the yellow coloured varieties lower phenolic content (Campos et al. 2006). Total carotenoid content ranged from 2 to 25 μg/g in oca, moisture content 80–85 % and lipophilic antioxidant in oca tubers ranged from 69 to 320 μg/g TE. For oca pigmented tubers, the total anthocyanin content ranged from 0.14 to 1.3 mg/g; anthocyanin was concentrated in the tuber skin.

Eight different anthocyanins were found in the coloured tubers of isla oca; the major compounds were malvidin 3-*O*-glucoside and malvidin 3,5-*O*-diglucoside; the rest were petunidin 3,5-*O*-diglucoside, peonidin 3,5-*O*-diglucoside, petunidin 3-*O*-glucoside, delphinidin 3-*O*-glucosides and peonidin3-*O*-glucoside (Alcalde-Eon et al. 2004).

Caffeic, vanillic and cinnamic acid derivatives, flavan-3-ols and flavones derivatives, were identified as the main non-anthocyanin phenolic compounds in the aqueous tuber fraction of two different coloured oca genotypes (Chirinos et al. 2009). Acid hydrolysis revealed the presence of vanillic, caffeic and cinnamic acids and malvidin in the aqueous fraction. The ethyl acetate tuber fraction was composed mainly of caffeic and cin-

namic acid derivatives as well as flavan-3-ols, flavones and flavanone derivatives. The flavan-3-ols, flavones and flavanones detected in both fractions corresponded to bound forms of catechin, luteolin and apigenin and naringenin, respectively. The aqueous tuber fractions were the major contributors to the ABTS antioxidant capacity (77–82 %).

Storage at 4 °C substantially extended the storage life of oca tubers held for 20 weeks (Kays et al. 1979). Respiratory rate (4 mg CO_2/kg/h at 4°), fresh weight and colour loss, and sprouting were retarded. Composition changes of the tubers (% reducing sugars, non-reducing sugars, total sugars, starches, total carbohydrates, total nitrogen and non-protein nitrogen) were less pronounced at 4 °C than at 21 °C. Tubers stored at 21 °C underwent substantial changes in composition, the majority of which tended to coincide with sprout formation. The mean dry matter content of freshly harvested oca tubers was 14.3 g/100 g fresh weight (FW), and after storage for 6 weeks at 16.4 °C was 14.6 g/100 g FW (Savage et al. 2008). The mean soluble oxalate content of freshly harvested tubers was 162.1 mg/100 g FW, and, after 6 weeks storage, 173.5 mg/100 g FW.

Six organic acids had been reported in oca tubers: ascorbic, malic, tartaric, succinic, glutaric and oxalic acids (Hermann and Erazo 2000; Ross et al. 1999; Bradbury and Emshwiller 2011). Of these oxalic acid is most deleterious to human health (Ross et al. 1999; Albihn and Savage 2001a, b; Sangketkit et al. 2001). King (1988) reported low levels of 20.3–50.3 mg/100 g FW oxalic acid in the tubers; in contrast, Ross et al. (1999) reported levels of 92–221 mg/100 g FW in 12 South American and two New Zealand cultivars of oca. Levels of soluble and total oxalate extracted from the tubers were not significantly different, suggesting that no calcium oxalate was formed in the tuber. Hermann and Erazo (2000) reported the highest oxalate value of 306–539 mg/100 g FW in freshly harvested tubers and 251–451 mg/100 g in sunned tubers. Sunning reduced oxalate levels by an average of 26 %. In comparison to fresh tubers, sunning increased dry matter content, soluble solids and total sugars but markedly decreased contents of starch and organic acid. The chemical composition (range, per 100 g edible matter) reported for fresh and sunned tubers was respectively as follows: dry matter 10.4–14.3 g, 16.1–20 g; starch 5.2–9.2 g, 2.2–6.5 g; soluble solids 6.2–92, 6.7–9.7 °Brix; total sugars 2119–3635 mg, 2910–5870 mg; sucrose 1208–1826 mg, 1901–3955 mg; fructose 477–1085 mg, 553–1217 mg; glucose 433–1025 mg, 456–988 mg; organic acids 2567–3385 mg, 937–1970 mg; glutarate 1071–1578 mg,121–516 mg; malate 636–1088 mg,139–660 mg; oxalate 306–539 mg,251–451 mg; succinate 270–375 mg, 294–364 mg and tartarate 57–138 mg, 56–191 mg. Twelve South American and two New Zealand cultivars of oca were found to contain total oxalate levels of 80–194 mg/100 g wet matter (WM) in raw tubers (Sangketkit et al. 2001). Oxalate levels ranged from 77 to 220 mg/100 g WM for boiled and steamed tubers, while the levels of oxalate found in baked tubers were significantly increased when compared to the raw tubers. The oxalate content of the baked tubers ranged from 164 to 335 mg/100 g WM. Total calcium content of the raw tubers ranged from 7.5 to 15.5 mg/100 g WM; cooking had a little effect on the calcium content. Among cultivars mean oxalate/calcium ratio of the raw, boiled and steamed tubers ranged from 2.5 to 9.9. Baked tubers had a significantly increased oxalate/calcium ratio (mean for all cultivars 9.5). Albihn and Savage (2001a, b) found that oca tuber contained moderately high levels of oxalate which existed in soluble form only. They found that oca tuber skin contained significantly higher oxalate level than the flesh 7.3 g/kg fresh weight (FW) compared to 1.7 and 1.4 g/kg FW in the outer and inner flesh, respectively). The highest concentration was found in the skin of the pinkish-red cultivar (10.9 g/kg FW). All cooking methods appeared to cause a migration of oxalate from the skin to the underlying flesh. On a fresh weight basis, baking significantly increased the oxalate concentration in the whole tuber, whereas boiling decreased the concentration and steaming had no significant effect. Boiling might therefore be a better way of cooking oca than baking when a low intake of oxalate

is desired. They found that the bioavailability of oxalate varied among individuals and depended on other constituents of a combined meal. Oca consumption with sour cream was found to significantly decrease the uptake of oxalate. On a dry matter basis, the mean soluble oxalate of the raw oca cultivars was 935.5 mg/100 g DM rising to 1364.8 mg/100 g DM when baked; in contrast, the mean vitamin C content of the raw tubers was 109.8 mg/100 g DM falling to a mean of 62.4 mg/100 g DM when the tubers were baked (Dubois et al. 2007). The skin and the tissue of all the cultivars were a very similar orange–yellow when cooked.

Fresh oca tubers were found to contain per 100 g edible portion 10.4–14.3 g dry matter, 5.2–9.2 g starch, 6.2–9.2 °Brix (soluble solids), 2119–3636 mg total sugars, 1208–1826 mg sucrose, 477–1085 mg fructose, 433–1025 mg glucose, 2567–3385 mg organic acids, 1071–1578 mg glutarate, 636–1088 mg malate, 306–539 mg oxalate, 270–315 mg succinate and 57–138 mg tartarate (Hermann and Erazo 2000). Sun-dried oca tubers were found to contain 16.1–20 g dry matter, 2.2–6.5 g starch, 6.7–9.7 °Brix (soluble solids), 2910–5870 mg total sugars, 1901–3955 mg sucrose, 553–1217 mg fructose, 456–988 mg glucose, 937–1970 mg organic acids, 121–516 mg glutarate, 139–660 mg malate, 251–451 mg oxalate, 294–364 mg succinate and 56–191 mg tartarate. Sun-drying reduced oxalate levels in dry matter by an average of 26 % and also sharply reduced starch content, organic acids, glutarate and malate but significantly increased total soluble solids, total sugars, sucrose, fructose and glucose.

Hairy root cultures of *O. tuberosa* transformed with *Agrobacterium rhizogenes* exuded constitutive levels of harmine (7-methoxy-1-methyl-β-carboline) and harmaline (3,4-dihydroharmine), the main fluorescent compounds detected from oca's root exudates (Bais et al. 2003, 2002). Transformed roots showed better growth and exudation of harmine and harmaline compared to the untransformed normal roots.

Antioxidant Activity

For oca tubers, the hydrophilic antioxidant capacity (HAC) and lipophilic antioxidant capacity (LAC) as determined by ABTS (2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid)) ranged from 1637 to 4771 μg TE/g and 69 to 320μgTE/g, respectively (Campos et al. 2006). HAC expressed on a phenolic basis ranged from 1935 to 3614 mg TE/g chlorogenic acid equivalent. Oca tubers presented HAC higher than those observed for blueberries and blackberries. HAC in oca was related to total phenolic and total anthocyanin content. Total phenolic content of oca tubers ranged from 0.71 to 1.32 mg/g with the purple coloured varieties having higher content and the yellow coloured varieties lower phenolic content. Total carotenoid content range from 2 to 25 μg/g in oca and moisture content 80–85 %. Total anthocyanin content ranged from 0.14 to 1.3 mg/g; anthocyanin was concentrated in the tuber skin. There was no correlation between LAC and total carotenoid content in oca tubers, the lipophilic fraction contributed 1.9–10.2 % to the total antioxidant capacity values for oca. According to the results obtained, the HAC range values for the crops studied followed the descending order mashua ≥ oca ≥ native potato ≥ ulluco.

Antimicrobial Activity

A protein of 18 kDa present in all oca morphotypes was found to be the most abundant protein in oca tubers (20–40 % of total soluble tuber protein) (Flores et al. 1999, 2002). This protein, ocatin, appeared to be a tuber-specific protein localized in the parenchyma cells of the pith and the peridermis, representing a good source of amino acids for the tuber. In addition to its storage role, ocatin was very active against the following fungal pathogens: *Rhizoctonia solani*, *Phytophthora cinnamomi*, *Fusarium oxysporum* and *Nectria haematococcus*. Anti-bacterial activity was also found against *Agrobacterium tume-*

faciens, *A. radiobacter*, *Serratia marcescens* and *Pseudomonas aureofaciens*, and the gene encoding ocatin was isolated and observed to have high homology with pathogenesis-related (PR) proteins found in a wide variety of species (Flores et al. 2002).

Other Uses

Oca plants, tubers and foliage can also be used as stock feed for livestock such as pigs which relish both tubers and foliage. Oca is also grown as home garden ornamentals.

Comments

Oca is usually propagated vegetatively by planting whole tubers and is a common component of a crop rotation system with potato, atost or faba beans.

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Piper methysticum

Scientific Name

***Piper methysticum* G. Forster**

Synonyms

Methysticum methysticum (G.Forst.) A.Lyons

Family

Piperaceae

Common/English Names

Awa, Kava, Kava-Kava, Kava Pepper, Kava Shrub, Kawa, Yangona Pepper

Vernacular Names

Arabic: Fulful Kâwah
Brazil: Cava Cava
Chinese: Ka Wa Hu Jiao
Czech: Pepřovník Opojný
Danish: Kava, Kava Kava, Kavarod
Esperanto: Kavao
Estonian: Kavapipar
Fiji: Yangona, Yaqona
Finnish: Kavakava
French: Ava, Kava, Kava Kava, Kawa-Kawa
German: Kava-Kava, Kavapfeffer, Kawa-Kawa, Kawa-Pfeffer, Kawapfeffer, Rauschpfeffer
Hawaiian: ʻAwa
Hungarian: Kava, Kávacserje, Mámorbors
Irian Jaya: Bari, Dikoi, Ikawati, Tigwa, Waghi, Wati
Italian: Pepe Kava
Marquesan: Kava, Kav-Kava
Niuean: Kavainu
Papua New Guinea: Ayuw, Bari, Bikwe, Dikoi, Gamada, Gamoda, Gumada, Irka, Jeliki, Ka, Karangimi, Kau, Keu, Koi, Komata, Koniak, Koriar, Kurar, Oyo, Sagainya, Sika, Tigwa, Toa, Toe, Towe, Tue, Tui, Tokarabu, Uati, Waghi, Wariki, Wati
Pohnpei: Sakau
Polish: Pieprz Kawakawa; Pieprz Metystynowy
Samoa: ʻAva, Ava Ava, Kava
Slovaščina: Kavakava
Spanish: Kava, Kava Kava, Kavaka, Kawa
Swedish: Kava Kava
Tahiti: Ava, Ava-Ava, Evava
Tongan: Kava, Kav-Kava
Tubuai: Ava
Turkish: Kava Biberi, Kawa Kawa

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
DOI 10.1007/978-3-319-26062-4_15

Vanuatu: M Nigui (Hiu), Maloku (Maewo), Namaloku (Nguna), Sini (Central Pentecost) Mele (south Pentecost), Maloku (North Pentecost), Nga (Ureparapara), Naga (Mota Lava), Gwie (Vanua Lava), Malop (Mere Lava), Amaloku (West Ambae), Maloku (East Ambae), Bir (Central Santo), Naxai (North Santo), Malou (Southwest Santo), Malohu (West Santo), Hae (Malo), Malox (North Malakula), Nem Leu, Melo, Melu, Malok (Northeast Malakula), Malk, Malox (Northwest Malakula), Nimvulm (Southwest Malakula), Maix, Namonggomongg, Monggmongg, Merox (Southeast Malakula), Meruh (East Malakula), Lewewe Ndrame (North Ambryn) Vatimeai (North Panama) Malou (South Panama), Malk, Miau, Mia, Mio, Mak (West Epi), Namaluk (Tongoa), Namaloku (Emae) Malok (Makira), Namloku (Nguna)

Wallis and Futuna: Kava

Origin/Distribution

The species is indigenous to and cultivated in the islands of south Pacific, from Hawaii to Papua New Guinea, with the notable exception of New Caledonia, New Zealand and most of the Solomon Islands (Singh 1992).

Phytochemical studies conducted by Lebot and Lèvesque (1989) to elucidate the origin of this Oceania plant found the lineage of chemical chemotypes suggested that *Piper wichmanii* was the wild species from which farmers domesticated cultivars of *Piper methysticum.* Based on morphological, chemical, cytological and genetic evidence demonstrating the absence of taxonomic distinction between *Piper methysticum* and *Piper wichmannii*, Lebot and Levesque (1996) concluded that *Piper methysticum* is not a separate species, but rather a group of sterile cultivars selected from somatic mutants of *P. wichmannii*. As *P. methysticum* was described first (1786), it had priority making *P. wichmannii* (1910) superfluous.

Agroecology

Piper methysticum being a tropical species requires tropical conditions to flourish. It thrives best in loose, well-drained, moist, well-composted soils in a protected, partially shaded position, between 300 and 500 m above sea level in a tropical environment of 20–35 °C, 70–100 % relative humidity and rainfall above 2000 mm per annuum.

Edible Plant Parts and Uses

The root and rhizome (underground stem) of kava are used to prepare beverages, extracts, capsules, tablets, and topical solutions (NCAM 2006). Its thick roots and stumps (stem bases) are shaved, mashed or grounded into powder (Plates 2 and 3) and made into a cold beverage used similarly to alcohol and has a sedative effect. Kava is widely and commonly consumed as a social beverage to establish kinship in the Pacific island communities (McDonald and Jowitt 2000). The roots or shavings can also be chewed. Chewing produces the strongest effect because it produces the finest particles.

Botany

An evergreen, robust, dioecious, vine-like perennial shrub, 1–4 m high, with glabrous, woody, branching stems and massive base with lateral roots to 2 m long and 8 cm diameter. Leaves green, alternate, glabrous, cordate, 10–30 cm by 9–24 cm, entire, apex acute, palmately veined and borne on 2–7 cm long petioles (Plate 1). The flowers are small, unisexual, whitish, occurring in short, irregular, axillary spikes or opposite leaves. The floral bracts are rounded and peltate on pubescent pedicels. The male spikes with flowers bearing two short stamens, female spikes (rare) female flower with a unilocular ovary and stigma. The fruit, a berry is seldom produced and the plant must be propagated by dividing the roots or through stem cuttings.

Nutritive/Medicinal Properties

Phytonutrients

Fresh kava root was reported to contain 43 % starch, 20 % fiber, 12 % water, 3.2 % sugars, 3.6 % proteins, 3.2 % minerals and up to 20 % kava lactones (Leung and Foster 1996). The composition of kava drug from kava basal stem and roots in Fiji was determined to have respectively: moisture 14.60, 13.66%; carbohydrates 74.11, 64.22 %; fibre 10.66, 13.09 %; ash 2.33, 3.57 %; K 2.161, 2.00 %; Ca 0.455, 0.201 %; mg 0.105, 0.179 %; Na 0.0362, 0.060 %; Al 0.0202, 0.15 %; Fe 0.017, 0.106 %; Zn 60.66, 55.35 ppm; Mn 12.04, 51.77 ppm; Cu 13,08, 16.95 ppm (Duve and Prasad 1983). Dry commercial kava powder was analysed by IRCC (Institut de Rechrches sur le Café et le Cacao) laboratory in Vanuatu to have sugars 0.50 % sucrose, 0.10 % maltose, 1.75 % fructose and 0.85 % glucose; amino acids – aspartic acid 0.28 %, threonin 0.08 %, serine 0.11 %, glutamic acid 0.26 %, glycine 0.11 %, phenylalanine 0.07 %, histidine 0.05 %, lysine 0.10 %, arginine 0.08 %, alanine 0.16 %, valine 0.11 %, methionine 0.02 %, isoleucine 0.07 %, leucine 0.14 % and tyrosine 0.06 %; kavalactones 5.23 %; dihydro-5,6 kavalactones plus dehydro-5,6-kavalctones; minerals K 2.37 %, Ca 0.372 %, Mg 0.099 %, Na 0.111 %, Fe 0.017 %, Zn 22.07 ppm, Mn 7.30 ppm, Cu 15 ppm, cl 0.012 ppm, S 0.018 ppm, B 11.6 ppm (Lebot and Cabalion 1988).

Phytochemicals – Kavalactones/ Chalcones

More than 40 compounds belonging to the classes of kavapyrones, alkaloids, steroids, chalcones, long-chained fatty acids and alcohols have been isolated and identified from *Piper methysticum* (Parmar et al. 1997). Van Veen (1939) isolated a

Plate 1 Cordate leaves of young kava seedling

Plate 2 Dried kava roots (*right*) and shavings (*left*)

Plate 3 Pure pounded kava powder

narcotic substance from dried kava stems and roots, and called it marindinin which later was found to be identical with dihydrokawain of Borsche. The concentrations of desmethoxyyangonin, yangonin, dihydromethysticin, methysticin, dihydrokawain and kawain in kava ether extract were determined (Young et al. 1966). Dutta et al. (1972) isolated yangonin and methysticin from kava roots. Recoveries of known compounds were 80–85 % for yangonin and 90–95 % for all others. Fresh kava root stock contained 80 % water, while dried rootstock consists of approximately 43 % starch, 20 % fibre, 12 % water, 3.2 % sugars, 3.6 % proteins, 3.2 % minerals and 15 % (3–20 %) kavalactones (Lebot et al. 1992). Kavalactone content was reported to be greatest in the roots and to decrease higher up the plant. Relative concentrations of 15 %, 10 % and 5 % have been observed in the root, stumpand basal stems, respectively. Kavalactones (amounting to %) had been reported in all parts of the kava plant comprising the major ones: kavain (1.8 %), methysticin (= kavahine, kavakin, kavatin, kanakin) (1.2 %), demethoxyyangonin (1 %), yangonin (1 %), dihydrokavain (0.6 %), dihydromethysticin (0.5 %) and traces of 11,12-dimethoxyhydrokavain, 11-hydroxy12-methoxykavain, 11-methoxy-nor-yangonin, 11-methoxy-yangonin and the two ethylketones cinnamoylacetone and methylendioxy-3,4-cinnamoylidenacetone (Shulgin 1973; Young et al. 1966).

The content (weight %) of six major kavalactones in the dried kava roots was reported as: kavain 2.58 %, dihydrokavain 1.37 %, methysticin 1.82 %, dihydromethysticin 1.89 %, yangonin 1.73 %, desmethoxyyangonin 0.81 % analysed in Hawaii (Young et al. 1966); kavain 1.90 %, dihydrokavain 2.37 %, methysticin 2.12 %, dihydromethysticin 1.12 %, yangonin 1.21 %, desmethoxyyangonin 0.59 % analysed in Fiji (Duve 1981); kavain 2.30 %, dihydrokavain 3.28 %, methysticin 2.06 %, dihydromethysticin 1.60 %, yangonin 1.16 %, desmethoxyyangonin 0.91 % analysed in Vanuatu (Lebot and Lévesque 1996). The composition of the major kavalatones in kava root, stem and leaf were reported respectively by Smith (1983) askavain (34.5, 0.6, 2.5 %); dihydrokavain (17.1,23.2,69.8 %); methysticin (20.8, 13.9, 0.8 %); dihydromethysticin (5.3, 59.6, 22.5 %); yangonin (0.8,0.8, 1.2 %) and desmethoxyyangonin (21.6, 1.8, 3.0 %).

The first compound isolated from *Piper methysticum* was methysticin (Cuzent 1981) also known as kavatin, kavahin and kanakin. The IUPAC has recommended the name 5,6-dihydro-4-methoxy-6-[3′,4′-(methylenedioxy)styryl]-2H-pyran-2-one but chemical abstracts indexing has adopted the latter path, using 5-hydroxy-3-methoxy-7-[3,4-methylenedioxyphenyl]-2,6-hepta-dienoic acid- lactone. The ethylenic dihydroanalog dihydromethysticin was isolated almost 50 years later by Winzheimer (1908).

Nolting and Kopp (1874) isolated yangonin. The most extensive studies on the constituents of kava plant were conducted by Borsche and coworkers in 13 papers wherein they reported the isolation and structure of two compounds kawain (also known as kavain and gonosan) and dihydrokawain and the structural elucidation of the crystalline components methysticin, dihydromethysticin and yangonin (Borsche 1927; Borsche and Bodenstein 1929; Borsch and Blount 1930, 1932, 1933; Borsche and Gerhard 1914; Borsch and Lewinsohn 1933; Borsche et al. 1927a, b, 1929a, b; Borsche and Peitzsch 1929a, b, 1930; Borsche and Roth 1921; Borsche and Walter 1927). Yangonin (= 4-methoxy-6-(p-methoxy-β-styryl)-α-pyrone) was not so recognised by Borsche and co-workers (Borsche and Gerhard 1914; Borsche and Bodenstein 1929). They had postulated it as a γ-pyrone, although they had correctly interpreted the structures of all other substances isolated from kava (Borsche et al. 1927a, b; Borsche and Peitzsch 1929a, 1930). Yangonin served as the basis for two additional substances the metamethoxy analogue 11-methoxyyangonin (Hänsel and Klaproth 1966) and the phenolic counterpart 11-methoxy-nor-yangonin (Hänsel et al. 1966c) isolated from Kava-kava, both of which had been established synthetically as possessing the α-pyrone ring. The completely conjugated analogue, 5,6-dehydromethysticin, was identifed as a component of kava-kava by Hänsel (1968). The following kavalactones were isolated from kava roots: 5,6,7,8-tetrahydro-yangonin (Achenbach et al. 1971); 11-hydroxy-12-methoxy-dihydrokawain and 11,12-dimethoxy-dihydrokawain (Achenbach et al. 1972). Two yellow pigment materials, flavokawin A and B, were isolated from kava rhizomes (Hänsel et al. 1961). The structures of these were established by synthesis to be substituted chalcones bearing an obvious biogenetic relationship to the styrylpyrones (Hänsel et al. 1963). Hänsel and Schulz (1973) synthesized 5,6,-*cis*-kavain 5-ol and 5,6-*trans*-kavain-5-ol. Flavokawin A was elucidated as 2′-hydroxy-4-4′-6′-trimethoxychalcone and flavokawin B as 2′-hydroxy-4′-6′ dimethoxychalcone. The flavokavins A, B and C were reported to have a different skeleton (Duve 1976; Hänsel et al. 1963; Dutta et al. 1973, 1976).

A total of 19 kavalactones namely 10-methoxyyangonin; hydroxykavain; dihydro-5,6-dehydrokavain; 7,8-dihydrokavain; 7,8-dihydroyangonin; kavain; 7,8-dihydro-5-hydroxykavain; 5,6-dihydroyangonin; 11-hydroxy-12-methoxydihydrokavain; 11-methoxyyangonin; 5,6-dehydrokavain (desmethoxyyangonin); 5,6,7,8-tetrahydroyangonin; methysticin; dihydromethysticin; 11,12 dimethoxydihydrokavain; yangonin; 11-methoxy-12-hydroxydehydrokavain; 11-hydroxyyangonin; 5,6-dehydromethysticin were identified in kava roots (Hänsel 1968; Lebot and Cabalion 1988; He et al. 1997; Whittaker et al. 2008; Dharmaratne et al. 2002; Xuan et al. 2008; Teschke 2011; WHO 2007), with flavokavains A, B and C (He et al. 1997); kava lactones (Hänsel et al. 1968) identified in kava roots included: kavain; 7,8-dihydrokavain; 5,6-dehydrokavain; yangonin; 5,6,7,8-tetrahydroyangonin; methysticin; dihydromethysticin; 5,6-dehydromethysticin; 5,6-dihydroyangonin; 7,8-dihydroyangonin; 10-methoxy-yangonin; 11-methoxy-yangonin; 11-hydroxy-yangonin; hydroxykavain; 11-methoxy-12-hydroxy-dehydrokavain (Lebot and Cabalion 1988). Major compounds identified in Kava extracts by low-resolution GC/MS included kava lactones like kavain, dihydro-and dehydrokavains, yangonin and tetrahydroyangonin, methysticin and dihydromethysticin (Nerurkar et al. 2004; Lopez-Avila and Benedicto 1997). Other kavalactones were identified as minor components including 1-methoxyyangonin (Hänsel and Klaproth 1966), 11-metho xynoryangonin and 5,6-dehydromethysticin (Hänsel et al. 1966b); 1-methoxyyangonin (Hänsel and Klaproth 1966), 11-methoxynoryangonin and 5,6-dehydromethysticin (Hänsel et al. 1966b); 10-methoxyyangonin, 11-hydroxyyangonin and 11-methoxy-12-hydroxydehydrokavain (Duve 1981; He et al. 1997). Additionally, three hydro-derivatives of yangonin were identified from kava plant. These include 5,6-dihydroyangonin (Hänsel 1968; Duve 1981), 7,8-dihydroyangonin (Duve 1981) and 5,6,7,8-tetrahydroyangonin (Achenbach et al. 1971; Hänsel 1968). Hydroxylated α-pyrone derivatives, including *cis*-5-hydroxykavain (Duve 1981) and 5-hydroxydihydrokavain (Achenbach and

Wittman 1970), had also been isolated from *P. methysticum* as minor components.

The kavalactone, 11-methoxy-5,6-dihydroyangoninand eight previously reported analogs along with four other aromatic compounds were isolated from kava root extracts (Ranjith et al. 2002). Nine kava lactones were detected from kava roots using GC-MS including desmethoxyyagonin, kavain, 7,8-dihydrokavain, hydroxykavain, yagonin, 5,6,7,8-tetrahydroxyyagonin, methysticin, dihydromethysticin and 11-hydroxy-12-methoxydihydrokavain (Xuan et al. 2006). Quantities of desmethoxyyagonin, kavain, 7,8-dihydrokavain, yagonin, methysticin and dihydromethysticin detected were 4.3, 6.9, 18.6, 5.7, 1.4 and 5.4 mg/g of dry weight, respectively. Eighteen kava lactones, cinnamic acid bornyl ester and 5,7-dimethoxy-flavanone, and seven compounds, including 2,5,8-trimethyl-1-naphthol; 5-methyl-1-phenylhexen-3-yn-5-ol; 8,11-octadecadienoic acid-methyl ester; 5,7-(OH)(2)-4′-one-6,8-dimethylflavanone; pinostrobin chalcone; and 7-dimethoxyflavanone-5-hydroxy-4′, were identified from kava roots (Xuan et al. 2008). Glutathione (26.3 mg/g) was found in the water extract. Dihydro-5,6-dehydrokavain (DDK) was present at a higher level than methysticin and desmethoxyyagonin, indicating that DDK to be a major constituent of kava roots.

Of 18 kavalactones or kava pyrones found in kava, kawain, dihydrokawain, methysticin, dihydromethysticin, yangonin and desmethoxyyangonin were the six major kavalactones (Whittaker et al. 2008). The following kavalactone compounds were isolated from kava roots: kavalactones:10-methoxyyagonin; hydroxykavain; dihydro-5,6-dehydrokavain; 7,8-dihydrokavain; 7,8-dihydroyagonin; kavain; 7,8-dihydro-5-hydroxykavain; 5,6-dihydroyagonin; 11-hydroxy-12-methoxydihydrokavain; 11-methoxyyagonin; desmethoxyyagonin, 5,6,7,8-tetrahydroyagonin; methysticin; dihydromethysticin; 11,12-dimethyoxydihydrokavain; yagonin; 11-methoxy-12-hydroxydehydrokavain; 11-hydroxyyagonin; and 5,6-dehydromethysticin (Xuan et al. 2008). Duve and Prasad (1983) investigated the stability of kavalactones in powdered kava root stored in screw-capped glass bottles at room temperature for 22, 36 and 39 months. After 39 months of storage 93.9 % of dihydrokavain, 81.6 % of kavain, 72.4 % of dehydrokavain, 54.9 % of tetrahydroyangonin, 25.8 % of dihydromethysticin, 32.1 % of yangonin and 29.5 % of methysticin had deteriorated in the powdered root samples.

Concentrations of total kava lactones (methysticin, dihydromethysticin, kawain, dihydrokawain, yangonin and desmethoxyyangonin), ranged between 135 and 0.035 mg per serving in 10 beverage products, two chocolate products, three unbrewed tea products, a drink mix product tested and between 40 and 61 mg per serving for the three dietary supplement products tested using LC-UV and LC-MS analyses (de Jager et al. 2004). One percent of kava extract could be detected in food supplements using liquid chromatography-atmospheric pressure chemical ionisation tandem mass spectrometry, corresponding to approximately 0.05–0.2 mg/g of the individual kava lactones kavain, dihydrokavain, yangonin, desmethoxyyangonin, methysticin and dihydromethysticin (Bobeldijk et al. 2005). Reliable quantification was obtained from concentrations of 0.25–1 mg/g, depending on the compound. Reliable quantification was obtained from concentrations of 0.25–1 mg/g, depending on the compound. Gautz et al. (2006) found the combination of near-infrared reflectance spectroscopy and partial least-squares methods to be a convenient, versatile and rapid analytical tool for determination of kavalactones in dried kava powder.

Major and trace constituents of kava resin were identified using methane negative ion chemical ionization (NICI) mass spectrometry (Duffield and Lidgard 1986; Duffield et al. 1986). Several of the kava lactones (kawain, methysticin, desmethoxyyangonin and yangonin) produced abundant molecular anions when analysed by methane NICI mass spectrometry, in contrast to their 7,8-dihydro analogues which ionized with poor efficiency to yield weak $[M-H]^-$ anions. Several new trace compounds formally resulting from decarboxylation of the 4-methoxy-2-pyrone ring system in the known compounds were also found. A simultaneous HPLC separa-

tion of the enantiomers of kavain, dihydrokavain, methysticin and dihydromethysticin as well as the achiral dienolides yangonin and desmethoxyyangonin was carried out on a ChiraSpher NT column (Boonen et al. 1997; Häberlein et al. 1997). Using reverse-phase high-performance liquid chromatographic method, six major kavalactones [methysticin, dihydromethysticin (DHM), kavain, dihydrokavain (DHK), demethoxyyangonin (DMY) and yangonin] in *Piper methysticum* (kava) were simultaneously determined (Shao et al. 1998). The detection limits ($S/N = 3$) for methysticin, DHM, kavain, DHK, DMY and yangonin are approximately 0.5, 1.1, 0.7, 1.1, 0.6 and 0.6 μg/ml, respectively. The average recoveries are 100.2 % for methysticin, 100.6 % for DHM, 100.0 % for kavain, 100.3 % for DHK, 98.9 for DMY and 98.2 % for yangonin. A rapid micellar electrokinetic chromatography method with diode-array detection was used to separate kavalactones kavain, dihydrokavain, methysticin, dihydromethysticin, yangonin and demethoxyyangonin from dry kava extracts (Lechtenberg Lechtenberg et al. 1999).

Three kava lactone constituents of *Piper methysticum*, namely, kawain, methysticin and desmethoxyyangonin, were separated and identified by reverse-phase HPLC using superheated deuterium oxide as the mobile phase and on-line 1H-NMR detection (Chienthavorn et al. 2005). Meissner and Häberlein (2005) used simultaneous HPLC for the separation of six major kavapyrones and the flavokavins A–C in an ethanolic extract of *Piper methysticum*. Flavokavins A–C contents of 0.62 mg/100 mg, 0.34 mg/100 mg and 0.14 mg/100 mg ethanolic kava extract was determined respectively. Compounds identified in commercial kava extracts by gas chromatography (GC) and quadrupole time-of-flight mass spectrometry (QTOFMS) with an electron ionization source: 7,8 dihyrokavain; kavain; 5,6-dehydrokavain; 5,67,8-tetrahydroyangonin; 7,8-dihydromethysticin; yangonin; methysticin; bornyl cinnamate; dihydroxy-methoxyphenyl-phenyl-propen-one; hydroxyl-dimethoxyphenyl-3-phenyl-2-propen-1-one; and hydroxyl-dimethoxyphenyl-3-methoxyphenyl-2-propen-1-one (Lopez-Avila and Yefchak 2009).

For ground kava (250–500 μm), 2 h of subcritical water extraction was required for a complete extraction of kava lactones at 100 °C, while at 175 °C, 20 min were sufficient (Kubátová et al. 2001). For a complete extraction of the unground (shredded) kava, the time of extraction was extended to 40 min at 175 °C. Boiling for 2 h and extraction with Soxhlet apparatus for 6 h, both of which employed water at atmospheric pressure, produced yields 40–60 % lower than those obtained with subcritical water. With unground kava, 40 min of subcritical water extraction yielded essentially the same recoveries of lactones as 18 h of sonication with acetone, methylene chloride or methanol. Kava root extracted in acetone yielded 100 % kavalactones, 96 % ethanol yielded 100 % kavalactones, 25 % ethanol yielded 15 % kavalactones and water yielded 2.97 % kavalactones (Denham et al. 2002). Extraction rates also varied depending on the temperature at which the products were prepared. Analysis of flavokavins in extracts of 172 samples originating from four cultivars groups (noble, medicinal, 2-days and wichmannii) indicated that the ratio flavokavin B /kavalactones was much higher in 2 days (0.39) and wichmannii (0.32) compared to nobles (0.09) and medicinal cultivars (0.10) (Lebot et al. 2014). For each group, the ratios of flavokavins/kavalactones did not change significantly between roots, stumps or basal stems and among clones, indicating that they were genetically controlled.

Phytochemicals – Alkaloids/ Flavonoids/Miscellaneous Compounds

There had been reports of isolation of alkaloids, flavonoids – flavokavins, sterols, organic acids, aliphatic alcohols and other compounds from kava plant. Three flavokavins (also known as flavokawins or flavokavains), designated A, B and C, had been identified from kava root (Dutta and Ray 1973; Dutta et al. 1973, 1976; Hänsel et al. 1961, 1963). Structures of these compounds had been confirmed by synthesis (Hänsel et al. 1963; Dutta et al. 1976; Dutta and Som 1978). Two

alkaloids were isolated from a methanolic extract of kava root and were identified as 1-cinnamoylpyrrolidine and 1-(methoxycinnamoyl)pyrrolidine (Achenbach and Karl 1970) and an alcohol dihydrokawain-5-ol (Achenbach and Wittman 1970). A third alkaloid, pipermethystine, was isolated from leaves by Smith (1979; 1983) and was found in small amounts in the stems and roots (Singh 1992). A few piperidine alkaloids (i.e., pipermethystine, 3,4-epoxy-5-pipermethystine, and awaine) were identified in the aerial parts of kava plant (stem peelings and leaves) (Dragull et al. 2003). Pipermethystine was concentrated in the stem peelings and leaves. 3,4-epoxy-5-pipermethystine and awaine were new alkaloids with 3,4-epoxy-5-pipermethystine found only in cv. Isa among the 11 cultivars examined, and awaine occurred primarily in young leaves of all cultivars. None of the three piperidine alkaloids were detected in the commercial root powders from Fiji, Tonga or Hawaii. Two conjugated diene ketones, cinnamylidineacetone and 3,4-methylenedioxycinnamylidineacetone (Jössang and Holho 1967), and organic acids (Achenbach and Karl 1971) were isolated from kava roots. Kava plant had been found to contain amides (2-methoxy cinnamic pyrrolide, cinnamic acid pyrollide), chalcones (flavokavin A and B) and free and aromatic acids, anisic acid, benzoic acid, caprionic acid, hydroxyl cinnamic acid and derivatives (Klohs 1967; Halzl et al. 1993). The kava methanol root extract yielded bornyl esters of 3,4-methylenedioxy cinnamic acid and cinnamic acid, pinostrobin, flavokawain B and 5,7-dimethoxyflavanone (Wu et al. 2002a). Two C-glycoside flavonoid compounds identified as 2″-*O*-rhamnosylvitexin and schaftoside were isolated from kava leaves (Jhoo et al. 2007) and phytosterols such as stigmasterol, stigmastanol, β-sitoserol and campesterol (Jössang and Molho 1970; Gracza and Ruff 1986). Trace amount of a nitrogen-containing compound (cepharadione) had also been isolated from the kava rootstock (Jaggy and Achenbach 1992). Alipahtic and alicyclic alcohols had been isolated from the rhizome: docosan-1-ol, docecanol-1-ol, eicosanol-1-ol, hexacosan-1-ol, hexadecane-1-ol, octadecanol-1ol and n-triacontane (Gracza and Ruff 1986).

The root was also known to contain flavokavins A and B, pipermethystine, cepharadione A, cinnamalketone, and methylene dioxy-3, 4-cinnamalketone (Lebot et al. 1992). Bornyl cinnamate and a series of hydroxylated compounds resulting from the decarbonylation of the lactones had also been identified in kava resin by methane chemical ionization GC/MS and two previously described *N*-cinnamoyl pyrrolidine alkaloids along with stigmasterol (Cheng et al. 1988). Three dihydrochalcones: flavokavain A, flavokavain B, flavokavain C; cinnamic acid bornyl ester and 5,7-dimethoxy-flavanone; and compounds detected for the first time in kava roots: 2,5,8-trimethyl-1-naphthol; 5-methyl-1-phenylhexen-3-yn-5-ol; 8,11-octadecadienoic acid-methyl ester; 5,7-(OH)(2)-4′-one-6,8-dimethylflavanone; pinostrobin chalcone; and 7-dimethoxyflavanone-5-hydroxy-4′. Glutathione (26.3 mg/g) was found in the water extract (Xuan et al. 2008). Acetone was the most effective solvent in terms of maximum yield and types of kava lactones isolated, followed by water and chloroform, whereas hexane, methanol and ethanol were less effective as solvents. Total phenolic and antioxidant activity varied among the extracting solvents, with acetone and chloroform producing the highest effects, followed by water, while methanol, ethanol and hexane were less effective. Two alkaloids, (−)-pipermethystine and (−)-epoxypipermethystine, and two lactones, (+)-dihydromethysticin and yangonin, were isolated from the kava plant (Naumov et al. 2008).

Pharmacological Activities

Kava kavalactones were reported to possess pharmacological effects which include sedative, anxiolytic, anti-stress, analgesic, local anaesthetic, anticonvulsant and neuroprotective properties (Gounder 2006). Kava's biological effects, due to a mixture of compounds called kavalactones, had been reported to include sedative, anxiolytic,

antistress, analgesic, local anaesthetic, anticonvulsant and neuroprotective properties (Singh and Singh 2002). The pharmacological properties of kava were postulated to include blockade of voltage-gated sodium ion channels, enhanced ligand binding to gamma-aminobutyric acid (GABA) type A receptors, diminished excitatory neurotransmitter release due to calcium ion channel blockade, reduced neuronal reuptake of noradrenaline (norepinephrine), reversible inhibition of monoamine oxidase B and suppression of the synthesis of the eicosanoid thromboxane A(2), that was antagonistic to GABA(A) receptor function.

Antioxidant Activity

The lipid oxidation assay did not reveal antioxidant activities for kava root compounds demethoxyangonin, dihydrokawain, kawain, dihydromethysticin or methysticin at 50 µg/ml (Wu et al. 2002b). The antioxidant activities of flavokawain A and yangonin could not be tested in the lipid oxidation assay due to solubility problems. However, yangonin and methysticin showed moderate antioxidant activities in the free radical scavenging assay at 2.5 mg/ml.

Cyclooxygenase Enzyme Inhibitory Activity

Six compounds isolated from the ethyl acetate kava root extract were found to possess cyclooxygenase inhibitory activity (Wu et al. 2002b). Dihydrokawain and yangonin showed the highest COX-I and COX-II inhibitory activities at 100 µg/ml, respectively. All kava compounds bornyl esters of 3,4-methylenedioxy cinnamic acid and cinnamic acid, pinostrobin, flavokawain B and 5,7-dimethoxyflavanone tested gave good COX-I and moderate COX-II enzyme inhibitory activities at 100 µg/mL (Wu et al. 2002a). Flavokawain B showed the highest COX-I inhibitory activity at 100 µg/mL.

Anticancer Activity

Findings of a cancer incidence survey for the Pacific Islands completed in the 1980s indicated that the more kava consumed by a population the lower the cancer incidence for that population (Steiner 2000). Crude kava extracts (dichloromethane and hexane fractions) showed good activity against A2780 ovarian tumour and K562 human leukaemia cancer cell lines in-vitro (Tabudravu and Jaspars 2005). Bioassay-guided isolation afforded six known kava lactones dihydromethysticin; 7,8 dihydrokavain; kavain; demethoxyyangonin; *cis*-yangonin and trans-yangonin and two flavokavains A and B. The anticancer of the fractions and eight compounds gave IC_{50} values ranging from 0.42 to 9.15 µg/ml against K562 and 0.43–5.15 µg/ml against A2780.

Flavokawain A, B and C naturally occurring chalcones isolated from kava may hold promising anti-cancer effects as numerous studies revealed that both flavokawain A and B were involved in the induction of cell cycle arrest in several cancer cell lines (Abu et al. 2013). Flavokawain B was shown to be more effective in treating in-vitro cancer cell lines as compared to flavokawain A and C. Flavokawain B also exerted antinociceptive effects as well as anti-inflammation properties. Flavokawain A, a chalcone from kava extract, induced apoptosis in bladder cancer cells by involvement of Bax protein-dependent and mitochondria-dependent apoptotic pathway and suppresses bladder tumor growth in mice (Zi and Simoneau 2005). Studies by Tang et al. (2008) found that kava flavokawain A exerted different effects in bladder cancer cells with wild-type versus mutant p53. In a p53 wild-type, low-grade, and papillary bladder cancer cell line (RT4), flavokawain A increased p21/WAF1 and p27/KIP1, which resulted in a decrease in cyclin-dependent kinase-2 (CDK2) kinase activity and subsequent G(1) arrest. In contrast, flavokawain A induced a G(2)-M arrest in six p53 mutant-type, high-grade bladder cancer cell lines (T24, UMUC3, TCCSUP, 5637, HT1376 and HT1197). Flavokawain A significantly reduced the expression of CDK1-inhibitory kinases, Myt1

and Wee1, and caused cyclin B1 protein accumulation leading to CDK1 activation in T24 cells. Suppression of p53 expression by small interfering RNA in RT4 cells restored Cdc25C expression and down-regulated p21/WAF1 expression, which allowed Cdc25C and CDK1 activation, which then led to a G(2)-M arrest and an enhanced growth-inhibitory effect by flavokawain A. Consistently, flavokawain A also caused a pronounced CDK1 activation and G(2)-M arrest in p53 knockout but not in p53 wild-type HCT116 cells.

Studies showed that a 30-week kava treatment inhibited 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone plus benzo[a]pyrene-induced lung tumorigenesis in A/J mice (Johnson et al. 2008). Kava treatment inhibited proliferation and enhanced apoptosis in lung tumors, as shown by a reduction in proliferating cell nuclear antigen (PCNA), an increase in caspase-3, and cleavage of poly(ADP-ribose) polymerase (PARP). Kava treatment also inhibited the activation of nuclear factor kappaBNF-kappaB, a potential upstream mechanism of kava chemoprevention. In subsequent studies, Johnson et al. (2011) reported that mice-fed diets containing kava at dosages of 1.25, 2.5, 5 and 10 mg/g of diet had 8.4, 6.6, 4.3 ± 2.4 and 3.8 lung adenomas per mouse, respectively corresponding to a reduction of 31 %, 46 %, 65 % and 69 % in tumor multiplicity. They found that flavokawains A, B and C, from kava, demonstrated greatly reduced chemopreventive efficacies even at concentrations much higher than their natural abundance, suggesting that they alone were unlikely to be responsible for kava's chemopreventive activity. Kava at all dosages and treatment regimens did not induce detectable adverse effects, particularly with respect to liver. Specifically, kava treatment showed no effect on liver integrity indicator enzymes or liver weight, indicating that kava may be potentially safe for long-term chemopreventive application. Shaik et al. (2009) demonstrated that kava suppressed nuclear factor-kappaB (NF-kappaB) activation in lung adenoma tissues, potentially a mechanism responsible for kava's chemopreventive activity. Methysticin was identified as a potent NF-kappaB inhibitor in kava with minimum toxicity. Other kava constituents, including four kavalactones of similar structures to methysticin, demonstrated minimum activities in inhibiting NF-kappaB. A potent chalcone analog, (E)-3-(3-hydroxy-4-methoxyphenyl)-1-(3,4,5-trimethoxyphenyl)prop-2-en-1-one derived from flavokawain compounds found in kava, dose-dependently inhibited A549 lung cancer cell viability, NF-κB, activation of caspases and activation of mitogen-activated protein kinases such as extracellular signal regulated kinase 1/2 (ERK1/2) and c-Jun N-terminal kinase (JNK) (Warmka et al. 2012)

Studies by Tang et al. (2010) demonstrated that flavokawain B (FKB), a kava chalcone, was about 4- to 12-fold more effective in reducing the cell viabilities of androgen receptor (AR)-negative, HRPC cell lines DU145 and PC-3 than AR-positive, hormone-sensitive prostate cancer cell lines LAPC4 and LNCaP, with minimal effect on normal prostatic epithelial and stromal cells. FKB induced apoptosis with an associated increased expression of proapoptotic proteins: death receptor-5, Bim and Puma and a decreased expression of inhibitors of apoptosis protein: XIAP and survivin. Additionally, FKB synergized with TNF-related apoptosis-inducing ligand (TRAIL) for markedly enhanced induction of apoptosis. Furthermore, FKB treatment of mice bearing DU145 xenograft tumors resulted in tumor growth inhibition and increased Bim expression in tumor tissues. Flavokawain B significantly inhibited the cell proliferation of human adenoid cystic carcinoma in-vitro in a dose-dependent manner that was associated with induced apoptosis and cell cycle G2-M arrest, and the half maximal inhibitory concentration (IC_50) of flavokawain-B treatment for 48 ourshwas estimated to be 4.69 μmol/L (Zhao et al. 2011). Induction of apoptosis was by up-regulation of Bim and down-regulation of Bcl-2 expression. Li et al. (2012) treated prostate cancer (LNCaP, LAPC-4, 22Rv1, C4-2B, DU145 and PC-3) cell lines having different androgen receptor (AR) expression and a transformed prostate myofibroblast cell line (WPMY-1), with a commercial kava extract, kavalactones (kawain, 5′6′-dehydrokawain, yangonin, methysticin) and

flavokawain B. The kava extract and flavokawain B effectively down-regulated the expression of both the full-length AR and AR splice variants. The kava extract and kavalactones accelerated AR protein degradation, while flavokawain B inhibited AR mRNA transcription via decreasing Sp1 expression and the binding of Sp1 to the AR promoter. The kava root extract and flavokawain B reduced tumor growth, AR expression in tumor tissues and levels of serum PSA in the patient-derived prostate cancer xenograft in mice. The results suggested a potential usefulness of a safe kava product or its active components for prevention and treatment of advanced prostate cancer by targeting AR.

Flavokawain B (FKB) potently inhibited the growth of synovial sarcoma cell lines SYO-I and HS-SY-II through induction of apoptosis (Sakai et al. 2012). Treatment with FKB increased caspase 8, 9 and 3/7 activity compared to vehicle-treated controls, indicating that both extrinsic and intrinsic apoptotic pathways were activated. In addition, FKB treatment of both cell lines resulted in increased mRNA and protein expression of death receptor-5 and the mitochondrial pro-apoptotic proteins Bim and Puma, while down-regulating the expression of an inhibitor of apoptosis, survivin in a dose-dependent manner. Treatment with flavokawain B (FKB), a novel kava chalcone, preferentially inhibited the growth of uterine leiomyosarcoma (SK-LMS-1), endometrial adenocarcinoma (ECC-1) cells compared to the non-malignant, human endometrium fibroblast-like (T-HESC) cell lines (Eskander et al. 2012). FKB treatment resulted in cell cycle arrest and a robust induction of apoptosis in SK-LMS-1 and ECC-1 cell lines.

In a recent study, flavokawain B, a kava chalcone, inhibited the growth of human osteosarcoma cell lines 143B and Saos-2 through G2/M cell cycle arrest and induction of apoptosis involving both extrinsic and intrinsic pathways (Ji et al. 2013). Furthermore, migration and invasion ability was decreased by FKB in a dose-dependent manner. The cytotoxicity profile showed FKB had significant lower side effects on bone marrow cells and small intestinal epithelial cells compared with adriamycin. Oral administration of flavokawain A (FKA), the predominant chalcone from kava, to UPII-SV40T transgenic mouse for 318 days inhibited the occurrence of high-grade papillary urothelial cell carcinoma, a precursor to invasive urothelial cancer, by 42.1 % (Liu et al. 2013). A decreased expression of Ki67, survivin and X-linked inhibitor of apoptotic proteins (XIAP) and increased expression of p27 and DR5, and the number of terminal deoxynucleotidyl transferase-mediated dUTP nick end labeling (TUNEL)-positive apoptotic cells were observed in the urothelial tissue of FKA-fed mice. The results suggested a potential of FKA in preventing the recurrence and progression of non-muscle-invasive urothelial cell carcinoma.

The results of animal studies by Triolet et al. (2012) suggested that kava may reduce colon cancer risk. After 14 weeks, rats fed the nonpolar fraction of kava extract 12 days prior to, during and after the administration of dimethylhydrazine, a colon-specific carcinogen, had a significant reduction in precancerous lesions [aberrant crypt (AC) foci (ACF)] as well as large ($\geq$ 4 AC/ACF) sialomucin-only expressing foci, an indicator of greater tumorigenic potential, compared to the control group (Triolet et al. 2012). Groups fed the ethanolic kava extract and polar kava fraction trended toward reductions in ACF and large sialomucin-only expressing foci. The combined kava groups had significantly fewer total AC, ACF, large ACF and large sialomucin-only expressing foci compared to the control group. Histological examination found no hepatic lesions in animals consuming the kava diets.

Studies by Leitzman et al. (2014) demonstrated the outstanding efficacy of kava in preventing 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone (NNK)-induced lung tumorigenesis in A/J mice with high selectivity for the initiation stage in association with the reduction of O^6-methylguanine adduct in DNA. Kava treatments covering the initiation stage reduced the multiplicity of lung adenomas by approximately 99 %. A minimum effective dose was not defined because kava at two lower dosages (2.5 and 1.25 mg/g of diet) were equally effective as 5 mg/g of diet in completely inhibiting lung adenoma formation. Dihydromethysticin from kava completely

suppressed tobacco carcinogen 4-(methylnitrosamino)-1-(3-pyridyl)-1-butanone-induced lung tumorigenesis and differentially reduced DNA damage in A/J mice (Narayanapillai et al. 2014a). Flavokawain A (FKA) from kava induced apoptosis in two breast cancer cell lines, MCF-7 and MDA-MB231, and inhibited the metastatic process in-vitro (Abu et al. 2014). FKA also halted the migration and invasion process in MDA-MB231.

Antiinflammatory Activity

Five known kawapyrones, 5,6-dehydrokawain (isolated yield: 0.12 %), dihydrokawain (0.35 %), kawain (0.47 %), yangonin (0.22 %) and methysticin (5.66 %) along with a new kavapyrone, 7,8-epoxyyangonin (6) (0.0059 %) isolated from the methanol extract of dried kava powder were tested for TNF-α (tumor necrosis factor-α) release assay from BALB/3 T3 cells treated with okadaic acid, a tumor promoter (Hashimoto et al. 2003). 5,6-Dehydrokawain (desmethoxyyangonin) (1) and yangonin (4) significantly inhibited TNF-α release with IC_{50} values of 17 μM and 40 μM; a potency as great as (−)-epigallocatechin gallate (EGCG) isolated from green tea extract. Among the kavapyrones, dihydrokawain was unique in showing the strongest inhibitory activity against TNF-α release in mice, but the weakest activity in the cells. Studies by Folmer et al. (2006) found that 320 μM (flavokavain A), 175 μM (flavokavain B) and 870 μM (kavain and dihydrokavain) inhibited both NF-kappa B-driven reporter gene expression and TNF alpha-induced binding of NF-kappaB. Moreover, kavain and flavokavains A and B treatment led to inhibition of both inhibitors of kappaB (IkappaB) degradation and subsequent translocation of p50 and p65 NF-kappa B subunits from the cytoplasm to the nucleus. Further, kinase selectivity screening demonstrated that flavokavain A, but not kavain, nor flavokavain B, inhibited the IkappaB kinase (IKK) as well as PRAK (p38-regulated/activated kinase), MAPKAP-K3 (MAPK-activated protein kinase 3), DYRK1A (dual-specificity tyrosine-phosporylated and regulated kinase 1A) and Aurora B. Altogether, the results elucidated the anti-inflammatory mechanisms triggered by traditionally used chemopreventive kava compounds for inflammatory diseases and asthma.

Of the kava-derived compounds tested in-vivo, kavain was found to render mice immune to lethal doses of lipopolysaccharide (Pollastri et al. 2009). Kavain demonstrated promising pharmaceutical properties, including good solubility and high cell permeability, but pharmacokinetic experiments in mice showed relatively rapid clearance. Of the kavain analogues synthesized, a ring-opened analog of kavain inhibited TNF-alpha secretion in THP-1 cell-based assay and suppressed lipopolysaccharide-induced TNF-alpha factor expression in the same cells, whereas the other compounds inhibited TNF-alpha secretion without affecting lipopolysaccharide-induced TNF-alpha factor levels, indicating a potential divergence in mechanism of action. Flavokawain A, from kava extract, significantly suppressed expression of iNOS and COX-2, as well as the subsequent production of NO and PGE_2 in the LPS-stimulated RAW 264.7 cells (Kwon et al. 2013). Flavokawain A significantly inhibited LPS-induced activation of NF-κB and AP-1 signaling pathways. The results suggested that flavokawain A may exert anti-inflammatory responses by suppressing LPS-induced expression of pro-inflammatory mediators via blockage of NF-κB-AP-1-JNK/p38 MAPK signaling pathways in the murine macrophages. Studies showed that a kavalactone derivative2′,6′-dichloro-5-methoxymethyl-5,6-dehydrokawain inhibited lipopolysaccharide-stimulated iNOS induction and NO production through activation of Nrf2 signaling in BV2 microglial cells (Terazawa et al. 2013). The data suggested that the compound had a potential to reduce neuroinflammation as well as oxidative stress in neurodegenerative diseases through activation of Nrf2 signaling.

Central Nervous Sytem (CNS) Activity

Animal studies showed that kava lactones altered neuronal excitation through direct interactions with voltage-dependent ion channels, giving rise

to kava's muscle relaxant, anaesthetic, anxiolytic and anticonvulsive properties (Cairney et al. 2002). Several isolated cases of psychotic and severe dystonic reactions following kava use suggested that kava also had psychoactive properties, yet there was no conclusive evidence to-date that kava interfered with normal cognitive processes. Although the psychotropic and neuroprotective mechanisms of the rhizome are not well elucidated, numerous studies had indicated that kava pyrones may exert their effects by activating several neurotransmitter systems, such as the adrenergic (Seitz et al. 1997b), mesolimbic dopaminergic (Baum et al. 1998), gabaminergic (Jussofie et al. 1994), glutamatergic (Schmitz et al. 1995; Schmidt and Ferger 2001; Gleitz et al. 1996a,b) and serotonergic receptor systems (Walden et al. 1997b; Boonen et al. 1998). An extract of the rhizome containing 58 % kava pyrones enhanced the binding of [^{3}H]muscimol to γ-aminobutyric acid-A receptors in a concentration-dependent manner in rat hippocampus, amygdala and medulla oblongata in-vitro (ED_{50} 200–300 µmol/l) (Jussofie et al. 1994). Contrariwise the study by Davies et al. (1992) found no significant interaction in-vitro or in-vivo of a dichloromethane rhizome extract or kava pyrones with γ-aminobutyric acid (A and B) or benzodiazepine receptor binding sites. Seitz et al. (1997b) showed that (+/−)-Kavain and (+)-kavain potently inhibited the uptake of [3H]-noradrenaline in synaptosomes prepared from the cerebral cortex and hippocampus of rats. Uptake of [3H]-noradrenaline was inhibited in the following order of potency: (+/−)-kavain = (+)-kavain > (+)-methysticine, whereas none of the kava pyrones efficiently blocked the uptake of [3H]-serotonin. The results indicated a pyrone-specific non-stereo-selective inhibition of the [3H]-noradrenaline uptake which might be responsible for or, at least, contribute to the psychotropic properties of kava pyrones. Both kawain and dihydromethysticin reduced the field potential changes induced by the serotonin-1A agonist, ipsapirone, in the CA1 and CA3 areas of guinea-pig hippocampal slices in-vitro (Walden et al. 1997a. The ipsapirone response was reduced by extracellular administration of kavain and dihydromethysticin in a dose-dependent manner down to 22.2 and 33.6 %, respectively. Intragastric administration of (+)-dihydromethysticin in a single dose (100 mg/kg body weight) or chronic intragastric administration of (±)-kawain (10.8 mg/kg body weight) daily for 78 days to rats did not alter dopamine or serotonin levels in the striatal or cortical brain regions (Boonen et al. 1998).

Dinh et al. (2001) found that the most potent binding inhibition was observed for kava leaf extracts to GABAA receptors (GABA binding site) with IC_{50} values of approximately 3 µg/ml, whereas root extracts were less active with $IC5_0$ values ranging from 5 µg/ml (Nene) to 87 µg/ml (Mahakea). The leaf extracts generally contained lower amounts of the kavalactones than the root extracts, indicating the existence of additional substances responsible for these activities. Leaf extracts also inhibited binding to dopamine D2, opioid (mu and delta) and histamine (H1 and H2) receptors more potently than the corresponding root extracts with IC_{50} values ranging from 1 to 100 µg/ml vs. > or = 100 µg/l, respectively. Significant differences in the potential of binding inhibition were also observed between cultivars. Binding to serotonin (5-HT6 and 5-HT7) and benzodiazepine receptors was only weakly inhibited by both root and leaf extracts of all four kava cultivars. Among the kava lactones tested, only yangonin exhibited affinity for the human recombinant CB_1 receptor ligand with a $K_i = 0.72$ µM and selectivity vs. the CB_2 receptor ($K_i > 10$ µM) (Ligresti et al. 2012). None of the compounds exhibited strong inhibitory effects on the two enzymes fatty acid amide hydrolase (FAAH) and monoacylglycerol lipase (MAGL) analyzed. The CB_1 receptor affinity of yangonin suggested that the endocannabinoid system might contribute to the complex human psychopharmacology of the traditional kava drink and the anxiolytic preparations obtained from the kava plant.

Anxiolytic Activity

In-Vitro Studies

Studies using hippocampal slice preparation of guinea pigs by Walden et al. (1997a) suggested

that single constituents of *Piper methysticum* may have additive actions; two kava components kawain and dihydromethysticin may enhance the effects of the anxiolytic serotonin-1A agonist ipsapirone and activation of NMDA receptors and/or voltage dependent calcium channels may be involved in the elementary mechanism of action of some kava-pyrones. A small dose of kava extract (20 mg/kg body weight i.p.) caused changes in rat behaviour and concentrations of dopamine in the nucleus accumbens (Baum et al. 1998). Higher doses (120 mg/kg i.p.) increased the levels of dopamine. With respect to the individual compounds, D,L-kawain induced in low doses a decrease in dopamine levels and in higher amounts either an increase or no change in dopamine concentrations. Yangonin resulted in a decrease of dopamine levels to below the detection limit and desmethoxyyangonin in an increase of dopamine levels. Dihydrokawain, methysticin and dihydromethysticin did not produce any significant changes of dopamine levels. D,L-kawain caused a decrease in 5-HT concentrations. Some of the other kavapyrones affected 5-HT levels as well. The results suggested that the relaxing and slightly euphoric actions may be caused by the activation of the mesolimbic dopaminergic neurones. Changes in the activity of 5-HT neurones could explain the sleep-inducing action. Studies by Langosch et al. (1998) found (+/−)-kavain to be an effective drug in modulating excitatory signals in the hippocampus of guinea pigs. In their paper, Nowakowska et al. (1998) concluded that kava-kava may be a useful alternative for synthetic anxiolytics.

Animal Studies

Aqueous kava root extracts were shown to have a depressant action on the central nervous system, evidenced by depression of spontaneous motor activity, marked reduction in irritability of rats having bilateral septal lesions, inhibition of the conditioned avoidance response in rats and blockade of EEG arousal patterns in cats (Furgiuele et al. 1965). Both chlordiazepoxide and kava extract (containing 30 % kavalactones), kavain, dihydrokavain, methysticin, dihydromethysticin, yangonin or desmethoxyyangonin (30 mg/ml per kg for kava compounds) attenuated separation-induced distress vocalizations and stress-induced analgesia in 8-day-old chicks (Smith et al. 2001). Dihydrokavain attenuated separation-induced distress vocalizations. Studies showed that administration of a kava preparation LI 150 to Wistar rats exhibited anxiolytic like behaviour similar to diazepam (15 mg/kg p.o.) in the elevated plus maze test (Rex et al. 2002). Using the chick social separation-stress procedure as an anxiolytic bioassay, *P. methysticum* samples containing 12.8–100.0 % total kavalactones in experiment 1 attenuated distress vocalizations in a concentration-dependent manner (Feltenstein et al. 2003). *P. methysticum* fractions that contained the highest concentration of dihydrokavain attenuated distress vocalizations in a manner equivalent to that of chlordiazepoxide in separate experiments. Kava extract samples and fractions that possessed anxiolytic properties did not possess the sedative properties found in chlordiazepoxide. Collectively, the findings suggested that dihydrokavain may be necessary and sufficient in mediating the anxiolytic properties of *P. methysticum* extract.

Kava extract produced statistically significant dose-dependent anxiolytic-like behavioral changes in BALB/cByJ inbred mice in both the mirrored chamber avoidance and elevated plus-maze assays of anxiolysis (Garrett et al. 2003). ED_{50} values for kava-induced increases in time spent inside the mirrored chamber and on the open arms of the plus maze were 125 mg/kg and 88 mg/kg, respectively. Kava extract also caused a profound decrease in locomotor activity (ED(50) of 172 mg/kg). Flumazenil, a competitive benzodiazepine receptor antagonist, blocked both the anxiolytic and sedative effects of diazepam, but had no effect on kava's behavioral actions. The results showed that kava anxiolytic and sedative effects were not mediated through the benzodiazepine binding site on the GABA(A) receptor complex. In animal studies, Bruner and Anderson (2009) found dose-dependent substitu-

tion of the anxiolytic chlordiazepoxide (CDP) by kava extracts. Partial substitution of kava extract for CDP suggested that kava may share a mechanism of action similar to CDP, but was less potent.

Clinical Studies

Two placebo-controlled trials investigated the effect of standardized Kava extracts in women with climacteric psychosomatic disturbances (Warnecke et al. 1990; Warnecke 1991). In the first study involving 40 such women, kava extract (200–400 mg extract = 30–60 mg kava pyrones) for 8 weeks was found to be superior to the placebo using the Kuppermann Index and Anxiety Status Index. In the second randomized, placebo-controlled double-blind study, two groups each containing 20 patients with climacteric-related symptomatology were treated for a period of 8 weeks with kava WS 1490 extract 3 × 100 mg/day or a placebo preparation. The Hamilton Anxiety Scale (HAMA) overall score of anxiety symptomatology revealed a significant difference in the kava-receiving group compared to the placebo group already after only 1 week of treatment. The course of such further parameters as depressive mood (DSI), subjective well-being (patient diary), severity of the disease (CGI) and the climacteric symptomatology (Kuppermann Index and Schneider scale) over the overall period of treatment demonstrated a high level of efficacy of kava extract WS 1490 in neurovegetative and psychosomatic dysfunctions in the climacteric, associated with very good tolerance of the preparation. A randomized, double-blind pilot study investigated the effects of the extract containing 15 % kava pyrones in 59 patients with pre-operative anxiety (Bhate et al. 1989). Although improvements in mood were observed using a psychostatus score, only two doses of the extract (equivalent to 60 mg kava pyrones daily) were administered, and thus the clinical significance of this study was questionable.

In a placebo-controlled double-blind study of 29 patients with anxiety syndromes, treatment with 100 mg of WS 1490 three times a day significantly reduced anxiety symptoms after 1 week; no adverse effects were noted during the 4-week treatment (Kinzler et al. 1991). In a one 6-month, double-blind study compared kava was found to be just as effective as two standard anxiety benzodiazepine drugs (oxazepam and bromazepam) in 174 people with anxiety symptoms (Woelk et al. 1993). Improvement in Hamilton Anxiety Scale (HAMA) scores was about the same in all groups. A 4 weeks, randomized, placebo-controlled double-blind study of 58 patients also assessed the efficacy of WS 1490 extract containing 70 % kava pyrones for the treatment of anxiety of non-psychotic origin (Lehmann et al. 1996). The Hamilton Anxiety Scale (HAMA) overall score of anxiety symptomatology revealed a significant reduction in the kava group compared with the placebo group after 1 week of treatment. The results of the secondary target variables were in agreement with the HAMA score and demonstrated the efficacy of WS 1490 in patients with anxiety disorders. In another randomized placebo-controlled 25-week outpatient trial of 101 outpatients suffering from anxiety of non-psychotic origin (Diagnostic and Statistical Manual of Mental Disorders (DSM) -III-R criteria: agoraphobia, specific phobia, generalized anxiety disorder and adjustment disorder with anxiety), treatment with kava-kava extract WS 1490 was found to be superior over placebo from week 8 onwards in the Hamilton Anxiety Scale (HAMA) (Volz and Kieser 1997). WS 1490 was also found to be superior with respect to the secondary outcome variables. The results supported WS 1490 as a treatment alternative to tricyclic antidepressants and benzodiazepines in anxiety disorders. In an outpatient observation study of 52 outpatients suffering from anxiety of nonpsychotic origin, the treatment of kava extract was found to be as an effective and safe alternative to antidepressants and tranquilizers in anxiety disorder without the tolerance problems associated with benzodiazepines (Scherer 1998). The results of a randomised study of 40 women in physiological or surgical menopause for the past 1–12 years showed that the association of

hormone replacement therapy (HRT) and kava-kava extract may represent an excellent therapeutic tool for the treatment of women in stabilized menopause, in particular those suffering from anxiety and depression, given that kava-kava therapy accelerated the resolution of psychological symptoms without diminishing the therapeutic action of estrogens on organic disease, such as osteoporosis and cardiovascular disease (De Leo et al. 2000).

Malsch and Kieser (2001) conducted a 5-week randomised, placebo-controlled, double-blind study to investigate the efficacy of kava-kava special extract WS1490 in 40 patients with non-psychotic nervous anxiety, tension and restlessness states. The study confirmed the anxiolytic efficacy and good tolerance of WS1490 over placebo and showed that a further symptom reduction was possible after a change over from benzodiazepine treatment. Studies by Watkins et al. (2001) suggested that kava might exert a favourable effect on reflex vagal control of heart rate in generalized anxiety disorder patients. Significantly more patients treated with kava showed improved baroreflex control of heart rate (BRC) compared to the placebo group. Further, the magnitude of improvement in BRC was significantly correlated with the degree of clinical improvement. In a 3-month randomized prospective open study of perimenopausal women, the administration of kava-kava plus calcium elicited an improvement of mood, particularly of anxiety (Cagnacci et al. 2003). Gastpar and Klimm (2003) investigated the efficacy and tolerability of 150 mg/day kava special extract WS 1490 versus placebo in a randomized, placebo-controlled, double-blind multicenter study in 41 adult, male and female out-patients suffering from neurotic anxiety wherein patients received 3 × 1 capsule of 50 mg/day WS 1490 or placebo for 4 weeks, followed by 2 weeks of observation without study-specific treatment. The results showed consistent advantages for WS 1490 over placebo in several psychiatric scales and indicated significant improvements in the patients' general well-being, the differences versus placebo were not as large as in previous trials which employed 300 mg/d of the same extract. WS 1490 was well tolerated, with no influence on liver function tests and only one trivial adverse event (tiredness) attributable to the study drug. In a 3-week placebo-controlled, double-blind crossover trial that recruited 60 adult participants with 1 month or more of elevated generalized anxiety, administration of 5 kava tablets per day containing 250 mg of kavalactones/day, produced significant anxiolytic and antidepressant activity and raised no safety concerns at the dose and duration studied (Sarris et al. 2009b). Kava appeared equally effective in cases where anxiety was accompanied by depression. In another 3-week placebo-controlled, double-blind, cross-over trial involving 60 adult participants (18–65) with elevated stable anxiety and varying levels of depressive symptoms, kava preparation exerted significant anxiolytic effects and appeared safe (Sarris et al. 2009a). In a randomized, placebo-controlled, double-blind study of 22 moderately anxious adults aged between 18 and 65 years, kava administration was found to have no negative effect on cognition, whereas a reduction in alertness occurred in the oxazepam condition (Sarris et al. 2012). Genetic analyses provided tentative evidence that noradrenaline (SLC6A2) transporter polymorphisms may have an effect on response to kava. They concluded that acute "medicinal level" doses of the particular kava cultivar in naive users did not provide anxiolytic activity, although the phytomedicine also appeared to have no negative effects on cognition.

In a more recent 6-week double-blind, randomized, placebo-controlled study of 75 participants with generalized anxiety disorder (GAD) and no comorbid mood disorder, treatment with kava produced a significant reduction in anxiety compared with the placebo group with a moderate effect size (Sarris et al. 2013b). Among participants with moderate to severe Diagnostic and Statistical Manual of Mental Disorders-diagnosed GAD, this effect was larger. The data suggested that standardized kava may be a moderately effective short-term option for the treatment of GAD. Furthermore, specific γ-aminobutyric acid (GABA) transporter polymorphisms appeared to

potentially modify anxiolytic response to kava. In another 6-week, double-blind, randomized controlled trial (n = 75) involving chronic administration of kava or placebo for participants with generalized anxiety disorder, no significant differences were found across groups for liver function tests nor were there any significant adverse reactions that could be attributed to kava (Sarris et al. 2013c). Interesting, kava significantly increased female's sexual drive compared to placebo on a sub-domain of the Arizona Sexual Experience Scale (ASEX), with no negative effects seen in males. Further, it was found that there was a highly significant correlation between ASEX reduction (improved sexual function and performance) and anxiety reduction in the whole sample.

Meta-analysis/Review Studies

In a meta-analysis of 11 randomised, controlled trials (RCTs), i.e. trials with a randomised generation of allocation sequences, and conducted placebo-controlled and double-blind, i.e. trials with blinding of patients and care providers and involving a total of 645 participants, Pittler and Ernst (2003) found that kava extract appeared to be an effective symptomatic treatment option for anxiety compared to placebo. The data available from the reviewed studies suggested kava to be relatively safe for short-term treatment (1–24 weeks), although more information was required. In a comprehensive review of efficacy, safety and psychopharmacology, Sarris et al. (2011) found that current evidence supported the use of kava in treatment of anxiety with a significant result occurring in four out of six studies reviewed. It was suggested that more studies were required to assess comparative efficacy and safety (on the liver, cognition, driving and sexual effects) versus established pharmaceutical comparators.

Sedative/Analgesic/Anaesthetic/ Anti-insomnia Activities

The local anaesthetic activity of kava was first observed by Lewin (1886). Kava had been reported to possess and to potentiate and prolong barbiturate narcosis (Frater 1958; Klohs et al. 1959; Meyer 1962; Meyer and May 1964). Frater (1958) demonstrated that a thin paste of kava powder applied to the lip mucous membrane produced a slightly burning sensation and a feeling of numbness when some kava roots were chewed for 15 min found the degree of anaesthesia was greater. Steinmetz (1960) described the narcotic effects of kava as a paralysis of the nervous system, through reduction of spinal rather than cerebral activity, followed by muscular stimulation and then paralysis particularly affecting the lower limbs. Also noted was a reduction of the cardiac rhythm followed by stimulation and slowing down of respiration. Steinmetz also stated that ingestion of a strong dose would affect eye vision, causing pupil dilation and inducing photophobia. A gel containing 6 % kava root crude extract called kavacaine was found to have potent topical anaesthetic effect (Morse and Sharma 2005). Administration of dihydromethysticin to mice potentiated pentobarbital-induced sleeping time by 400 %, while dihydrokawain, yangonin and kawain were only moderately active (150–235 %) (Klohs et al. 1959). Both dihydrokawain and dihydromethysticin exhibited analgesic effects when administered intraperitoneally to rats (140 mg/kg body weight), as determined by an increase in tail-flick reaction times (Brüggemann and Meyer 1962). Meyer (1962) found that administration of 150 mg/kg of hexobarbital sodium to white mice afforded 2 h of sleep. However, pretreament with 240 mg/kg dihydromethysticin induced 72 h of sleep. Meyer and May (1964) found all the kava lactones acted as local analgesics. Most of the kava lactones inhibited frog heart contraction. These actions were comparable to cocaine which also protected against ventricular fibrillation through its local anaesthetic effect. Dihydroymethysticin and dihydrokavain had been shown to intensify sleep-inducing effects (Hänsel 1968). Both compounds were found to be comparable to the drug dimethylaminophenazone in producing an analgesic effect in the drinker. The analgesic effect was found to be stronger than aspirin but weaker then morphine. Kavain had been shown to produce local aesthetic effect that was comparable to cocaine and do not produce any toxicity in the tissues (Kretzschmar and Meyer 1969).

The extent of frog sartorius muscle paralysis induced by kava was similar in both directly and indirectly stimulated mouse hemidiaphragms (Singh 1983). Intracellular recordings from frog sartorius muscles showed that kava depressed the amplitude of both miniature end-plate potentials (mepps) and end-plate potentials (epps) but had no effect on the frequency of mepps. Kava greatly prolonged the duration of mepps and epps and also slowed and depressed directly elicited muscle action potentials. The neuromuscular blockade produced was poorly reversed by calcium and by neostigmine. It was concluded that kava caused paralysis by mechanisms similar to local anaesthetics. Both the intoxicating beverage kava and the lipid soluble (kava resin) extracts showed analgesic effects in both tail immersion and abdominal constriction in mice (Jamieson and Duffield 1990b). Eight purified pyrones from the lipid soluble extract were also tested for activity in the tail immersion test, and kawain, dihydrokawain, methysticin and dihydromethysticin were found to be very effective in producing analgesia. Naloxone, in doses which inhibited morphine-induced analgesia in both tests, was indicating that analgesia produced by kava occurred via non-opiate pathways. The synthesized analogues of synthetic kavain, 6-(4-fluorophenyl)-4-methoxy-5,6-dihydropyran-2-one exerted potent and dose-dependent analgesic activity, inhibiting abdominal constrictions caused by acetic acid in mice, and being more active than some reference drugs (Kormann et al. 2012). It also presented activity in the other models of pain, with the exception of the hot plate test and the measurement of motor performance.

The lipid soluble extract of the psychoactive beverage kava was found to have hypnosedative properties which could be measured by the length of time that the righting reflex was lost (Jamieson and Duffield 1990a). Ethanol and the lipid soluble extract (kava resin) was shown greatly to increase each others' hypnotic action in mice. Ethanol also increased the toxicity of kava markedly. This interaction of kava and alcohol possessed important clinical and social consequences since, in contrast to traditional usage, kava had been reported to be taken in conjunction with alcoholic drinks. Psychopharmacological effects of kava had also been reported and the mood-altering effects of kavalactones had been described as hypnotic (Schultes and Hoffman 1992). The pharmacological properties of kavalactones were comparable to those of benzodiazepines, however, kavalactones bind very weakly to the gamma-aminobutyric acid (GABA) and benzodiazepine (Bilia et al. 2002). It was proposed that N-methyl-D-aspartate receptors and/or voltage dependent calcium channels may also be involved in the elementary mechanism of action. Only weak activity of kava resin was observed on GABAA binding sites washed synaptosomal membranes prepared from rat brain and this was abolished by extraction of the membranes with Triton X-100, suggesting that lipid soluble components were involved (Davies et al. 1992). No effects were observed on GABAB binding sites in rat brain membranes in-vitro. Kava resin and pyrones exerted some weak effects on benzodiazepine binding in-vitro but this did not correlate with pharmacological activity. In addition, in ex-vivo studies, no effects were observed on [3H] diazepam binding to brain membranes prepared from mice in which selected kava constituents were injected intraperitoneally, whereas similarly administered diazepam (5 mg/kg) inhibited [3H] diazepam binding by greater than 95 %. Similar lack of activity was observed in in-vivo binding studies; injection of kava resin failed to influence the CNS binding of the benzodiazepine-receptor ligand [3H]Ro15-1788 injected into mice prior to sacrifice. The pharmacological activities of kava resin and pyrones did not appear to be elucidated by any significant interaction with GABA or benzodiazepine binding sites. Studies by Jussofie et al. (1994) indicated that one way kavapyrone-enriched kava extract might mediate sedative effects in-vivo was through effects on gamma-aminobutyric acid (GABA*)* receptor binding. The sedative effect was demonstrated using membrane fractions obtained from target brain centers of kavapyrone action: hippocampus (HIP), amygdala (AMY) and medulla oblongata (MED), and from brain centers outside the main kavapyrone effects as frontal cortex (FC) and cer-

ebellum (CER). At a kavapyrone concentration of 500 μM, the order of enhancement in binding sites (Bmax) was HIP = AMY > MED > FC > CE R. When kavapyrones were included together with pentobarbital or 3-alpha-hydroxy-5-alpha--pregnane-20-one (HPO), the two classes of compounds produced a synergetic effect on [3H] muscimol binding.

In a double-blind, placebo-controlled study, the encephalotropic and psychotropic effects of kavain-a synthetic kava plant derivative as compared with clobazam were investigated in 15 normal volunteers, utilizing EEG brain mapping, psychometric and psychopysiological analyses (Saletu et al. 1989). Brain maps of drug induced pharmaco-EEG changes (pharmaco-EEG maps) demonstrated that kavain exerted a significant action on the human brain function as compared with placebo characterized by a dose-dependent increase of delta, theta and alpha 1 activity while alpha 2, beta activity and the centroid of the total activity decreased. These findings were indicative of a sedative effect which was, however, in type quite different from that of the 1,5-benzodiazepine. Further, 200 mg kavain induced with a decrease of delta and beta activity and an increase of alpha activity and of total power also vigilance promoting effects. Kavain improved the noopsyche as compared with placebo in all three doses as there was a significant improvement in intellectual performance (Pauli test), attention, concentration, reaction time and motor speed (rigidity test), while opposite findings were observed after 30 mg clobazam. In regard to thymopsychic variables such as drive, wakefulness, affectivity, mood and well-being, 200 mg kavain produced an improvement as compared with placebo while 600 mg kavain produced sedation as did 30 mg clobazam.

Dihydroymethysticin and dihydrokavain had been shown to intensify sleep-inducing effects (Hänsel 1968). Both compounds were found to be comparable to the drug dimethylaminophenazone in producing an analgesic effect in the drinker. The analgesic effect was found to be stronger than aspirin but weaker than morphine. Kavain had been shown to produce local aesthetic effect that was comparable to cocaine and do not produce any toxicity in the tissues (Kretzschmar and Meyer 1969). Examination of EEG recordings during sleep of healthy volunteers given a single dose of 300 mg extract (equivalent to 210 mg kava pyrones) showed an increased sleep spindle density of 20 % and an increase in slow-wave sleep (i.e. deep sleep), but the rapid eye movement phase was not suppressed (Emser and Bartylla 1991). Daily doses of 300 or 600 mg extract (equivalent to 210 or 420 mg kava pyrones), respectively, for 1 week increased the beta/alpha index typical for the pharmaco-EEG profile of anxiolytics without the sedative-hypnotic effects associated with benzodiazepines. The increase in beta activity was most marked in the $beta_2$ range (Johnson et al. 1991). In two studies, administration of 300 mg kava extract WS 1490 (equivalent to 210 mg kava pyrones) daily for either 8 or 14 days to healthy volunteers, taken with or without ethanol, had no potentiating or additive effect and had no influence on the safety-related performance of healthy volunteers (Herberg 1991, 1993). In another study administration of kava extract standardized to contain 30 % kava pyrones, bromazepam or a combination of extract and bromazepam, safety-related performance remained unaffected in healthy volunteers treated daily with 400 mg extract (equivalent to 120 mg kava pyrones for 14 days), whereas it was impaired after treatment with bromazepam (9 mg daily) or the extract/bromazepam combination (Herberg 1996). No differences were observed following treatment with bromazepam or the combination, indicating that the extract did not have an additive effect when given in combination with bromazepam. In a separate, randomized, double-blind crossover study involving 12 healthy volunteers, administration of daily single doses of a kava extract standardized to contain 30 % kava pyrones (400 mg extract containing 120 mg kava pyrones) was compared with daily single doses of diazepam (10 mg) or a placebo in a 7-day trial (Gessner and Cnota 1994). Changes in EEG recordings and psychometric test results showed no evidence of a decrease in vigilance in the group treated with the extract. Following administration of kava-kava extract at a dose of 300 mg/kg, a sig-

nificant shortening of the sleep latency in sleep-disturbed rats was observed while no effects were observed on the total waking and non-rapid eye movement (non-REM) sleep time (Shinomiya et al. 2005). In contrast, flunitrazepam showed a significant shortening in sleep latency, decrease in total waking time and increase in total non-REM sleep time. Although the effects of flunitrazepam were antagonized by the benzodiazepine receptor antagonist flumazenil, the effect of kava-kava extract was not antagonized by flumazenil. Kava-kava extract showed a significant increase in delta activity during non-REM sleep in sleep-disturbed rats, whereas a significant decrease in delta power during non-REM sleep was observed with flunitrazepam. The results showed that Kava-kava had not only hypnotic effects but also sleep quality-enhancement effects.

Two fractions, F1 and F2, from kava extract were found to decrease spontaneous motor activity in doses which did not alter forced motor activity of mice (O'Hara et al. 1965). Fraction F2, dihydromethysticin, desmethoxy-yangonin and kawain exhibited potent antiserotonin activity on the isolated rat uterus, whereas F1 appeared to be devoid of antiserotonin activity. F1, F2 and dihydromethysticin did not alter serotonin brain levels in mice. Intraperitoneal (i.p.) adminstration of an aqueous extract of kava (62.5 mg/kg body weight) caused a loss of spontaneous activity without loss of muscle tone in mice (Jamieson et al. 1989). No hypnotic effect was seen, but some analgesia was produced. The anticonvulsant effect against strychnine was very slight and there was no evidence of local anesthetic action. There was a slight anti-apomorphine effect and tetrabenazine-induced ptosis was decreased. The lipid-soluble extract (kava resin) also decreased spontaneous motility and markedly reduced motor control (Jamieson et al. 1989). Hypnosis, determined by loss of righting reflex, was produced, analgesia was marked, and a local anesthetic action was evident. Kava resin also decreased apomorphine-induced hyper-reactivity and partially reversed tetrabenazine-induced ptosis in rats. Kava resin produced a greater range of pharmacological actions than the aqueous extract, and the latter was orally inactive in mice and rats. The aqueous, pyrone-free extract from kava and the lipid-soluble extract (kava resin) reduced amphetamine-induced hypermotility (Duffield et al. 1989b). Aqueous kava extract in i.p. doses of 30 mg/kg to 500 mg/kg had no effect on conditioned avoidance responses. At or below 100 mg/kg i.p., kava resin also failed to modify the number of conditioned avoidance responses obtained. However, 125 mg/kg of resin significantly reduced the number of conditioned avoidance responses by 18 %. Increasing the dose of kava to 150 mg/kg caused ataxia and sedation. A minimally effective daily dose (50 mg/kg) of the aqueous kava extract for 3 days was sufficient to produce tolerance to a test dose of 150 mg/kg, which was close to the ED_{50} (Duffield and Jamieson 1991). Kava resin decreased spontaneous motility and caused a loss of muscle control. A minimally effective daily dose of kava resin (100 mg/kg) did not produce tolerance to the above effects of a weekly test dose of kava resin (166 mg/kg) within 7 weeks. Increasing the dose to 150 mg/kg twice daily caused partial tolerance to occur within 3 weeks, but very little further tolerance developed over the ensuing 2-week period. Intraperitoneal administration of an extract of kava rhizome (equivalent to 50–100 mg kava pyrones/kg body weight) or (±)-kawain, a synthetic kava lactone (10–50 mg/kg body weight), reduced muscle tone in cats (Holm et al. 1991). Intraperitoneal administration of kava rhizome (equivalent to 50–100 mg kava pyrones/kg body weight) to cats had a significant effect on EEG recordings, inducing high-amplitude delta waves, spindlelike formation and continuous alpha- or beta-synchronization in amygdala recordings. Hippocampal responses, following stimulation of the amygdala nucleus, increased significantly in amplitude in cats treated intraperitoneally with the rhizome extract or (±)-kawain.

Anticonvulsant Activity

Intraperitoneal administration of an aqueous extract (300 mg/kg body weight) or a chloroform extract (140 mg/kg body weight) of the rhizome to mice-inhibited strychnine-induced convulsions (Klohs et al. 1959). The anticonvulsant

activity of methysticin and other kava pyrones against electroshock- and chemically induced seizures has been demonstrated in mice and rats (Keller and Klohs 1963; Meyer and Meyer-Burg 1964; Kretzschmar and Meyer 1969; Kretzschmar et al. 1970). Intraperitoneal administration of dihydromethysticin and dihydrokawain inhibited electroshock-induced seizures at doses of 25 and 60 mg/kg body weight, respectively, in mice and rats (Meyer and Meyer-Burg 1964). Dihydrokavain and dihydromethysticin inhibited muscular contractions and the effect was found to be comparable to those of synthetic products such as phenobarbital (Kretzschmar and Meyer 1969). Dihydromethysticin was reported to have strong anticonvulsant action with the capability of inhibiting convulsions caused by strychnine in animals (Kretzschmar et al. 1970). Both compounds were reportedly more superior to benzodiazepine as muscle relaxants. It had been suggested that the anti-epileptic action of dihydryomethysticin may be used to treat schizophrenia. Isolated kavain, methysticin, dihydromethysticin and yangonin showed strong centrally mediated muscle relaxing activity in rabbits and yangonin was the most potent kavalactone (Kretzschmar et al. 1971). Studies had shown kava pyrones to be anticonvulsive (Gleitz et al. 1996b). The anticonvulsive action of (+/−)-kavain was estimated from its properties on stimulated synaptosomes and Na^+ channel receptor sites. The results suggested an interaction of (+/−)-kavain with voltage-dependent Na^+ and Ca^{2+} channels, thereby suppressing the 4-aminopyridine-induced increase in [Na^+]i, [$Ca2^+$]i and the release of endogenous glutamate. (+/−)-Kavain specifically and rapidly inhibited veratridine-activated voltage-dependent Na^+-channels in synaptosomes prepared from rat cerebral cortex (Gleitz et al. 1995). Further they found that (+/−)-kavain inhibited the veratridine-induced and KCl-induced increase in intracellular Ca^{2+} and glutamate-release of rat cerebrocortical synaptosomes (Gleitz et al. 1996a). The results suggested that (+/−)-kavain at concentrations sufficient to block Na^+ channels completely, moderately inhibited the non-inactivating Ca^{2+} channels located on mammalian presynaptic nerve endings. In rat temporal cortex slices containing the hippocampus and the entorhinal cortex, methysticin in a concentration range of 10–100 μM reversibly blocked all types of epileptiform activity (Schmitz et al. 1995). While responses to alvear stimulation were largely unaffected by methysticin, the responses to a paired pulse stimulus to stratum radiatum were depressed over the whole range of tested stimulus intervals. The findings suggested that methysticin had effects on different patterns of epileptiform activity possibly by interfering with processes responsible for frequency potentiation. Both (±)-kawain and methysticin inhibited voltage-dependent sodium channels in rat CA1 hippocampal neurons in-vitro (1–400 μmol/l) (Magura et al. 1997). In cultured dorsal root ganglion cells derived from neonatal rats, Schirrmacher et al. (1999) found that (+/−)-kavain reduced currents through voltage-activated Na^+ and Ca^{2+} channels.

Kava pyrones were reported to exert effects on neuronal transmission and transmembraneous cation currents similar to established mood stabilizers like carbamazepine, valproate and lamotrigine (Grunze et al. 2001). Findings of studies suggested that (i) kava pyrones had a weak Na^+ antagonistic effect that may contribute to their antiepileptic properties; (ii) they had pronounced L-type Ca^{2+} channel antagonistic properties and acted as a positive modulator of the early K^+ outward current; two actions of importance for mood stabilization; (iii) kava pyrones had additive effects with the serotonin-1A agonist ipsapirone probably contributing to their anxiolytic and sleep-inducing effects; and (iv) kava pyrones showed a distinct pattern of action on glutamatergic and GABAergic transmission without affecting long-term potentiation. It was found that kava pyrones exhibited a profile of cellular actions that showed a large overlap with several mood stabilizers, especially lamotrigine.

Neuroprotective Activity

The neuroprotective effects of an acetone extract of kava rhizome and kava pyrones had been demonstrated both in-vivo and in-vitro. Administration of kava extract (orally) and its constituents

methysticin and dihydromethysticin (intraperitoneally) protected against brain tissue against ischemic damage in mice and rats (Backhauss and Krieglstein 1992). The kava extract (150 mg/kg, 1 h before ischemia) diminished the infarct area in mouse brains and the infarct volume in rat brains. Methysticin, dihydromethysticin (both 10 and 30 mg/kg, 15 min before ischemia) and the reference substance memantine (20 mg/kg, 30 min before ischemia) significantly reduced the infarct area in mouse brains. The standardized extract also protected against neuronal damage in cultured neurons from chick embryo cerebral hemispheres (Backhauss and Krieglstein 1992). Kava pyrones exhibited neuroprotective and "recovery-supporting" effects on neurological deficits after cerebral infarction in rats (Kleiser et al. 1998).

Administration of the lower dosages of (+/−)-kavain (50 and 100 mg/kg) to male C57BL/6 mice afforded only a nonsignificant attenuation of MPTP (1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine)-induced dopamine depletion, but a high dosage of (+/−)-kavain (200 mg/kg) significantly antagonized the dopamine depletion to 58.93 % of saline control values (Schmidt and Ferger 2001). The MPTP-induced decrease of tyrosine hydroxylase-immunoreactivity as well as the loss of nigral neurons was completely prevented by (+/−)-kavain (200 mg/kg). They concluded that MPTP metabolism was not influenced by (+/−)-kavain and postulated the antiglutamatergic effects of (+/−)-kavain for its protective effects against MPTP toxicity. They asserted that kavain may be a novel candidate for further preclinical studies in animal models of Parkinson's disease and other disorders with glutamatergic overactivity.

Cognitive Activity

Kava was found to have no effect on the reaction times or errors of two groups of undergraduates who consumed doses thought usual (Experiment 1) and doses much greater (Experiment 2) than those associated with social functions (Russell et al. 1987). Münte et al. (1993) investigated the effects of oxazepam and kava root extract on behavior and event-related potentials (ERPs) in a recognition memory task in twelve healthy volunteers. Oxazepam led to a reduction of a negative component in the 250–500 ms range for both old and new words and to a reduction of the old/new difference in the ERP associated with a significantly worse recognition rate. Kava, on the other hand, showed a slightly increased recognition rate and a larger ERP difference between old and new words Heinze et al. (1994) investigated the effects of oxazepam and a standardized extract of kava roots (WS1490) on reaction time and event-related potentials (ERPs) in a visual search paradigm using a double-blind design in young, healthy males. Significant effects of oxazepam were obtained in a number of psychometric tests. Oxazepam led to a reduction of the amplitude of the parietal N1, frontal N2, posterior contralateral N2 and occipital P3 components. WS 1490 was associated with a greater posterior N1, posterior contralateral N2 and occipital P3. In a double-blind randomized placebo-controlled trial involving healthy volunteers, Thompson et al. (2004) found the intake of a single dose of kava extract (300 mg; p.o.) led to an increase in state cheerfulness, while the herbal medicine did not influence state seriousness and bad mood. The mood-elevating effects of kava were most prominent in trait cheerful subjects, indicating that trait cheerfulness moderated the drug-induced increase in cheerful mood. Further, Kava improved the accuracy and the speed of performing the partial report and the item recognition task, indicative of a beneficial effect of kava on visual attention and short-term memory retrieval, respectively.

In a systematic review of clinical trials on the effects of kava on cognition, La Porte et al. (2011) found the majority of evidence from 10 human clinical trials suggested that kava had no replicated significant negative effects on cognition. One acute study found that kava significantly improved visual attention and working memory processes while another found that kava increased body sway. One chronic study found that kava significantly impaired visual attention during high-cognitive demand.

In a randomized, placebo-controlled, double-blind study of 22 adults aged between 18 and 65 years, random administration of an acute medicinal dose of kava (180 mg of kavalactones), oxazepam (30 mg) or placebo 1 week apart in a crossover design showed that the medicinal dose of kava containing 180 mg of kavalactones did not impair driving ability, whereas 30 mg of oxazepam showed some impairment (Sarris et al. 2013a).

Antispasmodic Activity

An aqueous kava rhizome extract, kawain, dihydrokawain, methysticin and dihydromethysticin inhibited serotonin and nicotine-induced contractions of guinea-pig ileum in-vitro (Meyer 1965; Kretzschmar et al. 1969). The antispasmodic effects were attributed to a direct musculotropic action. Dihydromethysticin also inhibited contractions of rat colon and uterus in-vitro induced by serotonin, acetylcholine and barium (Meyer 1965). Desmethoxyyangonin, dihydromethysticin and kawain inhibited serotonin-induced contractions of rat uterus in-vitro at concentrations of 3.2, 7.5 and 10.0 μg/ml, respectively (Buckley et al. 1967). Aqueous, dichloromethane and lyophilized extracts of the rhizome induced relaxation of rat uterus in-vitro (ED_{50} 22.5 μg/ml) (O'Hara et al. 1965). Singh (1983) investigated the effects of an aqueous extract of kava rhizome on muscle contractility and neuromuscular transmission in mouse hemidiaphragms and frog sartorius muscles in-vitro using twitch tension and intracellular recording techniques. Kava extract (2–5 mg/ml) induced muscle relaxation by direct action on muscle contractility rather than by inhibition of neuromuscular transmission. It was concluded that kava caused paralysis by mechanisms similar to local anaesthetics.

(±)-Kavain (1 μM/mM) dose-dependently reduced contractions of isolated guinea-pig ileum evoked by carbachol (10 μM), by BAY K 8644 (0.3 μM) or by substance P (0.05 μM) (Seitz et al. 1997a). (±)-Kavain also inhibited the contractile responses induced by raising the extracellular K+ concentration from 4 to 20 mM and by blocking the K^+ channel by barium chloride (1 mM) or 4-aminopyridine (0.3 mM). After pre-incubation with 1 μM nifedipine, carbachol (1 μM) evoked 18.2 % of contraction at control (i.e. prior pre-incubation with nifedipine). This remaining response was completely abolished by high concentrations of (±)-kavain (400 μM). After treatment of the longitudinal ileum strips with pertussis toxin, carbachol (1 μM) evoked 27.0 % of the control response in untreated ileum. These contractions were also blocked by (±)-kavain (400 μM). However, (±)-kavain had no effect on the caffeine-induced (20 mM) contractions of ileum strips. Moreover, it failed to affect Ca^{2+}-evoked contractions of skinned muscles. The results suggested that the kava pyrone (±)-kavain may act in a non-specific musculotropic way on the smooth muscle membrane. In isolated isometrically contracted murine tracheal ring preparations, kavain was observed to diminish the maximal contractile response to both muscarinic receptor activation and voltage-operated calcium channel activation (Martin et al. 2000). The IC_{50} for kavain in rings precontracted with carbachol was found to be 177 μM, and, in rings precontracted with KCl, it was found to be 59.6 μM. In addition, pretreatment with kavain attenuated airway smooth muscle contraction evoked with either carbachol or KCl. The EC_{50} for KCl was not affected by kavain pretreatment. However, the EC_{50} for carbachol was significantly affected by a high kavain pretreatment dose. Further, Martin et al. (2002) reported that kavain (10^{-6} M to 10^{-3} M) relaxed rat aortic rings precontracted with phenylephrine (PE) in a dose-dependent manner. This response was not dependent on functional endothelium. In addition, kavain pretreatment (3×10^{-5} M or 3×10^{-4} M) attenuated vascular smooth muscle contraction evoked by PE. However, kavain failed to attenuate PE-mediated contraction in calcium (Ca^{2+})-free buffer, indicating that intracellular signaling processes were likely not affected. Also, kavain did attenuate the contraction elicited by the administration of Ca^{2+} to depolarized tissue. Also, in rings pre-treated with the selective L-type Ca^{2+} channel blocker nifedipine, kavain-mediated relaxation was inhibited. Lastly, in rings

selectively contracted with an L-type calcium channel activator, kavain elicited dose-dependent (and ultimately complete) relaxation. These data strongly suggested that kavain attenuated vascular smooth muscle contraction, likely through inhibition of Ca^{2+} channels.

Antitrypanosomal Activity

Otoguro et al. (2012) found two phenolic compounds β-phenethyl caffeate, farnesyl caffeate from propolis and three kawa lactones kawain, dihydrokawain and yangonin possessing an α-pyrone influenced antitrypanosomal property against *Trypanosoma brucei brucei*. In particular, β-phenethyl caffeate, farnesyl caffeate and dihydrokawain exhibited high or moderate selective and potent antitrypanosomal activity in-vitro.

Melanogenesis Stimulation Activity

P. methysticum rhizome ethanol extract showed potent stimulatory effect on melanogenesis in cultured murine B16 melanoma cells (Matsuda et al. 2006). Activity-guided fractionation of kava extract led to the isolation of two active kavalactones, yangonin and 7,8-epoxyyangonin, along with three inactive kavalactones, 5,6-dehydrokawain, (+)-kawain and (+)-methysticin, and a glucosylsterol, daucosterin. 7,8-Epoxyyangonin showed a significant stimulatory effect on melanogenesis in B16 melanoma cells. Yangonin exhibited a weak melanogenesis stimulation activity.

Antiplatelet Activity

Kava-kava extract was found to be a reversible inhibitor of MAO-B in intact platelets (IC_{50} 24 μM) and disrupted platelet homogenates (IC_{50} 1.2 μM) (Uebelhack et al. 1998). The order of potency was desmethoxyyangonin > (±)-methysticin > yangonin > (±)-dihydromethysticin > (±)-dihydrokavain > (±)-kavain. The two most potent kava pyrones, desmethoxyyangonin and (±±)-methysticin, displayed a competetive inhibition pattern with mean Ki 0.28 μoM and 1.14 μM, respectively. (+)-Kavain, a 4-methoxy-α-pyrone prepared from was found to have antithrombotic action on human platelets as evidenced from its ability to suppress arachidonic acid (AA)-induced aggregation, exocytosis of ATP and inhibition of cyclooxygenase (COX) and thromboxane synthase (TXS) activity, the latter two effects being estimated from the generation of prostaglandin E_2 (PGE_2) and thromboxane A_2 (TXA_2), respectively (Gleitz et al. 1997). An application of (+)-kavain 5 min before AA, dose-dependently diminished aggregation, ATP-release and the synthesis of TXA_2 and PGE_2 with IC_{50} values of 78, 115, 71 and 86 μmol/l, respectively.

Antimicrobial Activity

Kavain was reported to exhibit bactericidal activity against Gonococcus, the pathogenic agent of gonorrhoea and colon bacillus and blennorrhea (Steinmetz 1960). The pathogenic fungi *Trichophyton ferrugineum*, *Trichophyton tonsurans* and *Cryptococcus neoformans* were strongly inhibited by kava extracts (Hänsel et al. 1966a). Dihydromethysticin completely inhibited the growth of Aspergillus niger in-vitro (Shulgin 1973). The fungistatic principles of the kava root were found to be 4-methoxy-α-pyrones like dihydrokawain which completely inhibited *Aspergillus niger* at a concentration of 0.5 mg/ml. Other fungi (species of *Candida* and *Fusarium*) and bacteria were not inhibited by kava and dihydrokawain. A hydroalcoholic extract of kava rhizome inhibited the growth in-vitro of *Aspergillus fumigatus*, *A. niger*, *Penicillium digitatum*, *Rhizopus nigricans*, *Trichophyton mentagrophytes*, *Candida albicans* and *Saccharomyces pastorianus* (Guérin and Réveillère 1984). However, an aqueous extract of the rhizome weakly inhibited the growth in-vitro of *Trichophyton rubrum*, *Microsporum canis* or *Epidermophyton floccosum* (Locher et al. 1995).

Amoebicidal Activity

The amoebicidal activity of yangonin was found comparable to that of the commercial drugs enterovioform, enteroquinol, clefamide and furamidazole (Hänsel 1968; Sotheeswaran 1987).

Kava-Drug Interaction Activity

Kava (*Piper methysticum*) was one of the herbal remedies listed in the United States with the potential to significantly modulate the activity of drug-metabolizing enzymes (notably cytochrome P450 isozymes) and/or the drug transporter P-glycoprotein and could have potential adverse interactions with anticancer agents (Sparreboom et al. 2004).

Studies had shown that several kavalactones, the active principles of kava extracts, to be potent inhibitors of several enzymes of the CYP 450 system (CYP1A2, 2C9, 2C19, 2D6, 3A4 and 4A9/11) indicating that kava had a high potential for causing pharmacokinetic drug interactions with other herbal products or drugs, which are metabolised by the CYP 450 enzymes (Anke and Ramzan 2004). Analysis of a kava kava and a basil extract showed that the on-line HPLC system was applicable to complex mixtures, since in both extracts, peaks with human cytochrom P450 1A2 inhibiting activity were observed (Jeurissen et al. 2007). The results of studies by Guo et al. (2009) indicated that kava extract could significantly modulate drug metabolizing enzymes, particularly the CYP isozymes, which could cause herb-drug interactions and may potentially lead to hepatotoxicity.

Almeida and Grimsley (1996) reported a case of a 54-year-old man hospitalised in lethargic and disoriented state and found to be induced by possible drug interaction between kava a-pyrones and a benzodiazepine (alprazolam). Inhibitors of cytochrome P450 3A4 (CYP3A4) were identified in crude extracts from kava roots (Unger et al. 2002). Kavapyrones were identified as the main CYP3A4 inhibitory components of kava. Whole kava extract (normalized to 100 μM total kavalactones) caused concentration-dependent decreases in cytochrome P450 (P450) enzymes activities, with significant inhibition of the activities of CYP1A2 (56 % inhibition), 2C9 (92 %), 2C19 (86 %), 2D6 (73 %), 3A4 (78 %) and 4A9/11 (65 %) following preincubation for 15 min with human liver microsomes (HLMs) and NADPH; CYP2A6, 2C8 and 2E1 activities were unaffected (Mathews et al. 2002). Of its major kavalactones, kavain did not inhibit these enzymes, there was significant inhibition of CYP2C9 by desmethoxyyangonin (42 %), methysticin (58 %) and dihydromethysticin (69 %); 2C19 by dihydromethysticin (76 %); 2D6 by methysticin (44 %); and 3A4 by desmethoxyyangonin (40 %), methysticin (27 %) and dihydromethysticin (54 %). These data indicated that kava possessed a high potential for causing drug interactions through inhibition of P450 enzymes responsible for the majority of the metabolism of pharmaceutical agents. Effects reported for the kava extracts may result from the different preparation protocols used. In cDNA-expressed human enzymes and cryopreserved human hepatocytes, the kava extract and the three kava lactones (methysticin, desmethoxyyangonin and yangonin) were found to be potent inhibitors of a panel of P450 isoforms (CYPs 1A2, 2C9, 2C19, 2E1 and 3A4) with IC_{50} values of approximately 10 μM (Zou et al. 2004b). The test compounds were also moderately cytotoxic to human hepatocytes (EC_{50} values of approximately 50 μM). Methysticin was the most potent enzyme inhibitor as well as the most cytotoxic, followed by (in order of potency) the kava root extract, desmethoxyyangonin and yangonin. Commercial kava extracts (prepared in acetone, ethanol or methanol) exhibited more pronounced inhibition of P450 enzymes (CYP3A4, CYP1A2, CYP2C9 and CYP2C19) than traditional kava (aqueous) extract (Côté et al. 2004). Among kava kavalactones, only desmethoxyyangonin and dihydromethysticin markedly induced the expression of CYP3A23 (approximately 7-fold) in rat hepatocytes (Ma et al. 2004). The results suggested that induction of CYP3A23 by dihydromethysticin and desmethoxyyangonin involved transcription activation, probably through a human pregnane X receptor (PXR)-independent or PXR-involved indirect mechanism.

Treatment of F-344 rats with pipermethystine (10 mg/kg) and kava root acetone-water extract (100 mg/kg) for 2 weeks failed to elicit any significant changes in liver function tests or cause severe hepatic toxicity as measured by lipid peroxidation and apoptosis markers such as malondialdehyde, Bax and Bcl-2 (Lim et al. 2007). However, pipermethystine-treated rats demonstrated a significant increase in hepatic glutathione, cytosolic superoxide dismutase (Cu/ZnSOD), tumor necrosis factor alpha mRNA expression and cytochrome P450 (CYP) 2E1 and 1A2, suggesting adaptation to oxidative stress and possible drug-drug interactions. Yamazaki et al. (2008) found that a high dose (equivalent to approximately 380 mg kavalactones/kg/day; 100 times of the suggested dosage for human use) of two different types of kava products for 8 days significantly increased liver weights in rats. CYP1A2 mRNA expression was moderately increased (2.8–7.3 fold). More importantly, the high dose of kava markedly enhanced CYP1A1 mRNA expression (75–220 fold) as well as ethoxyresorufin *O*-deethylase activities and CYP1A1 immunoreactivities. Thus, no observed adverse effect levels of kavalactones would be lower than 380 mg/kg/day. They advised that considerable attention should be paid to the possibility that kava products could induce hepatic CYP1A1 expression in human especially in sensitive individuals.

Gene expression profiling in male B6C3F1 mouse livers administered kava extract by gavage for 14 weeks identified the differentially expressed drug metabolizing genes in response to kava treatments (Guo et al. 2010). It was found that the levels of significant numbers of genes involving drug metabolism were changed and that the pathways involving xenobiotics metabolism, Nrf2-mediated oxidative stress response, mitochondrial functions and others were altered. Their results indicated that kava extract can significantly modulate drug metabolizing enzymes, potentially leading to herb-drug interactions and hepatotoxicity. Studies showed that kava extract displayed a concentration-dependent effect on hepatic CYP1A1 induction (Li et al. 2011). Among the six major kavalactones, methysticin triggered the most profound inducing effect on CYP1A1 followed by 7,8-dihydromethysticin. The other four kavalactones (yangonin, 5,6-dehydrokawain, kawain and 7,8-dihydrokawain) did not show significant effects on CYP1A1. It was found that kava extract induced the expression of CYP1A1 via an aryl hydrocarbon receptor (AhR)-dependent mechanism and that methysticin and 7,8-dihydromethysticin contributed to CYP1A1 induction. The induction of CYP1A1 indicated a potential interaction between kava or kavalactones and CYP1A1-mediated chemical carcinogenesis.

Weiss et al. (2005) demonstrated P-glycoprotein inhibitory activity of kava-kava and its kavalactones kavalactones kavain, dihydrokavain, methysticin, dihydromethysticin, yangonin and desmethoxyyangonin in P-glycoprotein-overexpressing cell line P388/dx and the corresponding cell line P388. The crude extract and the kavalactones showed a moderate to potent inhibitory activity with f2 (concentration needed to double baseline fluorescence) values of 170 μg/ml and 17–90 μM, respectively. The f2 value of yangonin could not be determined due to its higher lipophilicity. Mathews et al. (2005) found that kava could cause adverse drug reactions via inhibition of drug metabolism. The 7-day pretreatment with kava extract only modestly induced hepatic cytochrome P450 activities. The human hepatic microsomal P450s most strongly inhibited by kava extract (CYP2C9, CYP2C19, CYP2D6, CYP3A4) were inhibited to the same degree by a "composite" kava formulation composed of the six major kavalactones contained in the extract. K_i values for the inhibition of CYP2C9 and CYP2C19 activities by methysticin, dihydromethysticin and desmethoxyyangonin ranged from 5 to 10 μM. Kava extract and kavalactones (< or =9 μM) modestly stimulated P-glycoprotein ATPase activities. Two cases of patients seen on the psychiatric emergency and consult service who developed severe side effects from psychotropic medications in the context of kava use were reported by Toohey et al. (2013). In both cases, kava use may have affected the metabolism of the psychotropic medications, leading to serious side effects. Growing research indicated that kava

most likely altered concentrations of co-administered psychotropics possibly by inhibiting cytochrome P450 enzymes.

Pharmacokinetic Studies

After the administration of kava pyrones to rats, about half the dose (400 mg/kg, p.o.) of dihydrokawain was found in the urine in 48 h, about two-thirds of this was hydroxylated metabolites (three mono- and three di-hydroxylated derivatives), of which p-hydroxydihydrokawain was the most abundant (Rasmussen et al. 1979). The remaining third consisted of metabolites formed by scission of the 5,6-dihydro-alpha-pyrone ring and included hippuric acid (9–13 % dose). Lower amounts of urinary metabolites were excreted when kawain was administered, but both hydroxylated and ring-opened products were formed. Methysticin afforded only small amounts of two urinary metabolites formed by demethylenation of the methylenedioxyphenyl moiety. Urinary metabolites of the alpha-pyrones, 7,8-dihydroxyangonin and yangonin were formed via omicron-demethylation. No ring-opened products were detected. These lipophilic kava pyrones had extremely low solubility in water, which would be expected to reduce their absorption rates and appeared to be responsible for the variable and low extent of metabolism observed.

Intraperitoneal (i.p.) administration of mice with 100 mg/kg of dihydrokawain, kawain, desmethoxyyangonin and yangonin was investigated in relation to uptake by mouse brain (Keledjian et al. 1988). After 5 min, dihydrokawain and kawain attained maximum concentrations of 64.7 and 29.3 ng/mg wet brain tissue, respectively. Desmethoxyyangonin and yangonin had poorly defined maxima corresponding to concentrations of 10.4 and 1.2 ng/mg wet brain tissue, respectively, and these compounds were more slowly eliminated from brain tissue. When crude kava resin was administered i.p. at a dose of 120 mg/kg, the concentrations of kawain and yangonin markedly increased (2 and 20 times, respectively) relative to the values measured from their individual injection. Dihydrokawain and desmethoxyyangonin levels remained the same as those established for their individual administration. Methane chemical ionization (CI) gas chromatography–mass spectrometry (GC–MS) was used by Duffield et al. (1989a) to identify some of the human urinary metabolites of the kava lactones following the ingestion of aqueous kava extract. All seven major, and several minor, kava lactones were identified in human urine. Observed metabolic transformations include the reduction of the 3,4-double bond and/or demethylation of the 4-methoxyl group of the α-pyrone ring system. Demethylation of the 12-methoxy substituent in yangonin (or alternatively hydroxylation at C-12 of desmethoxyyangonin) was also observed. In contrast to the situation prevailing in the rat, no dihydroxylated metabolites of the kava lactones, or products from ring opening of the 2-pyrone ring system, were identified in human urine. Abourashed and Khan (2000) used fungal models to mimic the mammalian metabolism of two major kava styryl alpha-pyrones, D-kawain and D-methysticin. The culture broth of *Cunninghamella elegans* yielded 4′-hydroxykawain from D-kawain, the same metabolite identified in rat urine. The fungus *Torulopsis petrophilum* biotransformed D-methysticin to 3′-hydroxy-4′-methoxykawain which was analogous, but not identical, to a known rat metabolite of methysticin. Kavalactones appeared to be hydroxylated by the cytochrome P450 system and their metabolism may be enhanced by the presence of glutathione (Russmann et al. 2001; Tinsley 1999).

The oral pharmacokinetics of the kavalactone, kawain (100 mg/kg), were determined in rats with and without coadministration of kava extract (256 mg/kg) to study the effect of the extract on drug disposition (Mathews et al. 2005). Kawain was well absorbed, with >90 % of the dose eliminated within 72 h, chiefly in urine. Compared with kawain alone, co-administration with kava extract caused a tripling of kawain AUC (0–8 h) and a doubling of C_{max}. However, a 7-day pretreatment with kava extract (256 mg /kg/day) had no effect on the pharmacokinetics of kawain administered on day 8. Studies by Fu et al. (2012) found among the six major kavalactones (kavain,

methysticin and desmethoxyyangonin) and their respective metabolites (*p*-hydroxykavain, *m,p*-dihydroxykavain and *p*-hydroxy-5,6-dehydrokavain), *p*-hydroxykavain and *m,p*-dihydroxykavain were the only metabolites detected in the perfusate of rat liver. Kavalactone biliary excretion was negligible. Kavalactones were found to be potentially bioavailable as they all readily crossed the Caco-2 cell monolayers with apparent permeabilities (P_{app}) increasing from 42×10^{-6} cm/s and most exhibiting more than 70 % crossing within 90 min (Matthias et al. 2007). Not all differences in their bioavailability can be related to kavalactone structural differences as it appeared that bioavailability may also be affected by co-extracted compounds. For example, the P_{app} for kawain from ethanol extracts was higher than the values obtained for the same compound from water extracts or for the kavalactone alone. The pilot study by Tarbah et al. (2013) found that kavalactones (kavain; 7,8-dihydrokavain, methysticin; 7,8-dihydromethysticin; 5,6-dehydrokavain (=desmethyoxyyangonin); and yangonin) accumulated in the keratin matrix of hair and could provide an easily applicable system for assessing chronic consumption of kava.

Toxicological Studies

Oral administration of a test mixture of 40 % kavain, 40 % dihydrokavain, and 20 % yangonin at doses of 100 or 500 mg/kg on days 6–15 of gestation.was found not teratogenic or embryotoxic in Wistar rats (Hapke et al. 1971). The mixture was also negative for teratogenic activity in New Zealand strain rabbits when administered orally at doses of 20 or 200 mg/kg on days 6–18 after mating. However, there was a significant dose-related reduction of foetal weight in treated rabbits. In subchronic toxicological studies of Kavaform®, a German geriatric preparation containing 50 mg of d,1-kavain and 200 mg of magnesium orotatein in Wistar rats and mongrel dogs, serum glutamate pyruvate transaminase (SGPT) levels were significantly increased in high-dose rats; however, liver cell damage was not confirmed by histological examination. In high-dose dogs, Kavaform was mildly toxic; proliferation of the small cells of the thyroid epithelium and a multicentric necrosis of the parenchyma of the liver were observed as a single histological finding in one high-dose dog. Hsu et al. (1994) tested dihydrokavain and desmethoxyyangonin in mice and Wistar rats on oral application. An application of 30, 100 or 300 mg/kg twice a day for 2 weeks did not yield any clinically relevant changes in haematological and histological parameters. Rats were administered similar dosages over 3 months. Only with the use of desmethoxyangonin, transient changes of serum glucose, cholesterol and triglycerides were found, however, without a clear dosage–effect relationship. Overall, the experiment did not yield hints on toxic effects of kavalactones. Feeding Wistar rats of both sexes with 7.3 or 73 mg/kg body weight of ethanolic kava extract for 3 and 6 months elicited no signs of toxicity in relation to changes in body weight, hematological and liver parameters, and macroscopical and microscopical histological changes in the major organs (Sorrentino et al. 2006).

None of the six major kavalactones was found to be positive in the experimental concentration ranges tested by the umu test (a sensitive test for point mutations) (Jhoo et al. 2007). However, among the different solvent fractions, the n-butanol fraction of kava leaves was positive for mutagenicity. Further investigations using bioassay-directed isolation and analysis indicated that 2 C-glycoside flavonoid compounds identified as 2″-*O*-rhamnosylvitexin and schaftoside accounted for the positive mutagenic results. Whittaker et al. (2008) evaluated the toxicity and mutagenicity of two commercial samples of kava, Kaviar and KavaPure, and the six pure kavalactones, kawain, dihydrokawain, methysticin, dihydromethysticin, yangonin and desmethoxyyangoni including both D-kawain and DL-kawain, in L5178Y mouse lymphoma cells. They found neither the kava samples nor the kavalactones induced a mutagenic response in the L5178Y mouse lymphoma mutation assay with the addition of human liver S9 activation.

Under the conditions of the 2-year toxicology and carcinogenesis studies of kava kava extract

(CAS No. 9000-38-8) in F344/N rats and B6C3F1 mice (gavage studies) by US Department of Health and Human Services, National Toxicology Program, there was equivocal evidence of carcinogenic activity of kava kava extract in male F344/N rats based on marginal increases in the incidences of testicular interstitial cell adenoma (NTP 2012). There was no evidence of carcinogenic activity of kava kava extract in female F344/N rats administered 0.1, 0.3 or 1.0 g/kg. There was clear evidence of carcinogenic activity of kava kava extract in male B6C3F1 mice based on increased incidences of hepatoblastoma. There was some evidence of carcinogenic activity of kava kava extract in female B6C3F1 mice based on increased incidences of hepatocellular adenoma or carcinoma (combined). In gentic toxicology, kava kava extract was negative in *Salmonella typhimurium* strains TA97, TA98, TA100 and TA1535 with and without S9 activation and also negative in *Escherichia coli* WP2 *uvrA*/pKM101 with and without S9. In-vivo, no increases in the frequencies of micronucleated erythrocytes were observed in peripheral blood of male or female B6C3F1 mice administered kava kava extract by gavage for 3 months.

Kava Hepatotoxicity

In-Vitro Studies

Exposure of human hepatoma cells, HepG2, to 100 μM pipermethystine caused 90 % loss in cell viability within 24 h, while 50 μM caused 65 % cell death (Nerurkar et al. 2004). Similar concentrations of kavalactones (7,8-dihydromethysticin and desmethoxyyangonin) did not affect cell viability for up to 8 days of treatment. Mechanistic studies indicated that, in contrast to kavalactones, pipermethystine significantly decreased cellular ATP levels and mitochondrial membrane potential and induced apoptosis as measured by the release of caspase-3 after 24 h of treatment. These observations suggested that pipermethystine, rather than kavalactones, was capable of causing cell death, probably in part by disrupting mitochondrial function. Thus, it was concluded that pipermethystine may contribute to rare but severe hepatotoxic reactions to kava. Incubation of kava lactones (methysticin, yangonin and desmethoxyyangonin) and an ethanolic extract of dried kava root in culture with MCL-5 cells, a human lymphoblastoid cell line stably transfected with five human P450's (CYP 1A1, 1A2, 2A6, 2E1 and 3A4) and human epoxide hydrolase and a control cell line (cH2) derived from the same parental line as MCL-5, but transfected with two empty vectors, elicited varying degrees of metabolic toxicity ($IC5_0$ values ranged from 50 to > 100 μM) to both MCL-5 and cH2 cell lines; however, both cell lines were equally sensitive to the test compounds (Zou et al. 2004a). The results suggested that the parent compound for each of the four test compounds was primarily responsible for the observed cell toxicity and that CYP 1A1, 1A2, 2A6, 2E1 and 3A4 or epoxide hydroxylase did not appear to be involved. It was concluded that in-vitro kava did not appear to be activated to toxic metabolites by enzymes known to be important in metabolic toxicity. Studies by Whitton et al. (2003) found that the extraction process (aqueous vs. acetone in the two types of preparations) was responsible for the difference in toxicity as extraction of glutathione in addition to the kava lactones was important to provide protection against hepatotoxicity. The Michael reaction between glutathione and kava lactones, resulting in opening of the lactone ring, reduced the side effects of the kava kava extracts. This protective activity was demonstrated using *Acanthamoebae castellanii* in which 100 % cell death occurred with 100 mg/ml kava lactones alone, and 40 % cell death with a mixture of 100 mg/ml glutathione and 100 mg/ml kava lactones.

Jhoo et al. (2006) found that organic solvent fractions displayed a much stronger cytotoxicity than water fractions for kava root, leaf and stem peelings as evaluated in HepG2 cells based on the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide assay and lactate dehydrogenase and aspartate aminotransferase enzyme leakage assays. The hexane fraction of the root exhibited stronger cytotoxic effects than fractions of root extracted with other solvents (ethyl acetate, n-butanol and water) or extracts

from the other parts of kava. Further investigations using bioassay-directed isolation and analysis of the hexane fraction indicated that the compound responsible for the cytotoxicity was flavokavain B.

The pyridone alkaloid pipermethystine had been considered to be responsible for alleged hepatoxicity of Kava products (Lechtenberg et al. 2008). Investigation of a series of retain samples of finished products from the German market and self-produced extracts from root and stem material of *Piper methysticum* clearly showed that pipermethystine was absent from all root and retain samples and extracts, with a limit of quantification of 45 ppm. Thus they stated that pipermethystine should not be the responsible constituent in hepatoxic case reports with ethanolic kava extracts produced in Germany.

Studies by Lüde et al. (2008) found kava extracts were toxic to mitochondria, leading to inhibition of the respiratory chain, increase in ROS production, decrease in the mitochondrial membrane potential and eventually to apoptosis of exposed HepG2cells. The methanolic and an acetonic kava root and a methanolic leaf extracts showed cytotoxicity starting at a concentration of 50 μg/ml (lactate dehydrogenase leakage) or 1 μg/ml (MTT test). The mitochondrial membrane potential was decreased (root extracts starting at 50 μg/ml) and the respiratory chain inhibited and uncoupled (root extracts) or only uncoupled (leaf extract) at 150 μg/ml, and mitochondrial beta-oxidation was inhibited by all extracts starting at 100 μg/ml. Induction of apoptosis was demonstrated by all extracts at a concentration of 150 μg/ml. They stated that in predisposed patients, mitochondrial toxicity of kava extract may explain hepatic adverse reactions of this drug. Kava was found to potentiate acetaminophen-induced hepatocyte cytotoxicity (Yang and Salminen 2011). The findings indicated that kava potentiated acetaminophen-induced cytotoxicity of rat primary hepatocytes by increasing the magnitude of glutathione depletion, resulting in oxidative stress and mitochondrial dysfunction, ultimately leading to cell death.

Studies by Zhou et al. (2010) demonstrated that flavokawain B (FKB), a chalcone from kava root, to be a potent hepatocellular toxin, inducing cell death in HepG2 (LD_{50} = 15.3 μM) and L-02 (LD_{50} = 32 μM) cells. Hepatocellular toxicity of FKB was mediated by induction of oxidative stress, depletion of reduced glutathione (GSH), inhibition of IKK activity leading to NF-κB transcriptional blockade and constitutive TNF-α-independent activation of mitogen-activated protein kinase (MAPK) signaling pathways, namely, ERK, p38 and JNK. They further demonstrated by non-invasive bioluminescence imaging that oral consumption of FKB leads to the inhibition of hepatic NF-κB transcriptional activity in-vivo and severe liver damage.

Hepatotoxicity could occur as an acute, severe form or a chronic, mild form in relation to kava ingestion (Rowe et al. 2011). Inflammation appeared to be involved in both forms and may result from the activation of liver macrophages (Kupffer cells), either directly or via kava metabolites. Pharmacogenomics may influence the severity of this inflammatory response. According to Clouatre (2004), three possible mechanisms for kavalactone hepatotoxicity were known: inhibition of cytochrome P450, reduction in liver glutathione content and, more remotely, inhibition of cyclooxygenase enzyme activity. The pathophysiology of kava hepatotoxicity remains inclonclusive despite the existence of circumstantial evidence for the roles of toxic metabolites, inhibition of cyclooxygenase (COX) enzymes and depletion of liver glutathione (Zhang et al. 2011). Experimental and clinical cases of hepatotoxicity showed evidence of hepatitis.

Animal Studies

Studies by Singh and Devkota (2003) found that aqueous kava extract did not affect liver function in rats. The data showed that none of the enzymes such as alanine aminotransferase, aspartate aminotransferase, alkaline phosphatase,lactate dehydrogenase andmalondialdehyde were elevated; in fact in some cases they were significantly reduced, suggesting the lack of a toxic effect by kava on the liver. Separate studies by DiSilvestro et al. (2007) found 3 months of kava feeding in rats at three different doses (31.25, 62.5 and

133 mg/kg diet) produced no liver injury based on serum markers of liver damage (sorbitol dehydrogenase activities, bile acid concentrations and beta-glucuronidase activities) and serum lipid peroxide readings. For some measurements and some kava doses, the injury marker readings were below control values. Moreover, for these same parameters, kava feeding did not enhance the effects of the hepatotoxin galactosamine (500 mg/kg ip); some kava doses even showed modest protection against liver injury. Liver histology analysis showed no signs of kava causing or enhancing liver injury. Their study did not support the concept that kava produces or aggravates liver injury. Studies by Narayanapillai et al. (2014b) found that kava alone revealed no adverse hapatoxic effects for long-term usage even at a dose of 500 mg/kg bodyweight in C57BL/6 mice. In contrast, a 3-day kava pretreatment potentiated acetaminophen P-induced hepatotoxicity, resulted in an increased serum ALT and AST and increased severity of liver lesions. It was found that flavokawains A and B in kava, not dihydromethysticin, potentiated acetaminophen-induced hepatotoxicity.

Dietary feeding of flavokawain A (FKA), a major kava chalcone, did not affect food consumption and body weight of male FVB/N mice (Li et al. 2014). Histopathological examination of liver, kidney, colon, lung, heart, spleen and thymus revealed no signs of FKA-induced toxicity. Biochemical serum analysis and histological examination confirmed normal organ function in FKA-treated mice. The cytotoxicity profile showed FKA had minimal side effects on bone marrow and small intestinal epithelial cells compared with adriamycin. In addition, oral feeding of FKA increased activities of both glutathione S-transferase and quinone reductase in the liver, lung, prostate and bladder tissues of mice. In comparison, dietary feeding of 0.6 % commercial kava root extract increased liver/body weight ratio and decreased spleen, thymus and testis/body weight ratios, as well as induced nodular proliferation in liver tissues. Therefore, dietary feeding FKA showed no adverse effects on major organ function and homeostasis in mice, suggesting the potential of FKA for chemoprevention study of human cancers. Zhang et al. (2013) found that liver macrophage depletion ameliorated kavalactone damage in isolated perfused rat liver.

In prechronic studies, orally administered kava at 0.125–2 g/kg body weight revealed dose-related increases in liver weights and incidences of hepatocellular hypertrophy in F344/N rats and B6C3F1 mice (Behl et al. 2011). In the chronic studies, there were dose-related increases in the incidences of hepatocellular hypertrophy in rats and mice administered kava kava for up to 1 g/kg body weight. This was accompanied by significant increase in incidences of centrilobular fatty change. Male mice showed a significant dose-related increase in the incidence of hepatoblastomas. In female mice, there was a significant increase in the combined incidence of hepatocellular adenoma and carcinoma in the low- and mid-dose groups but not in the high-dose group. These findings were accompanied by several nonneoplastic hepatic lesions.

Clinical Studies/Reports

A case of a woman with acute necrotizing hepatitis after taking herbal remedies as alternative medication, containing kava, was reported in Germany in 1998 (Strahl et al. 1998). Viral, autoimmune and metabolic causes of the hepatitis were excluded. Campo et al. (2002) reported a case of a girl aged 14 years who was hospitalised with kava-induced fulminant hepatic failure in December 2000, after taking two kava products from August to December. Initial liver biopsy revealed active fulminant hepatitis with extensive centrilobular necrosis, approximately 25 % hepatocellular viability, and mixed inflammatory infiltrates consisting of lymphocytes, histiocytes, scattered eosinophils and occasional neutrophils. No viral cytopathic changes were identified, and immunohistochemical stains for hepatitis B surface and core antigens were negative. Humberston et al. (2003) described a case of a previously healthy 14-year-old female was admitted to the hospital with hepatic failure. Initial therapy, including plasmapheresis, was unsuccessful and she deteriorated. She ultimately required a liver transplant and now remains well. The liver biopsy

showed hepatocellular necrosis consistent with chemical hepatitis. A work-up for alternative causes of liver failure was negative. The patient gave a history of taking a kava kava – containing product for 4 months.

Russmann et al. (2003) reported that traditional aqueous kava extracts were the most probable cause of hepatitis in two patients presenting with markedly elevated transaminases and hyperbilirubinaemia. A consequent survey of 27 heavy kava drinkers in New Caledonia showed elevated gamma glutamyl transferase in 23/27 and minimally elevated transaminases in 8/27. They concluded that not only commercially available but also traditionally prepared kava extracts may rarely cause liver injury. The increased activity of gamma glutamyl transferase in heavy kava consumers in the presence of normal or minimally elevated transaminases was probably not a sign of liver injury, but rather reflected an induction of CYP450 enzymes. In a cross-sectional study with 98 indigenous Australian participants, 36 of whom had never used kava, it was found that more recent kava use was independently associated with higher levels of liver enzymes gamma-glutamyl transferase (GGT) and alkaline phosphatase (ALP), but not with alanine aminotransferase or bilirubin, which were not elevated (Clough et al. 2003a). In those who were not heavy alcohol users, only those who used kava within the previous 24 h showed GGT levels higher than nonusers, whereas higher ALP levels occurred only in those who last used kava 1–2 weeks and 24 h previously. It was concluded that liver function changes in users of aqueous kava extracts at these moderate levels of consumption appeared to be reversible and may begin to return to baseline after 1–2 weeks abstinence from kava. No evidence for irreversible liver damage had been found. In another paper, Clough et al. (2003b) conducted a cross-sectional study of 101 aboriginal adults in east Arnhem Land in the Northern Territory. They found that kava use was associated with dermopathy, liver function abnormalities and decreased lymphocytes. Gow et al. (2003) described a case of acute liver failure and death associated with the use of a preparation containing the "natural" anxiolytic kava and passionflower (*Passiflora incarnata*). The patient died after a report by the Therapeutic Goods Administration (TGA) warning of the potential for hepatotoxicity associated with the use of kava-containing products. In a study of 31 healthy adult Tongan kava drinkers versus a control group of 31 healthy adult Tongan non-kava drinkers in Oahu Hawaii, it was found that chronic heavy kava beverage consumption was associated with the elevation of γ-glutamyl transpeptidase in 65 % of the kava drinkers versus 26 % in the controls (Brown et al. 2007). Alkaline phosphatase was elevated in 23 % of kava drinkers versus 3 % in the controls.

In an otherwise healthy 48-year-old female patient, acute hepatitis with transaminase increase (glutamic oxaloacetic transaminase (GOT) up to 613 U/l, glutamic pyruvic transminase (GPT) up to 752 U/l), inconspicuous hepatitis serology findings, negative autoantibody status and negative virus serology was observed after a 10-week long intake of kava kava (1–3 × 200 mg/day) and St John's Wort (1 × 425 mg/day) (Musch et al. 2006). Biopsy of the liver showed lobular and portal necroinflammatory activity without indication of cirrhosis. Discontinuation of the existing medication and simultaneous onset of immunosuppressive combination therapy of cortisone, azathioprine and ursodeoxycholic acid resulted in normalisation of the liver parameters within a period of 2 months. It appeared that simultaneous intake of St John's Wort possibly potentiated the toxicity of kavapyrones. On the other hand, an immune-mediated mechanism, induced by kava kava, could not be completely excluded. A comparative study of two structured quantitative analytical methods: the system of Maria and Victorino (MV) and that of the Council for International Organizations of Medical Sciences (CIOMS) for causality assessment of kava hepatotoxicity was carried out on 26 patients with assumed hepatotoxicity by the herb (Teschke et al. 2010). Grades of causality for suspected hepatotoxicity by kava were much lower when evaluated by structured quantitative causality assessment scales than by regulatory ad hoc judgements. The quantitative CIOMS scale was found to be the preferable tool for causality

assessment of spontaneous reports of hepatotoxcity involving kava.

Review/Analytical Studies

Stickel et al. (2003) analyzed 29 novel cases of hepatitis along with kava ingestion which occurred between 1990 and 2002 in addition to the seven already published case reports using a clinical diagnostic scale established for adverse hepatic drug reactions. They found that hepatic necrosis or cholestatic hepatitis were observed with both alcoholic and acetonic kava extracts. The majority of the 29 patients and the additional seven published reports were women (27 females, nine males). Both the cumulative dose and the latency to when the hepatotoxic reaction emerged were highly variable. Nine patients developed fulminant liver failure, of which eight patients underwent liver transplantation. Three patients died, two following unsuccessful liver transplantation and one without. In all other patients, a complete recovery was noticed after the withdrawal of kava. Their report highlighted the potentially severe hepatotoxicity of kava which led to the retraction of kava-containing drugs by the pharmacovigilance authorities in Germany. In January 2003, kava extracts had been banned in the entire European Union and Canada, and were subject to cautions and advisories by the US FDA as a result of 11 cases of hepatic failure leading to liver transplants, including four deaths (Clouatre 2004). A total of 78 cases of hepatotoxicity repeatedly linked to kava ingestion were available for review from various databases. Teschke (2003) reported that almost 80 % of the patients took kavapyrones in overdose (maximally 480 mg/day) and/or for a prolonged time of more than 3 months up to 2 years, which exceeded the commonly recommended daily dose of 60–120 mg kavapyrones and the duration of the therapy of up to 3 months for anxiety therapy. Additional risks factors include co-medication with up to five other chemically defined or herbal drugs with in part potentially hepatotoxic properties as well as a genetic deficiency of the hepatic microsomal cytochrome P450 2D6. Based on findings of a clinical survey and critical analysis of 26 suspected cases of kava hepatotoxicity, Teschke et al. (2008) found that kava taken as recommended to be associated with rare hepatotoxicity, whereas overdose, prolonged treatment and co-medication may carry an increased risk. In a comparative study with nine patients from Germany and Switzerland with established causality of hepatotoxicity by ethanolic and acetonic kava extracts and five patients from New Caledonia, Australia, the United States and Germany for aqueous kava extracts and kava-herbs mixtures, Teschke et al. (2009) in a comparative study of hepatotoxicty caused by aqueous, acetonin and ethnaolic kava extracts found that the clinical picture in all 14 patients was similar, independently whether aqueous, ethanolic and acetonic kava extracts or kava-herbs mixtures were used, substantiating that the solvents employed to prepare the various kava extracts were not causally related to the development of liver injury in these cases. This finding confirmed the WHO kava report (2007) that traditional aqueous kava extracts may exert rare potential hepatotoxicity similar to acetonic and ethanolic extracts.

Teschke (2010) reviewed and discussed the possible pathogenetic factors for the development of kava-induced liver injury. He concluded that kava hepatotoxicity occurred independently of the extraction medium used for the kava extracts and may primarily be attributed to daily overdose, prolonged treatment and to a few kava extract batches of poor quality; by improving kava quality and adherence to therapy recommendation under avoidance of comedication, liver injury by kava should be a preventable disease, at least to a major extent. Several reports of hepatotoxicity had been linked to the consumption of kava extracts in Western countries, where mainly ethanolic or acetonic extracts were used (Olsen et al. 2011). The mechanism of toxicity had not been established, although several theories had proposed. On the basis of the chemical structures of kava constituents, the formation of reactive metabolites had also been suggested as a basis of toxicity. Furthermore, skin rash a side effect in kava consumers, may be indicative of

the formation of reactive metabolites and covalent binding to skin proteins leading to immune-mediated responses. Reactive metabolites of kava lactones had been identified in-vitro as glutathione (GSH) conjugates and in-vivo as mercapturates excreted in urine. Unfortunately, only a few studies had investigated the toxicity of the minor constituents present in kava extract, such as pipermethystine and the flavokavains, where some have been shown to display higher in-vitro cytotoxicity than the lactones. They reiterated that to date, there remains no indisputable reason for the increased prevalence of kava-induced hepatotoxicity in Western countries. Teschke et al. (2012) in a review of cases analyzed by the World Health Organization and published case reports found that traditional aqueous extracts used in New Caledonia, Australia, the USA and Germany may also be hepatotoxic and may not be restricted to use of Western acetonic and ethanolic extracts. They stated that the primary cause of toxicity may reside in the time before the preparation of the various kava extracts, possibly attributed to poor quality of the raw material caused by mould hepatotoxins. They advised for rigorous testing of kava raw material, in addition to Pan-Pacific kava manufacturing quality standards. According to Teschke et al. (2011a;b) thus far no clear evidence existed for the for a causative hepatotoxic role of kavalactones and non-kavalactone constituents, such as pipermethystine and flavokavain B identified from kava. They asserted that studies should focus on the identification of further potential hepatotoxic constituents, considering in particular possible kava adulterants and impurities with special reference to ochratoxin A and aflatoxins (AFs) producing *Aspergillus* varieties. Also due to to high temperature and humidity in the South Pacific area, kava raw material might have been contaminated by mould hepatotoxins such as aflatoxins after harvest and during storage (Teschke et al. 2011b). The analysis conducted by Teschke et al. (2011c) showed poor quality of kava raw material as a cause for its liver toxicity and suggested preventative measures by going back to the traditional use of kava for the sake of the patients and the South Pacific economy. Consequently as a solution to kava hepatotoxicity, they (Teschke et al. 2011d) proposed a six-point plan for new kava standardization: (1) use of a noble kava cultivar such as Borogu, at least 5 years old at time of harvest; (2) use of peeled and dried rhizomes and roots; (3) aqueous extraction; (4) dosage recommendation of $\leq$ 250 mg kavalactones per day (for medicinal use); (5) systematic rigorous future research; and (6) a Pan Pacific quality control system enforced by strict policing. Teschke and Lebot (2011) recommended for the establishment of Pan-Pacific kava quality legislation as an important part of the proposed Kava Quality Standardization Code. They riterated that a sophisticated approach to establish kava quality standardizations was needed for safe human use of kava as relaxing traditional beverages, anxiolytic drugs and recreational dietary supplements. Teschke et al. (2013) reported that kava hepatotoxicity was presently not reproducible experimentally in preclinical models, as demonstrated by studies showing whole kava extracts were not hepatotoxic. This led them to propose the "working hypothesis" that contaminant hepatotoxins including moulds might have caused rare kava hepatotoxicity in humans and that further studies were warranted to proof or disproof their working hypothesis. Currently, there is a paucity of evidence supporting the recent speculation that adulterants or impurities such as the mould hepatotoxin aflatoxin could more likely cause kava hepatotoxicity rather than kava components, such as kavalactones, pipermethystine and flavokavain B, that had demonstrated hepatotoxicity (Rowe and Ramzan 2012). Although there was limited similarity between acute kava hepatotoxicity and acute aflatoxicosis, and background levels of aflatoxin had been detected in kava samples, there is an urgent need for epidemiological investigations to uncover direct evidence implicating mould hepatotoxins.

Other Adverse Health/ Dermatological Issues

In a hospital-based health survey of 150 people on kava drinking in Vanuatu, Grace (2003) found

that 59 % of men and 15 % of women drank kava (approximately 4:1). 51 % of all men drank kava at least weekly, compared to 11 % of women. For any given kava-drinking episode, men drank more than women, (4.3 vs 3.3 shells). There was no significant difference in age between drinkers and non-drinkers or in usage rates between patient groups or staff. The study revealed that the consumption of fresh kava on a regular basis was very common in Vanuatu. Studies by Cairney et al. (2003) on a group of current, ex and non-kava users among an indigenous population in northern Australia found no impairment in cognitive or saccade function in individuals who were currently heavy kava users (and had been for up to 18 years), nor was there any impairment in individuals who had been heavy kava users in the past but had abstained for longer than 6 months. Current and ex-kava users showed a higher rate of kava dermopathy, lower body mass index, lowered blood lymphocytes and, in addition, current kava users showed elevated liver enzymes. They found no evidence of brain dysfunction in heavy and long-term kava users. In 2000 dermopathy characteristic of heavy use, abnormally low body mass index (BMI), low blood lymphocytes and abnormally high gamma-glutamyl transferase (GGT) occurred more frequently with increased kava use in Arnhem Land Aboriginal communities in the Northern Territory (Clough 2003). These acute effects emerged at average consumption levels of 310–440 g/week of kava powder. The proportion of men drinking kava reached 70 % and women 62 % from mid-1990, with 20 % of the population spending unprecedented amounts of time (14+hours/week) in activities where kava was consumed.

Kava being used for a wide spectrum of therapeutic properties, including sedative, anxiolytic, analgesic and neuroprotective effects, was one of eight herbal supplements identified that could pose the greatest potential risks in surgical patients in the United States (Sullivan et al. 2009). An Australia-wide ban on commercial importation of kava has been in place since mid-2007, but published literature on the impact of the ban had been lacking to date on the impact of the ban (Rychetnik and Madronio 2011). In a review of key evidence, their findings were as follows: causality indicated: scaly skin rash, weight loss, raised gamma glutamyl transpeptidase liver enzyme levels, nausea, loss of appetite or indigestion; association indicated but causality unclear: red sore eyes, impotence or loss of sexual drive, self-reported poor health, raised cholesterol, and loss of time and money, low motivation and "slow/lazy" days following use, reduced alcohol consumption and related violence; association hypothesised: fits or seizures, melioidosis, ischaemic heart disease, protective effects for cancer; no association indicated: cognitive performance; no association suggested: cognitive impairment, liver toxicity or permanent liver damage and other pneumonia; no association hypothesised: hallucinations. The study of Vignier et al. (2011) found that kava drinking was associated with suicidal behaviour among young Kanaks using kava in New Caledonia but information on the effects of kava on mental health in young people was lacking and require further investigations.

Chronic consumption (6 months) of large quantities of an infusion of kava rhizome (5–6 cups daily) had been reported to cause anorexia, diarrhoea and visual disturbances (Siegel 1976). In a healthy volunteer, disturbances of visual accommodation, such as enlargement of the pupils and disturbances in oculomotor equilibrium, were reported following the ingestion of large doses of kava (Garner and Klinger 1985). No changes were recorded in visual or stereoacuity or in ocular refractive error. Mathews et al. (1988) conducted a pilot health survey on kava usage involving 20 very heavy users of kava (mean consumption 440 g/week), 15 were heavy users (310 g/week) and 4 were occasional users (100 g/week). They found that in addition to causing acute intoxication, sedation and relaxation, a rash and weight loss in long-term users, kava may also cause liver and renal dysfunction, hematological abnormalities and possibly pulmonary hypertension. The conclusion that kava affected the liver was based on the markedly elevated plasma levels of γ-glutamyl transferase observed in kava users. Heavy consumption of kava has been reported to lead to adverse health

effects in some Australian Aborigines including the occurrence of pellagroid dermopathy (Cawte 1986, 1988). Bilia et al. (2002) reviewed nine clinical trials and found that three of these trials reported no adverse events, while the other six studies reported gastrointestinal symptoms, tiredness, restlessness, tremor and headache. The number of patients reporting the complaints was similar in the placebo groups. Aside from liver abnormalities or toxicity, adverse effects attributed to kava extracts included gastrointestinal complaints, restlessness, mydriasis, allergic skin reactions, dermatomyositis (Ernst et al. 2001), visual accommodation disorders, pupil dilation and disorders of oculomotor equilibrium (Singh and Blumenthal 1997). Toxic doses (several times the therapeutic dose of approximately 70 mg of kavalactones three times daily) could cause progressive ataxia, muscle weakness and ascending paralysis (Spillane et al. 1997).

Heavy kava drinkers were reported to acquire a reversible peculiar, scaly, ichthyosiform eruption on the skin and kava dermopathy (Norton and Ruze 1994). Traditional kava use at frequent high doses had been found to cause a reversible dermatological condition known as ichthyosiform ichthyosiform kava dermopathy (Süss and Lehmann 1996; Dentali 1997), known as kanikani in Fijian (Gounder 2006). Kava dermopathy was believed to be related to interference with cholesterol metabolism (Ruze 1990; Norton and Ruze 1994; Dentali 1997). Ruze (1990) found that the pellagroid dermopathy was not related to niacin deficiency and was more characteristic of an acquired ichthyosis. In Fiji in 2012, over 1000 kava participants underwent full skin examination, and kava dermopathy was a common cutaneous finding (Hannam et al. 2014). The clinical manifestations of kava dermopathy shared similarities with the spectrum of autosomal recessive congenital ichthyoses, predominantly lamellar ichthyosis. The pathogenesis of Kava dermopathy may be associated with a functional defect in one or more cytochrome P450 enzymes implicated in epidermal integrity, thus mimicking the genetic defect as seen in lamellar ichthyosis type 3. Jappe et al. (1998) described two patients, a 70-year-old man and a 52-year-old woman, with sebotropic drug eruption in sebaceous gland areas induced by 3 weeks of systemic kava kava anti-depressant therapy. Huynh et al. (2014) reported a 55-year-old man presented with an eruption in a sebotropic distribution after consuming kava kava for 3 weeks, which resolved after discontinuation of the supplement. Shimoda et al. (2012) found that mast cells exposed to standardised kava aqueous extracts displayed robust intracellular free calcium responses and concomitant release of proinflammatory mediators. In contrast, mast cells were refractory to single or combinatorial stimulation with kavalactones, including methysticin, dihydromethysticin and kavain. The study suggested that mast cell activation may be a mechanistic component of kava-related skin inflammations.

Studies by Xia et al. (2012) suggested that kava was photocytotoxic and photogenotoxic, both mediated by free radicals generated during photoirradiation. They found that UVA irradiation of kava in the presence of a lipid, methyl linoleate, generated lipid peroxidation which was mediated by singlet oxygen generated during photoirradiation. Of the six major kavalactones (yangonin; 7,8-dihydrokawain; kawain, 7,8-dihydromethysticin; methysticin; and 5,6-dehydrokawain), only 5,6-dehydrokawain and yangonin-induced a low level of lipid peroxidation. UVA irradiation of kava in human HaCaT skin keratinocytes induced cytotoxicity which was mediated by oxidative stress, led to DNA strand cleavage, and produced 8-hydroxy-2′-deoxyguanosine (8-OHdG) adduct. Study by the electron spin resonance (ESR) method revealed that UVA irradiation of kava produced singlet oxygen and carbon-centered radicals.

Schelosky et al. (1995) reported four cases of patients who developed clinical signs suggestive of central dopamine antagonisms after exposure to various kava preparations for anxiety. These case histories suggested that the sedative effects of kava might result from dopamine antagonistic properties of kava extracts. They highlighted the pyramidal side effects of kava preparations and cautioned their use particularly in elderly patients.

Meseguer et al. (2002) reported a 45-year-old female with severe parkinsonism induced by kava kava. The patient, who had a family history of essential tremor, developed severe and persistent parkinsonism after days of treatment with kava extract for anxiety. The symptoms improved with anticholinergics. They asserted that kava derivatives could produce severe parkinsonism in individuals with genetic susceptibility.

A case of rhabdomyolysis temporally related to the ingestion of a large amount of kava was reported by Bodkin et al. (2012) in addition to an earlier case of rhabdomyolysis related to the ingestion of kava. Their patient developed peak creatine phosphokinase levels in excess of 30 000 U/L but had no significant renal damage. In May 2013, a case of hepatitis A infection was reported to a Western Australian regional public health unit, with infection acquired in Fiji (Parker et al. 2014). Following this, two further cases were linked to the index case by kava drinking and one further case was a household contact of a secondary case. This outbreak highlighted that the preparation of kava drink and/or the use of a common drinking vessel could be a vehicle for the transmission of hepatitis A virus.

Traditional Medicinal Uses

Kava has been used in social and ceremonial life in the Pacific islands from ancient times for the soporific and narcotic effects (Bilia et al. 2002). In Polynesia, about thirty syndromes were treated with kava-based preparations (Zepernick 1972). The traditional medicinal uses of kava include treatment of gonorrhoea, syphilis, and cystitis; induction of muscle relation and sleep (Ernst et al. 2001); and treatment of boils, asthma, headache and urinary infections (Hirsch 2000). In the Pacific Oceania, kava is held in high esteem primarily as a ritual offering or a ritualised form of payment (Lebot and Cabalion 1988). To treat injury caused by fish spines, dry kava root is burnt and the injury exposed to the smoke generated.

In Tubuai, a maceration of young kava shoot is taken orally for inflammation of the genito-urinary system (Aitken 1930) In the Pacific Islands, kava is taken as a drink for gonorrhoea and chronic cystitis (Steinmetz 1960). In Papua New Guinea, kava is used as an anaesthetic and stimulant for lactation (Steinmetz 1960); the bark of scraped and masticated root is used to relive sore throats, juice from leaves is used to treat cuts and drunk as tonic (Holdsworth 1977). In certain tribes of Papua New Guinea, women drink fresh masticated kava as an anaesthetic, when they are being tattooed (Steinmetz 1960). They also drink large quantities when they are pregnant, especially just before delivery, to stimulate milk production. In Irian Jaya, the internal skin of the kava plant is used for toothache (Aufenanger and Hötker 1940). In Tahiti, according to Sterly (1970), the masticated root is considered a remedy for gonorrhoea. In American Samoa, kava roots together with fruit of polo fe'u (chilli, *Capsicum annuum*), leaves of fisoa (soap bush, *Colubrina asiatica*) and inner bark of moli'aina (orange, *Citrus sinensis*) are taken internally for gonorrhoea; kava leaves are taken internally for mumu tuala uli (swollen head, sore eyes, cold sweat, dizziness, numbness of legs), and the inner bark with juice of fasa (screw-pine, *Pandanus tectorius*) is taken internally for tulita fasia (urinary tract infection) Harrington and Scotese (2001).

In Hawaii, awa root is used to treat difficulties in urination (Handy et al. 1934; Titcomb 1948) and irritation of the genito-urinary system (Handy et al. 1934); masticated awa and drinking awa are employed for feminine puberty syndromes and weakness, painful migraine, headache, maceration of awa for vaginal prolapus, maceration of masticated awa diluted, boiled and taken orally for general weakness (Titcomb 1948); awa-based medication is used for menstrual problems and dysmenorrhoea, and masticated awa is drank to prevent risk of infection (Handy et al. 1934); maceration of masticated awa is diluted, boiled and taken orally for chills and sleeping problems (Titcomb 1948: Handy et al. 1934; Handy 1940;

Hänsel 1968); masticated awa or as a drink is employed for headaches (Handy et al. 1934; Handy 1940; Titcomb 1948); maceration of rhizome is taken orally for rheumatism and against fat intake (Handy 1940; Titcomb 1948); awa preparation is employed for the irritation of respiratory tract, a maceration of rhizome is taken orally for gastro-intestinal upsets, masticated awa is drank for pulmonary pains, awa is used for certain skin disease and masticated rhizome as poultice against suppuration (Titcomb 1948). Awa drink is administered to children to calm their nervousness (Titcomb 1948), juice from rhizome is used in medication for tuberculosis, medication containing masticated rhizome used externally for leprosy (Degener 1945) and masticated rhizome is used in poultice for skin disease (Hänsel 1968). Awa leaves are placed in-situ to provoke abortion (Handy et al. 1934), and fumigation with leaves is used for chill and general disease treatment (Handy 1940).

In Hawaii, Awa is taken as a therapy for soothing the nerves, relaxing fatigue-stiff muscles, general debility and inducing sleep and a treatment for excessive fat for restoring the body to normal fitness (Titcomb 1948). Awa treatment was also said to overcome scaly and ulcerous skin. Mouritz (1916) stated that an alcoholic awa solution injected into the skin causes anaesthesia, followed by paralysis of the peripheral nerves for several hours. He added that both Hawaiian and *haole* (foreign) doctors use it for venereal and kidney diseases, and, in alcoholic solution or as an unguent, in affections of the skin, including leprosy. Handy et al. (1934) stated that bits of awa root chewed at frequent intervals and awa leaves wrapped around the head were said to protect against contagious disease and to cure headache. *Awa* leaves, stuffed into the vagina, were said to induce miscarriage. Jarrett (1933) mentioned that awa was extensively used in Germany prior to the World War, in the manufacture of certain drugs and medicines.

In Fiji, yaqona is considered a powerful diaphoretic (Parham 1939, 1941). It is also consumed by women as a fortifying drink, laxative and diuretic. In pregnancy, small amount taken is said to facilitate delivery. During breast feeding, awa is taken to stimulate milk production. Kava is used medicinally also for kidney and bladder troubles and as a strong sudorific. Though like all other drugs, if taken in excess it has bad results on account of its excessive action on the skin, and may even super-induce elephantiasis, that terrible complaint, so prevalent in Fijian villages. In Fiji, kava leaves are softened in fire and applied as poultice against suppurations (Degener 1949). Fijian kava is used in traditional medicine against urinary tract infections and asthma (Folmer et al. 2006). Japanese newspaper in early 1985 reported virtues of Fijian yaqona as a remedy against colds and coughing (Lebot and Cabalion 1988)

Ingestion of kava is also reported to aid in first stage of diarrhoea (Thomson 1908; Sterly 1970). In Motalava, Vanuatu, kava roots are used in drink to cure constipation and used for conjunctivitis (Vienne 1981). Eyes are washed with juice squeezed from kava leaves.

Other Uses

The use of kava over the centuries is in the form of a traditional ethnic beverage forming an integral part of social gatherings and ceremonies to increase kinship and amiability, especially in the Polynesian and Melanesian societies, and is widely consumed on a daily basis.

Kava leaf/root/stem extract is used as cosmetic skin-conditioning agents at concentrations from 0.0001 to 0.1 % (Robinson et al. 2009). Data is still wanting on whether kava-derived ingredients would be substantially absorbed through the skin.

Kava had been reported to have antifungal and herbicidal property.

Kava showed a strong inhibition on growth of barnyardgrass (*Echinochloa crus-galli*), monochoria (*Monochoria vaginalis*) and knotgrass

(*Paspalum distichum*), some of the most harmful paddy weeds (Xuan et al. 2003). Kava completely controlled emergence of monochoria and barnyardgrass at a treated dose of 0.5 and 1.0 g, respectively. Application of kava at 1 tonne/ha 6 days after saturating paddy soil with water was an effective treatment. This caused around 80 % reduction of natural paddy weed growth and increased tillering and root number of rice. In addition, kava significantly inhibited growth of the five fungi: *Fusarium solani*, *Pyricularia grisea*, *Rhizopus stolonifer*, *Taphrina deformans* and *Thanatephorus cucumeris*. The effect on *R. stolonifer* was the greatest and *T. cucumeris* and *P. grisea* were the second most affected. Aqueous extract of kava roots showed high allelopathic potential and strongly suppressed germination and growth of lettuce, radish, barnyardgrass and *Monochoria* (Xuan et al. 2006). The six major lactones desmethoxyyagonin, kavain, 7,8-dihydrokavain, yagonin, methysticin and dihydromethystici in kava roots showed great herbicidal and antifungal activities. Growth of lettuce and barnyardgrass were significantly inhibited at 1–10 ppm, and four plant fungi including *Colletotrichum gloeosporioides*, *Fusarium solani*, *Fusarium oxysporum* and *Trichoderma viride* were significantly inhibited at 10–50 ppm (Xuan et al. 2006).

Comments

Kava is readily propagated from mature, freshly harvested entire stems or 1–4 node sections of stems, or by division of the root-mass, or by removal of offsets from the root ball of the plant.

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Chrysopogon zizanioides

Scientific Name

***Chrysopogon zizanioides* (L.) Roberty**

Synonyms

Agrostis verticillata Lam. (illeg.), *Anatherum muricatum* (Retz.) P.Beauv., *Anatherum zizanioides* (L.) Hitchc. & Chase, *Andropogon aromaticus* Roxb. ex Schult. (inval.), *Andropogon muricatum* Retz., *Andropogon muricatus* Retz., *Andropogon nardus* Blanco (illeg.), *Andropogon odoratus* Steud. (inval.), *Andropogon zizanioides* (L.) Urb., *Chamaeraphis muricata* (Retz.) Merr., *Holcus zizanioides* (L.) Stuck., *Oplismenus abortivus* Roem. & Schult. (inval.), *Phalaris zizanioides* L. (basionym), *Rhaphis muricata* (Retz.) Steud. (inval.), *Rhaphis zizanioides* (L.) Roberty, *Sorghum zizanioides* (L.) Kuntze, *Vetiveria arundinacea* Griseb., *Vetiveria muricata* (Retz.) Griseb., *Vetiveria odorata* Virey, *Vetiveria odoratissima* Lem.-Lis., *Vetiveria zizanioides* (L.) Nash, *Vetiveria zizanioides* var. *tonkinensis* A.Camus

Family

Poaceae

Common/English Names

Cus-Cus, Cuscus Grass, Indian Couch Grass, Khus-Khus Grass, Kuskus, Vetiver, Vetiver Grass, Vetiveria

Vernacular Names

Arabic: Izkhir, Usir
Bangladesh: Khas Khas, Bena, Gandhabena, Benamul
Brazil: Capim-De-Cheiro, Capim-Sândalo, Patcholi, Patchuli, Patchuli-Falso, Vetiver (Portuguese)
Burmese: Miyamoe
Chinese: Yan Lan Cao, Xiang Gen Cao
Cook Islands: A'I, Mauku A'I (Maori)
Danish: Vetiverrod
Dutch: Vetivergras, Akar Wangie
Eastonian: Lõhnav Vetiveeria
Ethiopia: Yesero Mekelakeya
Fijian: Mulimuli
French: Chiendent Odorant, Chiendent Des Indes, Vétiver, Vetyver
German: Vetiver, Vetivergras, Vetiverwurzel
Ghana: Dag, Kulikarili (N. Terr.)
Hungarian: Indiai Szövőfű

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India: Usir, Virina (Assamese), Khas, Khas-Khas, Khus-Khus, Khus, Shanader, Vala Bala, Venarramula (Bengali), Sugandhi Valo, Valo (Gujarati), Bala, Balah, Bena, Gandar, Ganrar, Garara, Khas, Khas Bena, Khas-Khas, Khus-Khus, Khus Onei, Panni, Verran Mool (Hindu), Chaaladaberu, Dhappa-Sajjaihullu, Ganduganjala Garike, Kaadu Dappa Kari Sajje Hullu, Kaadu Karay Dappasajje Hullu, Kaddu, Kadu-Karai, Karidappasajjehallu, Kasavu Hullu, Laamancha, Laamanchi, Laavancha, Lamanci, Lavancha, Lavanchi, Madivaala, Marakabbu Hullu, Mudivaala Gida, Mudivala, Usheera, Vattiveeru, Vettiveru (Kannada), Ramaccam, Ramacciam, Ramachehamver, Ramachham, Vettiver, Vettiveru (Malayalam), Bala, Vala, Khas-Khas (Marathi), Birnijono, Sirum, Sirumjon (Mundari), Benachera, Ushira (Oriya), Tin (Oudh), Khas, Panni (Punjabi), Birni (Sadani), Abhaya, Amranala, Amrinala, Avadaha, Dahaharana, Gandhadhya, Haripriya, Indragupta, Ishtakapatha, Jalamoda, Jalashaya, Jalavasa, Katayana, Laghubhaya, Lamajjaka, Mbhu, Nalada, Ramacca, Ranapriya, Raula, Reshira, Samagandhaka, Samagandhika, Sevya, Sevyah, Shishira, Shitamulaka, Sugandhimulah, Sugandhimuta, Ushira, Usira, Usirah, Usiram, Valakam, Vira, Virabhadra, Virana, Viranamula, Viranasipha, Virataru, Vitanamulaka (Sanskrit), Sirom (Santali), Acalamankam, Aciram, Akaru, Alakumulam, Alapatam, Alarppakam, Amaiyam, Amayappul, Amirinalam, Ammai, Ampai, Ampiramulakam, Ampiramulakaver, Aniver, Apayalai, Aram, Arikeca, Avaiyam, Avatanamutircci, Avayakam, Avayakaver, Avayam, Avayavam, Avintuvi, Cailakaver, Calacayam, Calam, Cannakkaranai, Cantanati, Catai, Cayilam, Cayilamalai, Cayilankacceti, Cayilankam, Cayilankamalai, Celam, Celiyal, Celiyam, Celiyaver, Ceviyal, Ceviyam, Ceviyaver, Ceviyitam, Cilettuari, Cilettumavari, Ciram, Ciramam, Ciramappul, Ciravacciram, Cukantamuli, Cukantitam, Curatakanacini, Ilakucam, Ilamaccai, Ilamaccam, Ilamiccaiver, Ilamiccam, Ilamiccam Ver, Ilamichamver, Imiri, Iralam, Irantuvacaver, Iriparaver, Iriperam, Irucatai, Irunakam, Iruveli, Iruver, Istakapatam, Itunakam, Kampu, Kapatam, Kecampu, Koci, Kocikam, Kocikaver, Koki, Koranaipputu, Kulavancanati, Kuruver, Kutiyaippati, Kuttavicartti, Mayilitam, Miccai, Miccu, Mirucirakam, Miruciram, Mirunalam, Mutiver, Nakavi, Nalaccam, Nalakam, Nalakaver, Nalaram, Nalikam, Naruk-kumulam, Narumpul, Natacalacayam, Nerumatankaikkuriyan, Nitinayakan, Paccaivilamiccaiver, Paccaivilamiccaiver, Paiyam, Palam, Piccam, Piccuraver, Pillikkurayan, Pitakam, Talakam, Tampavakam, Tampavakaver, Tirkkamulam, Tiyamam, Uciram, Ukiram, Ukkiram, Uticam, Uticaver, Uticciyam, Uyir, Uyiru, Vacam, Vacanaiver, Vacu, Valakam, Vanticuratakanacani, Varikecam, Vatacancalam, Vattiver, Vekumulam, Vekuvatakam, Vekuvatakaver, Venappili, Venappilikam, Venpilikacceti, Vericceti, Veripitakam, Vetiver, Vetti, Vetti Ver, Vettiver, Vicitalam, Vikarpakam, Vilal, Vilalver, Vilamiccai, Vilamiccaiver, Vilamiccam, Vilamiccu, Vilamicham-Pul, Vilampiccai, Vilari, Vilaricceti, Vilhalver, Viram, Viranam, Viranam, Virani, Virataram, Virkel, Vitacaki, Viyal (Tamil), Avurugaddivaeru, Avurugad-diveru, Kuruvaeru, Kuruveeru, Kuruveru, Lamajjakamuvaeru, Lamajjakamuveru, Vatti Veru, Vattivaeru, Vattiveru, Vettiveellu, Vetti-Vellu, Vettiveerum, Vetti-Veru, Vettiveru, Vidavalivaeru, Vidavaliveru, Wuttay-Gaddi, Wuttee (Telugu), Khas (Urdu)

Indonesia: Akar Manis Akar Wangi, Larasetu (Javanese), Usar (Sundanese)

Italian: Gramigna Indiana, Gramigna Delle Indie

Laos: Faek

Malaysia: Akar Wangi, Khus-Khus, Nara Setu, Nara Wastu

Nepal: Khus Khus

Northern Nigeria: Chor'dor'de, Ngongonari, So'dornde, So'mayo, Zemako (Fulani), Jema (Huasa)
Persian: Bikhiwala, Khas
Philippines: Mora, Mortas, Rimoras (Bikol), Mora, Moras, Tres Moras (Bisaya), Muda (Cebu), Amora (Cebu-Bisaya), Amoras, Anis De Moro (Iloko), Anias De Moras, Ilib (Pampangan), Giron, Rimodas (Panay Bisaya), Remora (Sambali), Raiz De Moras (Spanish), Narawasta (Sulu), Moras, Moro (Tagalog)
Polish: Wetiweria Pachnąca
Portuguese: Vetiver-Da-India
Puerto Rico: Pachuli
Sahel: Babin, Ngoko Ba, Ngongon (Bambara), Dimi, Kieli, Pallol (Fulani), Kulkadere (Gurma), Roudoum (Mossi), Kamare (Sarakolle), Diri (Songhai)
Senegal: Toul (Falor), Semban (Tuk), Sep, Tiep (Wolof)
Sierra Leone: Sumare (Manding-Mandinka), Pindi (Mende), Barewali, Kale (Susu), An-Wunga Ro-Gban, Ka-Bɛnis (Temne)
Spanish: Lacate Violeta, Pachuli, Vetiver
Sri Lanka: Saivander, Savandramul, Sawandara (Sinhalese)
Swedish: Etiveriagräs
Thai: Faek, Ya-Faekhom, Ya-Faeklum
Tibetan: Pu-Sel, Rdo-Dreg
Tongan: Ahisiaina
Vietnamese: Cỏ Hương Bài, Hương Bài, Hương Lau

Origin/Distribution

According to Chen and Phillips (2000) and Truong et al. (2008), the species is native to India and is now distributed globally throughout the warm parts of the Old World and introduced into the United States and West Indies. Vetiver grass is native to tropical Asia in India, Pakistan, Nepal, Myanmar, Sri Lanka and South East Asia and is cultivated in tropical Africa, China, United States and Costa Rica (USDA-ARS 2014).

Agroecology

In its native range, it is found in the plains and lower hills, ascending to an altitude of 1200 m. Vetiver grass is tolerant of extreme soil and climatic variations, such as soil acidity, prolonged drought, flood, submergence and extreme temperature from −14 °C to +55 °C (Truong 2003; Truong et al. 2008). It is robust and rejuvenates rapidly after being affected by drought, frosts, salinity and adverse condition after amelioration with soil amendments. It tolerates soil pH from 3.3 to 12.5 without soil amendment. The plant is highly tolerant to growing medium high in acidity, alkalinity, salinity, sodicity and magnesium and is highly tolerant to Al, Mn and heavy metals such as As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soils. Vetiver grass is also highly efficient in absorbing dissolved nutrients such as N and P and heavy metals in polluted water. It is intolerant of shading. For the production of vetiver oil, light sandy soils are required to facilitate harvesting of the smaller roots, which contain the most oil (de Guzman and Oyen 1999). Also it can survive fire, rough trampling and grazing.The average maximum temperature required for good growth is 25°–35 °C, and this plant grows in areas with annual precipitation ranging from (300–)1000–2000(−3000) mm.

Glasshouse and field studies showed that vetiver grass could produce high biomass (>100 t/ha/year) and to be highly tolerant of extreme climatic variation, such as prolonged drought, flood, submergence and extreme temperatures (−15°–55° C), and soils high in acidity and alkalinity (pH 3.3–9.5), Al (85 % saturation percentage), Mn (578 mg kg(−1)), salinity (ECse 47.5 dS m(−1)) and sodicity (ESP 48 %) and soils with a wide range of heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn) (Danh et al. 2009). Barren soil with minimal organic carbon and moderate salinity showing no plant growth, improved in fertility status along with decrease in salinity by the growth of vetiver in a *Rhizophora*-induced soil environment (Vimala and Kataria 2003). Vetiver survived better than an established wetland species, *Rhizophora*, in all soils, thus indicating that

it is a strong candidate for reclamation of wet land soils. Dudai et al. (2006) found that vetiver could grow in a wide range of substrates, such as sandy soil, loamy sand, clay soil, crushed limestone, sandy clay loam and tuff/peat mixture under Mediterranean conditions.

Edible Plant Parts and Uses

The roots are also used to provide an important ingredient in curry, khasu-khasu in India. In India it yields a fragrant oil which is used in khas syrup and khas water to flavour sherbets as well as to perfume soaps and cosmetics. This extract, called 'khus essence', is added to a sugar, water and citric acid syrup. In India, vetiver essence is used to flavour a soft drink (Sharbat), syrup and ice cream (Lavania 2003). Chopped, dried vetiver roots can be made into potpourri by mixing them with dried fragrant flower petals and spices (Chomchalow and Chapman 2003). A stimulant drink is made from fresh rhizomes in India. In Thailand the Thai traditional beverage 'Nam Ya Faek' is made from vetiver grass (Chomchalow and Hicks 2001; Chomchalow and Chapman 2003).

In the hilly regions of Karnataka, India, people made use of vetiver roots to prepare refreshing drinking water (Sastry 1998). Roots are used to prepare sherbets, ice cream or soft drinks during summer in northern India (Lavania 2003; Pareek and Kumar 2013). Vetiver oil is used for flavouring syrups and ice cream, and in food preservation. Khus essence is used in cool drinks and for reducing pungency of chewing tobacco preparations and to provide sweet note to other masticatories. Vetiver roots are used domestically in cooking; it is infused in tea and also used in baking (Balasankar et al. 2013). In certain canned foods, e.g. asparagus and peas, fractions of vetiver oil are used to reinforce the natural odour and taste (De Guzman and Oyen 1999).

Vetiver grass is used as a flavouring agent, usually through khus syrup. Khus syrup is made by adding khus essence to sugar, water and citric acid syrup. Khus essence is a dark green thick syrup made from the roots of khus grass (vetiver grass). It has a woody taste and a scent similar to khus. The syrup is used to flavour milkshakes and yoghurt drinks like lassi, but can also be used in ice creams, mixed beverages like Shirley Temples and as a dessert topping.

Botany

Vetiver is a coarse, aromatic perennial grass forming large dense clumps with massive, spongy, finely structured, fibrous root systems spreading to a depth of 4 m (Plate 1). Culms are robust, erect, 1–2.5 m tall, and about 5 mm in diameter. Leaf sheaths glabrous, lower sharply keeled, laterally compressed and imbricate in fanlike clusters; leaf blades linear, pale green, stiff, 30–90 × 0.5–1 cm, pilose on adaxial surface towards base, otherwise glabrous (Plate 2); ligule with a scarious margin. Panicle open, exserted, oblong in outline (Plate 3), 15–40 cm, usually

Plate 1 Vetiver grass large dense clump

Plate 2 Vetiver grass—linear leaves

Plate 3 Vetiver grass inflorescence

contracted, purplish; branches numerous, internodes and pedicels slightly scabrid. Spikelets in pairs, 1 sessile and 1 pedicelled, 2-flowered, the pair falling as a unit. Sessile spikelet linear–lanceolate to almost linear, 4–5 mm; callus rounded, subglabrous; lower glume muricate, 3–5-veined, veins spinulosely aculeate, apex acute; upper glume lanceolate, spinulosely aculeate on keel, not awned; upper lemma slightly 2-toothed, awnless or mucronate; not exserted; palea oblong, hyaline, not veined and without keels. Pedicelled spikelet staminate, sparingly aculeolate or almost smooth. Stamens 3, with orange anthers about 2 mm long; pistil with glabrous ovary and 2 plumose, purple stigmas; lodicules 2, free, flesh. Caryopsis with adherent pericarp, rarely formed.

Nutritive/Medicinal Properties

Root Phytochemicals

Vetiver root oil, as one of the finest fixatives used in perfumery, is a highly complex oil containing more than 200 components, mainly sesquiterpene hydrocarbons and their oxygenated derivatives (Pripdeevech et al. 2010). Among these, the major active constituents identified were khusimol, vetivone, eudesmol, khusimone, zizaene and prezizaene (Weyerstahl et al. 2000a, b; Sellier et al. 1991; Martinez et al. 2004; Adams et al. 2004; Hanayama et al. 1973; Kim et al. 2005, Akhila and Rani 2002). Champagnat et al. (2006) reported that the characteristic root oil constituents were β-vetispirene, khusimol, vetiselinenol and α-vetivone.

Vetiver oil is composed of more than 170 compounds that are mainly sesquiterpenes and their derivatives (Nguyen and Fetizon 1963, 1965; Nigam et al. 1968a; Weyerstahl et al. 2000b). Vetiver oil is complex mixture of sesquiterpene alcohols and hydrocarbons; 17 structural types of vetiver oil sesquiterpenes had been identified (Bhatwadekar et al. 1983), and more than 150 sesquiterpenes had been reported (Akhila et al. 1981; Akhila and Rani 2002).

Sesquiterpenes khusone, cussol, khusol, khusenic acid and khusene were isolated from Indian vetiver oil (Zutshi and Sadgopal 1957). The sesquiterpene tricyclovétivène isolated from vetiver essence was found to have the structure 2-méthylène-9-isopropyl-3,6-endométhylène-(0,3,5)-bicyclodécane Ce sesquiterpène (Chiurdoglu and Tullen 1957). Bicyclovetivene and veticadinene were isolated from the products of dehydration of a mixture of bicyclovetivenol and veticadinol, tertiary sesquiterpenic alcohols

of vetiver oil (Chiurdoglu and Delesemme 1961). The structure of the bicyclovetivenol was elucidated as 2-methylene-6-methyl-9-(β-hydroxyisopropyl)-bicyclo-(0,3,5)-decane and that of veticadinol as 2-methylene-8-methyI-(β-hydroxyisopropyl)-bicyclo-5-(0,4,4)-decane. Dihydrobicyclovetivene and dihydroveticadinene were also obtained by dehydration of the corresponding dihydro-alcohols. The structures of two diolefins and two olefins were also determined. A laevorotatory crystalline sesquiterpene alcohol laevojunenol and a dextrorotatory alcohol junenol were isolated from North Indian vetiver oil (Bhattacharyya et al. 1960; Shaligram et al. 1962). The absolute configuration of these two alcohols, from the eudesman group of compounds, has been determined on the basis of the synthesis of dihydrojunenol from santanolide 'c'. The dextrorotatory alcohol junenol has also been similarly synthesised from the ten-membered carbocyclic lactone costunolide (Shaligram et al. 1962). A sesquiterpene hydrocarbon, isobisabolene (Kalsi et al. 1962); antipodal sesquiterpene cadinenic alcohol, khusol (Khalsi et al. 1963); a laevorotatory aldehyde khusilal (Kalsi et al. 1964); antipodal sesquiterpene alcohol cadinane, eudesmane (Kalsi et al. 1979a); cadinane terpenoids, khusinoloxide and epi-khusinol (Kalsi and Talwar 1981); C14 keto-alcohol khusitoneol, a hydroxyl derivative of khusitone (Kalsi et al. 1985a); and antipodal C14 terpenoid norkhusinoloxide (Kalsi et al. 1985b) were isolated from Indian vetiver oil. A sesquiterpene hydrocarbon, (−)γ_2-cadinene was isolated from North Indian vetiver oil (Kartha et al. 1963). Khusinol, a crystalline secondary sesquiterpene alcohol, was isolated from North Indian vetiver oil (Rao et al. 1963). It was found to belong to the unusual antipodal group of cadinenes. A sesquiterpene zizanoic acid (Kido et al. 1967) and minor acids cyclocopacamphenic and epicyclocopacamphenic acids (Kido et al. 1969) were found in vetiver oil. A laevorotatory ketone, khusitone (Trivedi et al. 1964) and γ-cadinene, α-muurolol (old name δ-cadinol) and khusimol (Trivedi et al. 1971) were isolated from North Indian vetiver oil. The authors reported that γ-cadinene co-occurred with γ_2-cadinene, another constituent of the same oil. Two tricyclic sesquiterpene acids khusenic acid and isokhusenic acid were isolated from vetiver oil (Nigam and Komae 1967). Khusimene was isolated from Japanese vetiver oil (Morikawa and Hirose 1967). A laevorotatory antipodal sesquiterpene epoxy alcohol, khusinoloxide, was isolated from North Indian vetiver oil (Seshadri et al. 1967). Zizanoic acid has been identified as a constituent of vetiver oil from Zambia (Grove et al. 1968). Jentsch and Triebs (1968a, b) isolated tertiary vetivenols: tert-bicyclovetivenol and tert-tricyclovetivenol. A sesquiterpenic tricyclic primary alcohol named khusenol was isolated from Angola vetiver oil (Nigam et al. 1968b). α-Vetivone (isonootkatone) (Marshall and Andersen 1967) and β-vetivone (Marshall and Johnson 1970) were identified in Haiti vetiver oil. Tricyclic sesquiterpenes khusenol, tricyclovetivenol and khusimol were reported from Congo and South Indian vetiver oils (Nigam et al. 1968a). Minor sesquiterpene acids zizanoic acid, isovalencenic acid, epizizanoic acid (Hanayama et al. 1968), khusenic acid and isokhusenic acid (Komae and Nigam 1968) were identified in vetiver oil. A bicyclic primary alcohol was isolated from vetiver oil; its structure elucidated it to be a member of the eremophilane series, by correlation with α-vetivone (isonootkatone) (Takahashi 1968). Three aromatic sesquiterpene hydrocarbons α-calacorene, dehydro-curcumene and a cadalene-type hydrocarbon sesquiterpene were isolated from Réunion vetiver oil (Mizrahi and Nigam 1969). An unnamed acidic constituent with a kusilane skeleton was found in vetiver oil (Kalsi and Bhatia 1969). Two sesquiterpene primary alcohols khusimol (Umarani et al. 1969b) and isokhusimol (Umarani et al. 1969a, b) and a C_{14} ketone khusimone (Umarani et al. 1970) were isolated from Indian vetiver oil. Minor sesquiterpene alcohols vetiselinenol, zizanol, cyclocopacamphenol and epicyclocopacamphenol besides khusimol, valerianol (kusunol), β-eudesmol and elemol were found in vetiver oil (Homma et al. 1970). MacSweeney et al. (1970) reported the co-occurrence of tricyclovetivene, tricyclovetivenol and zizanoic acid with α-vetivone and β-vetivone in vetiver oil. A rare nor-terpenoid hydrocarbon

with khusilane framework was isolated from North Indian vetiver oil (Kalsi 1970). The following sesquiterpenes were reported in Reunion and Haitian vetiver oils: α-vetivone, β-vetivone, khusinol, khusimyl acetate elemol, β-eudesmol, vetiselinenol, 2-keto-4,10-*epi*-eudesmane, laevojunenol and zizanene ((+)-α-amorphene), prezizaene, zizanol, agarospirol, α-vetisperene, β-vetisperene, β-vetivenene, vetiselinol, 2-keto-5-hydroxyeudesmane, anhydro-β-rotunol, hinesol, nootkatone, (−)-selina-4(14),7(11)-diene and (−)-δ-selinene (Andersen 1970a, b, c; Andersen et al. 1970; Andersen and Falcone 1971). North Indian variety vetiver oil was found to be distinctly different from that of Reunion and Haiti and may represent a chemically distinct race of *Vetiveria zizanioides* species (Andersen 1970a). A C_{14} hydrocarbon, (+)-khisitene was isolated from North Indian vetiver oil (Raj et al. 1971). The sesquiterpene alcohol epi-khusinol (Kalsi et al. 1972) and isokhusinoloxide, a new sesquiterpene epoxy alcohol (Kalsi et al. 1979b), were found in North Indian vetiver oil. Two new C_{12}-ketones, (+)-(1*S*, 10*R*)-1,10-dimethylbicyclo[4.4.0] dec-6-en-3-one and (+)-(6*S*, 10*S*)-6,10-dimethylbicyclo[4.4.0]dec-1-en-3-one, were isolated from Reunion vetiver oil (Maurer et al. 1972). Structure and absolute configuration of the former compound were established by a four-step synthesis from (+)-isonootkatone ((+)-α-vetivone), while the absolute configuration of the latter was established by chemical correlation with (+)-α-eudesmol. Kaiser and Naegeli (1972) identified 10-epi-γ-eudesmol; β-bisabolol; acora-4,9-diene; acora-4,7-diene; α-cedrene; α-cedrenol; α-cedrenal; α-funebrene; α-funebrenol; α-funebrenal; and α-funebrenic acid in vetiver oil. Two sesquiterpene carboxylic acids, zizanoic and epizizanoic acids, were isolated from the essential oil of vetiver (Hanayama et al. 1973). Minor sesquiterpenes acora-4,9-diene; acora-4,7-diene; α-cedrene; α-cedrenol; α-cedrenal; α-funebrene; α-funebrenol; α-funebrenal; and α-funebrenic acid were found in Indian vetiver oil (Paknikar et al. 1975). Minor sesquiterpene alcohols isovalencenol, vestiselinenol and isovestiselinenol were isolated from North Indian vetiver oil (Karkhanis et al. 1978). Khusinol and allokhusinol were found in vetiver oil (Ganguly et al. 1978a; b). Zizanal and epizizanal were isolated from Javanese vetiver oil (Jain et al. 1982).

Several rare phenols, including 4-vinylphenol, 4-vinyl-2-methoxyphenol and *trans*-isoeugenol, were identified in oil of vetiver (Shibamoto and Nishimura 1982). The tricyclic ketone 2-*epi*-zizanone was isolated from Indian vetiver oil (Moosanagar variety) (Bhatwadekar et al. 1983). An antipodal sesquiterpene diol, vetidol, was isolated from vetiver oil (Kalsi and Talwar 1987).

Oxidation of the sesquiterpenic fraction of Bourbon vetiver essential oil (BVEO) with *m*-chloroperbenzoic acid afforded three new oxidised products, including a zizaene monoepoxide and two diepoxides derived from zizanene and valencene (Bombarda et al. 1996). Reduction reaction of sesquiterpenic epoxides of BVEO led to three sesquiterpenols, including two zizanol epimers and an epoxialcohol derived from valencene, which has been synthesised in high yields (85–100 %).

Four new sesquiterpene ethers, 7β,10β-epoxy-4β*H*-eremophila-1,11(12)-diene; 10β, 11-epoxy-4β*H*-eremophil-1-ene; 4α,7-epoxy-10β*H*-spirovetiva-2,11(12)-diene; and 6α,12-epoxy-7β*H*,10β*H*-spiroax-4-ene, were isolated from the unpolar part of the Haitian vetiver oil (Weyerstahl et al. 1996). The new *cis*-eudesma-6,11-diene was isolated from vetiver oil as a main constituent of the sesquiterpene hydrocarbon fraction (Weyerstahl et al. 1997). Further, six derivatives, 13-*nor*-*cis*-eudesm-6-en-11-one; *cis*-eudesm-6-en-11-ol; *cis*-eudesm-6-en-12-al (2 epimers); 13-*nor*-*cis*-eudesm-6-en-8-one; and *cis*-eudesma-6,11-dien-3-ol, were identified in the oil. The following (*nor*-)sesquiterpene alcohols were isolated as their methyl ethers from the polar part of commercial Haitian vetiver oil and identified as 12-*nor*-ziza-6(13)-en-2β-; and -2α-ol; eudesma-4(15),7-dien-3β-; and -2β-ol; eudesma-3,5-dien-1α-ol; eremophila-1(10),4(15)-dien-2α-ol; eremophila-1(10),11-dien-2α-ol (nootkatol); guaia-1(5),11-dien-3-ol; spirovetiva-3,7(11)-dien-12-ol; preziza-7(15)-en-3α-ol; and helifol-1-en-14-ol (syn. khusien-

14-ol) (Weyerstahl et al. 2000a). Furthermore, the hemi-acetal 7,10-epoxy-salvialan-10-ol was identified. The structure of some artefacts formed by alkylation of β-vetivone 52 and of 11,12, 13-tri-*nor*-eudesmenone was also elucidated. One hundred and fifty-five constituents in the neutral part of commercial Haitian vetiver oil were identified (Weyerstahl et al. 2000a). The following new compounds were found: acora-2,4-diene; and its 10-epimer; 3-isopropyl-2-(3-methyl-cyclopent-2-enyl)-tetrahydrofuran; 3-isopropyl-6-methyl-2-(3-methylcyclopent-2-enyl)-3,4-dihydro-2H-pyran and its precursor 6-hydroxy-3-isopropyl-6-methyl-2-(3-methycyclopent-2-enyl)-3,4,5,6-tetrahydr-2H-opyran; 12,13-di-*nor*-6(7 ← 8)-*abeo*-eremophil-1(10)-en-7-one; 8α-methyl-11,12,13-tri-*nor*-eremophil-1(10)-en-7-one; eudesma-5,7-dien-4-ol (cascarilladienol; 13-*nor*-7,8-epoxy-eremophil-1(10)-en-11-one; eremophil-7(11)-en-10β-ol; 7,11-epoxy-eremophila-1,9-dien-8α-ol and two epimers of 6,12;7,11-diepoxy-eudesm-4-ene and of 7,11;8,12-diepoxy-eremophil-9-ene β-Vetispirene; γ-amorphene; β-vetivenene; elema-1,3-dien-6α-ol (6-*epi*-shyobunol; eudesm-4(15)-en-5β-ol; *trans*-eudesma-4(15),7-dien-12-yl formate (vetiselinenyl formate; ziza-6(13)-en-12-yl acetate; preziza-7(15)-en-12-yl acetate; methyl (*E*)-eremophila-1(10),7(11)-dien-12-oate; and (*E*)-eremophila-1 (10),7(11)-dien-12-yl (isovalencenyl acetate) were also described. The following new natural compounds were characterised from the medium polar part of commercial Haitian vetiver oil (Weyerstahl et al. 2000b): 1,7-cyclogermacra-1(10),4-dien-15-al; 10-*epi*-acor-3-en-5-one; 10-*epi*-acora-3,11-dien-15-al; (*E*)-opposita-4(15), 7(11)-dien-12-al; 13-*nor*-opposit-4(15)-en-11-one; 7-*epi*-*cis*-dracunculifoliol (ax-4(15)-en-7-ol; elema-1,11-dien-15-al (2 epimers); 6,12-epoxyelema-1,3-diene; eremophila-1; 6-dien-12-al (2 epimers); 15-*nor*-funebran-3-one; 7,15-epoxyprezizaane; 15-*nor*-prezizaan-7-one; 12-*nor*-preziza-7(15)-en-2-one; prezizaan-15-al; cyclocopacamphan-12-al (2 epimers); 5,6-*seco*-6,7-furoeudesman-5-one; 11,12,13-tri-*nor*-*cis*-eudesm-5-en-7-one; 11,12, 13-tri-*nor*-*cis*-eudesma-5,8-dien-7-one; 13-*nor*-eudesm-5-en-11-one (2 epimers) and 13-*nor*-*trans*-eudesma-4(15),7-dien-11-one. Two oxiranes, 13-*nor*-4,5-epoxyeudesm-6-en-11-one and 13-*nor*-7,8-epoxy-*trans*-eudesm-4(15)-en-11-one, were also isolated and may be artefacts. The polar part of the oil was converted to the methyl ethers. Distillative and chromatographic separation furnished, among others, β-funebrenyl methyl ether, prezizaenyl methyl ether, khusimyl methyl ether and cyclocopacamphanyl methyl ethers (2-epimers). The presence of alcohols β-funebren-14-ol and prezizaen-12-ol was confirmed. The formerly described configurations of the prezizaane derivatives jinkohol, jinkohol II and jinkoholic acid were formulated as the 2-*epi*-compounds. α-Vetivone, β-vetivone and khusimol could be considered as the 'fingerprint' of vetiver oil (Demole et al. 1995). (*5R,10R*)-(−)-β-vetivone = (*5R,10R*)-(−)-2-isopropylidene-6,10-dimethyl-spiro[4.5]dec-6-en-8-one was reported to have quinoline-like, fruity (cassis, grapefruit) aroma with a woody by-note and (*5S,10S*)-(+)-β-vetivone = (*5S,10S*)-(+)-2-isopropylidene-6,10-dimethyl-spiro[4.5]dec-6-en-8-one to have an unpleasant cresolic, medicinal note (Spreitzer et al. 1998). In 1993, Chen and Lin (1993) isolated from Haitian vetiver oil acoradiene, a kind of spirocyclic sesquiterpene containing the spiro[4.5]decane nucleus.

The major volatile components of vetiver oil (Sri Lankan type) belonged to the sesquiterpene group such as khusimol (12.7 %), α-longipinene (4.20 %), valerenol (3.93 %), epizizanal (3.33 %), α-vetivone (2.02 %) and β-vetivone (1.62 %) (Thubthimthed et al. 2003). Other constituents included terpinene-4-ol (3.75 %), 5-epiprezizane (0.71 %), khusimene (0.66 %), α-muurolene (1.14 %), khusimone (1.49 %), calacorene (0.94 %), β-humulene (2.37 %), γ-selinene (4.13 %), δ-selinene (1.63 %), δ-cadinene (1.72 %), valencene (2.30 %), calarene,-gurjunene (9.84 %), α-amorphene (2.07 %), 3-epizizanol (2.97 %) and isokhusimol (0.57 %). Kim et al. (2005) found over 160 compounds in the crude vetiver oil including major components like khusimol (16.2 %) and bicyclovetivenol (21.3 %) accounting for 37 % of the total crude oil. Other important constituents included β-vetivenene

(1.2 %), α-vetivone (6.6 %) and β-vetivone (5.2 %). In vetiver roots, most of the volatiles in roots were sesquiterpenes; the main component was valencene (30.36 %) (Huang et al. 2004). Nitrogen-containing compounds (33) of vetiver oil comprised substituted pyridines, pyrazines and indolines; two were tentatively identified as isomers of trimethylindoline and isocyanatomethylbenzene (Clery et al. 2005).

Fourteen compounds were identified in vetiver root essential oil from Bangladesh (Bhuiyan et al. 2008): 2,6-dimethyl-10-methylene-12--oxatricyclo[7.3.1.0(1,6)]tridec-2-ene (21.34 %); 2-(4a,8-dimethyl-1,2,3,4,4a,5,6,7-octahydronaphthalen-2-yl)-prop-2-en-1-ol (12.44 %); caryophyllene oxide (5.78 %); juniper camphor (3.49 %); 2-methylenecholestan-3-ol (7.13 %); τ-muurolol (7.54 %); tricyclo[8.6.0.0(2,9)] hexadeca-3,15-diene, *trans*-2,9-anti-9,10-*trans*-1,10- (3.34 %); androstan-17-one; 3-ethyl-3-hydroxy-, (5α)- (4.95 %); 1H-cycloprop[e] azulen-7-ol, decahydro-1,1,7-trimethyl-4-methylene-,[1ar-(1aα,4aα,7β,7aβ,7bα)]- (4.44 %); β-vatirene (4.75 %); 3a,7-methano-3aH-cyclopentacyclooctene, 1,4,5,6,7,8,9,9a-octahydro-1,1,7-trimethyl-,[3aR-(3aα,7α,9aβ)]- (9.59 %); 2(3H)-naphthalenone, 4,4a,5,6,7,8-hexahydro-4,4a-dimethyl-6-(1-methylethenyl)- (4.03 %); 2(1H)naphthalenone, 3,5,6,7,8,8a-hexahydro-4,8a-dimethyl-6-(1-methylethenyl)- (7.78 %); and naphthalene, 1,2,3,5,6,7,8,8a-octahydro-1,8a-dimethyl-7-(1-methylethenyl)-, [1R-(1α,7β,8aα)]- (3.42 %). The Vetiver roots from Banthra near Lucknow on hydrodistillation afforded 0.28 % oil on dry weight basis (Chowdhury et al. 2009). The oil contained sesquiterpene and sesquiterpene derivatives mainly γ-cadinene, clovene, α-amorphene, aromadendrene, junipene, β-himachalene, farnesene, β-bisabolene, *cis*-caryophyllene, khusimol, epiglobulol, spathulenol, khusinol, khusinone, khusimone and khusinol acetate which contributed to the characteristic odour of Vetiver oil. The oil also contained eugenol and isoeugenol. Among 94 isolated compounds, 21 aromatic volatile components were identified from vetiver oil in China, accounting for 53.9 % of the total content (Wang et al. 2009). (2-Isopopenyl-decahyero-4,7-methano-azulen-8-yl)-methanol and other terpene compounds accounted for 11.4 %. Isoeugenol and vanillin were detected in the oil for the first time.

Six compounds, 5,10-pentadecadiyn-1-ol, α-curcumene, hydroxy junipene, (+) cycloisosativene, valencine and selino 3,7 (11)-diene, were isolated from vetiver oil (Gupta et al. 2011). Chou et al. (2012) identified 25 components of vetiver oil and the major components as cedr-8-en-13-ol (12.4 %), α-amorphene (7.80 %), β-vatirenene (5.94 %) and α-gurjunene (5.91 %).

The major components of Brazilian vetiver essential oil were identified as khusimol (19.57 %), *E*-isovalencenol (13.24 %), α-vetivone (5.25 %), α-cadinol (5.01 %), β-vetivone (4.87 %), hydroxy-valencene (4.64 %), junenol (3.58 %), 2-*epi*-ziza-6(13)-em-3-ol (2.79 %) and mustakone (2.75 %) (Lima et al. 2012). Other minor constituents (<2.5 %) were vetivenic acid, nootkatone, spirovetiva-3,7-(11)-dien-12-ol, (*Z*)-β-curcumen-12-ol, nootkatol, junicedranol, 1,7-diepi-α-cedranal, cubenol, 10-*epi*-γ-eudesmol, β-atlantol, khusimone, viridiflorol, maaliol, β-vetivenene, elemol, γ-amorphene, β-vetispirene, γ-gurjunene, khusimene and prezizaene. Eighty constituents, representing 94.5–97.8 % of the oils, were identified in Vetiver oils from Bangalore, Hyderabad, Kundapur and Mettupalayam in South India (Mallavarapu et al. 2012). The oils were found to be rich in sesquiterpenes and oxygenated sesquiterpenes with cedrane, bisabolane, eudesmane, eremophilane and zizaane skeletons. The main components of the four essential oils were eudesma-4,6-diene (δ-selinene) + β-vetispirene (3.9–6.1 %); β-vetivenene (0.9–9.4 %); 13-*nor*-*trans*-eudesma-4(15),7-dien-11-one + amorph-4-en-10-ol (5.0–6.4 %); *trans*-eudesma-4(15),7-dien-12-ol (vetiselinenol) + (*E*)-opposita-4(15),7(11)-dien-12-ol (3.7–5.9 %); eremophila-1 (10),11-dien-2α-ol (nootkatol) + ziza-6(13)-en-12-ol (khusimol) (16.1–19.2 %); and eremophila-1(10),7(11)-dien-2α-ol (isonootkatol) + (*E*)-eremophila-1(10),7(11)-12-ol (isovalencenol) (5.6–6.9 %). The important compounds that imparted the characteristic vetiver odour were

khusimene, δ-selinene, β-vetivenene, cyclocopacamphan-12-ol (epimers A and B), vetiselinenol, khusimol, isovalencenol, khusimone, α-vetivone and β-vetivone. The chemical profiles of the oils were comparable to Haitian vetiver oil.

The in-vitro generated long morphotype vetiver plant in addition to possessing an increase in percentage yield of oil (2.1 %) also showed enhanced composition of oil with respect to important components like α-thujene, camphene, linalyl acetate, bornyl acetate, geranyl acetate, β-elemene, valencene, β-eudesmol and α-cardinol in the long morphotype compared to control plants (1.8 %) (Saraswathi et al. 2011). The chemical composition of essential oil (total oil yield) in natural vetiver plants comprised khusimol (21.45 %), β-vetivone (8.29 %), vetiselinol (5.60 %), α-vetivone (4.30 %), nooketone (4.13 %), β-bisabolol (4.70 %), γ-cadinene (3.61 %), β-vetivenene (2.99 %), vetiverol (2.26 %), α-cardinol (1.73 %), elemol (1.60 %), borneol (1.51 %), zizaene (1.24 %), β-bisabolene (1.19 %) and α-bisabol (1.06) as the major components. Other minor components (<1 % of total oil) were α-thujene, α-pinene, camphene, myrcene, α-terpinene, limonene, (*Z*)-β-ocimene, linalool, (*Z*)-β-terpineol, (*E*)-β-terpineol, terpinene-4-ol, α-terpineol, nerol, geraniol, linalyl acetate, bornyl acetate, neryl acetate, geranyl acetate, β-elemene, valencene, β-eudesmol, α-copaene, β-bourbonene, β-caryophyllene, β-elemene, valencene, salina-4(14)17-diene, nootkatene, 10-epi-γ-eudesmol and β-eudesmol.

Method of cultivation was found to have significant effects on both percentage yield and volatile composition of the vetiver root essential oils obtained by simultaneous steam distillation and solvent extraction (Pripdeevech et al. 2006). The resulting essential oils appeared as brown-yellow viscous liquids, obtained in 0.18, 0.27 and 0.06%yields from vetiver cultivated in normal soil, normal soil with added microbes and semihydroponically, respectively. Volatile components in essential oils obtained from root of vetiver grass cultivated in three different systems, normal soil (37 compounds), normal soil with microbes added (39 compounds) and semihydroponic cultivation (36 compounds), were determined, respectively, as follows: α-nonanal (0, 0, 1.06 %), nonanoic acid (0, 0, 0.99 %), 1-decanal (0, 0, 0.45 %), (*E*)-9,10-dehydro-2-norzizaene (1.87, 5.30, 0.46 %), (*Z*)-9,10-dehydro-2-norzizaene (20.78, 46.03, 14.71 %), α-funebrene (0.14, 0.60, 0.02 %), 2-norzizaene (0.2, 1.56, 0.29 %), acora-2,4-diene (1.93, 1.73, 0.65 %), α-cedrene (0.19, 0.28, 0 %), cascarilladiene (2.26, 2.27, 2.04 %), 11,12,13-tri-*nor*-eremophil-1(10)-en-7-one (0.43, 0.34, 0 %), γ-elemene (0.48, 0.47, 0.18 %), prezizaene (1.55,0.35,0 %), khusimene (3.04, 0.89, 0.42 %), *ar*-curcumene (0.60, 0.44, 0.09 %), 4,7-epoxy-spirovetiva-2,11-diene (1.35,5.59,2.94 %), α-amorphene (0.76, 1.47, 1.30 %), *cis*-eudesma-6,11-diene (0.07, 0.65, 0.14 %), sesquicineole (0, 0.34, 0 %), δ-cadinene (0, 0.22, 0 %), γ-vetivenene (0.83, 1.83, 0.07 %), 10,11-epoxy-eremophil-1-ene (0.56, 0.95, 0.55 %), (+)(6S,10R)-6,10-dimethylbicyclo-[4.4.0]dec-1-en-3-one (2.44, 2.00, 3.21 %), β-calacorene (0.22, 1.18, 0.30 %), 15-*nor*-funebran-3-one (1.45, 1.46, 2.91 %), *cis*-eudesm-6-en-11-ol (1.58, 2.37, 1.09 %), khusimone (20.57, 6.13, 20.91 %), 13-*nor*-*cis*-eudesm-6-en-11-one (1.80, 0.66, 1.35 %), *trans*-dracunculifoliol (1.07, 0.63, 0.77 %), 13-*nor*-eremophila-1(10)-en-11-one (0.18, 0.21, 0.55 %), eudesm-4(15),7-dien-3β-ol (0.43, 0.22, 0.27 %), β-eudesmol (2.61, 2.37, 4.48 %), (*E*)-opposita-4(15),7(11)-dien-12-al (7.71, 3.00, 10.55 %), prezizaan-15-al (0.67, 0.41,0.51 %), 2-epi-ziza-6(13)-en-3α-ol (5.31,1.83, 6.85 %), zizanal (0.09, 0.12, 1.40 %), khusian-2-ol (2.74, 1.24,4.65 %), (*E*)-opposita-4(15),7(11)-dien-12-ol (0.59, 0.41, 0.56 %), cadina-1(10),6,8-triene (0.83, 0.43, 0.79 %), khusimol (1.11,3.55, 12.21 %), 9,10-dehydro-isolongifolene (1.43,0.19, 0 %) and nootkatone (0.21, 0.21, 0.31 %).

Oil yields of 21 vetiver accession ranged from 0.29 to 9.61 %; oil yields (% oil/dry wt.) were highest in those from Nepal and Portugal (Adams et al. 2003). Essential oil production (g/plant) was highest in Nepal and Florida and ranged from 0.02 to 4.17 (g/plant). Khusimol 36 % (China, Guang Dong) to 4.5 % (France, Alternative Therapies Lab.) and (E)-isovalencenol 16.1 %

(Haiti, Texaroma) to 2.2 % (Java, Djasala) were the major components in all genotypes. Most commercial oils contained 1.2–2.9 % vetivenic acid except China, Guang Dong (25.2 %). Nootkanone was found only in traces or absent except for Java, Balansula (0.8 %). Also quantitative differences were found between genotype oils in vetiselinenol, β-vetivone and α-vetivone. Adams et al. (2004) found that non-cleansed (normal) vetiver had typical vetiver oil profile and yielded 0.02 % clear oil, whereas the tissue-cultured (cleansed) vetiver yielded a 0.35 % yield of light yellow oil containing large amounts of C_{19}–C_{29} alkanes plus several alkanols along with typical vetiver oil compounds, but lacked presumed fungal metabolites such as β-funebrene, prezizaene, α-amorphene and β-vetispirene. An unidentified biotic factor (apparently bacteria or fungi) appeared to enhance the oil production in normal vetiver by both increasing yield and by the generation of signature oil compounds. Compounds found in the essential oil of 5-month-old non-cleansed vetiver plant included: khusimol (13.1–24.6 %), (*E*)-isovalencenol (8.9–11.8 %), sesquiterpene alcohol (M222) (2.5–4.5 %), α-cadinol (2–4.6 %), sesquiterpene alcohol (M220) (2.8–3.7 %), β-vetivone (2.1–2.7 %), α-vetivone (1.5–2 %), vetiselinenol (2.4–3 %), β-vetivenene (2–3.7 %) and other minor components: longicyclene, α-duprezianene, β-elemene, β-funebrene, prezizaene, α-amorphene, β-vetispirene, 6,9-guaiadene, (*E*)-isoeugenol, khusimene, δ-amorphene, γ-vetivene, elemol, eudesm-7(11)-en-4-ol, nootkatol and 14-hydroxy-δ-cadinene. Compounds found in the essential oil of 5-month-old cleansed vetiver plant included: khusimol (11.5 %), (*E*)-isoeugenol (6.4 %), (*E*)-isovalencenol (4.2 %), tetracosane (5.2 %), pentacosane (4.9 %), tricosane (4.3 %), hexacosane (3.8 %), *epi*-zizanone (2.4 %), heptacosane (2.4 %), docosane (2.4 %) and other minor components (<2 %): pentadecane; hexadecane; sesquiterpene alcohol (M222); α-cadinol; vetiselinenol; nootkatol; tetradecanol; heptadecanol; octadecane; sesquiterpene ketone (M218); sesquiterpene alcohol (M220); α-vetivone; β-vetivone; 14-hydroxy-δ-cadinene; khusimene; eicosane; heneicosane; nonacosane; octacosane; manool; hexadecanoic acid; nonadecane; 1-dodecanamide, *N,N*-dimethyl-; *o*-guaiacol; *p*-vinylguaiacol; (*Z*)-isoeugenol (tr) and decanal (tr). In subsequent studies they found that tissue-cultured vs. natural plantlets of 'Karnataka' and 'Malaysia' cultivars of vetiver grown in sterilised soil resulted in the largest number of differences in compounds (Adams et al. 2008). The least number of differences of compounds was between tissue-cultured (bacteria and fungi-free) vs. natural plantlets grown in non-sterile soil. Fifty essential oil components were compared, predominated by khusimol (= zizanol) (18.92–25.68 %), *epi*-zizanone (3.20–6.81 %), (*E*)-isovalencenol (7.11–10.06 %), vetiselinenol (2.18–8.76 %), α-vetivone (1.76–3.50 %), α-cadinol (1.45–3.11 %), KI 1675 (unidentified sesquiterpene alcohol, 2.79–15.10 %), KI 1625 (unidentified sesquiterpene alcohol, 4.57–7.19 %), KI 1682 (unidentified sesquiterpene alcohol, 1.49–3.35 %) and KI 1698 (unidentified sesquiterpene alcohol, 2.18–3.14 %) as major components. The other fully identified minor components included: (*E*)-isoeugenol + prezizaene, khusimene, α-amorphene, valencene, α-muurolene, δ-amorphene, elemol, β-vetivenene, *trans*-sesquisabinene hydrate, khusimone, zizanal, nootkatol, 13-hydroxyl valencene, α-costol, nootkatone, β-vetivone, cyclohexadecanolide and hexadecanoic acid. For the Malaysian genotype, zizanal was absent only in the ECHO (Ecological Concerns for Hunger Organization) (natural) plants grown in sterilised soil. For the Karnataka genotype, KI 1605 (unidentified sesquiterpene hydrocarbon) and KI 1679 (unidentified sesquiterpene alcohol) were present in the tissue-cultured plants, but absent in normal (ECHO) plants.

Vetiver oil produced from root cultures of crown explants contained the highest content of terpenoids (19.024 %) followed by rooted callus (10.35 %) and rootip explants (1.68 %) (Esyanti et al. 2013). The following were indentified: monoterpenes 4-ethyl-m-xylene, ψ-cumene, 2-ethyl-1,4-dimethyl-benzene and dandurene and sesquiterpene, phenol,2,4,6-tris (1-methylethyl).

No meaningful differences were observed in the composition of vetiver essential oil from nine geographical origins Brazil, China, Haiti, India,

Java, Madagascar, Mexico, Reunion and Salvador (Champagnat et al. 2006). About 110 constituents were identified in the oils, mainly sesquiterpenes. The characteristic constituents were β-vetispirene (1.6–4.5 %), khusimol (3.4–13.7 %), vetiselinenol (1.3–7.8 %) and α-vetivone (2.5–6.3 %). Steam distillation of dried roots afforded a viscous light-brown oil in about 0.3–1.0 % v/w yield with balsamic earthy and sweet woody odour. Supercritical carbon dioxide extraction resulted in high yield (3.2 %) of vetiver oil in significantly less time than hydrodistillation (Martinez et al. 2004). Brazilian samples had a greater acid amount (especially zizanoic acid) and could be chemically transformed into an alcohol (khusimol) of desirable sensorial properties. Sensory evaluation indicated that the Brazilian volatile oil without acid could be used in perfumery and the extract obtained with supercritical carbon dioxide could have application in food. Pripdeevech et al. (2010) found that comprehensive two-dimensional gas chromatography–mass spectrometry was more efficient in differentiating the quality of vetiver essential oils obtained from diverse extraction conditions in terms of their volatile compositions and content than gas chromatography–mass spectrometry. Vetiver alcohols (such as khusimol, isovalencenol, vetiselinenol) and esters in Haitian vetiver essential oils and vetiver acetates were purified and quantified using high-performance thin-layer chromatography by Paillat et al. (2012). High linear correlation with $R^2 = 0.9995$ for alcohols and $R^2 = 0.9996$ for acetates were obtained. Skeleton of vetiver alcohols were identified in both standard 1 reference mixtures RM1 (eudesmane, helifolane) and standard 2 RM2 (cadinane, eremophilane, spirovetivane, zizaane/prezizaane and cyclocopacamphane).

Aerial Part Phytochemicals

The contents of K, N, Ca, P, Mg and S in vetiver leaves were 11.2, 7.6, 4.3, 2.7, 2.8 and 1.5 mg/g, respectively (Zhou and Yu 2012). Contents of cellulose, hemicellulose and lignin in vetiver leaf cultivated in experimental field were 326.1, 380.2 and 147.8 mg/g and cultivated in the beach were 321.7, 369.5 and 154.0 mg/g respectively. Contents of benzene–ethanol extractives were 59.5 and 54.1 mg/g and ash were 81.7 and 71.7 mg/g between the two locations respectively. Among hydrolysis products in the leaf of vetiver cultivated in experimental field and beach, contents of glucose and xylose were higher with 368.3 and 359.9 mg/g and 245.7 and 204.3 mg/g, respectively, and contents of arabinose, galactose and mannose were lower with total contents of 58.6 and 55.8 mg/g, respectively.

In vetiver shoots and leaves, the major compounds found were 9-octadecenamide (33.50 %), 2,6,10,15,19,23-hexamethyl-2,6,10,14,18,22-tetracosahexaene (27.46 %) and 1,2-benzendicarboxylic acid, diisooctyl ester (18.29 %) (Huang et al. 2004). Three monoterpenes, two sesquiterpenes and one triterpene were found among the shoot volatiles. Nine compounds cholesterol; 1,2-*bis*(4-hydroxy-3-methoxyphenyl)-propane-1,3-diol; 1-*O*-feruloylglycerol; 1-*O*-p-coumaroylglycerol; *trans*-*p*-hydroxycinnamic acid; vladinol E; vladinol F; tricin 4'-*O*-(*erythro*-guaiacylglyceryl) ether, and tricin 4'-*O*-(*threo*-guaiacylglyceryl) ether were isolated from aerial parts of vetiver grass (Gao et al. 2012).

Studies showed that when vetiver grass was exposed to moderate (20 % and 40 % polyethylene glycol (PEG) 6000 solutions) and severe (60 % PEG solution) water deficit for 6 days, the plant injury degree (expressed as the parameters of plant growth, cell membrane integrity, water relations and photosynthesis) increased and contents of free and conjugated putrescine decreased with the rise of PEG concentration (Zhou and Yu 2010). Under moderate water deficit, the plants could survive by the reduced osmotic potential and increased free and conjugated spermidine and spermine in leaves. After subsequent rewatering, the osmotic balance was re-established, most of the above investigated physiological parameters were fully or partly reverted to control levels. The data indicated that vetiver grass could cope well with the moderate water deficit/drought stress by using the strategies of osmotic adjustment and maintenance of total contents of free, conjugated and bound polyamines in leaves.

Antioxidant Activity

Vetiver oil at 10 µl/ml concentration exhibited higher DPPH radical scavenging effect (93 %) than that of 1 mM BHT (73 %) and equivalent to 1 mM α-tocopherol (93 %) (Chen et al. 2003). Studies showed that vetiver oil (VO) possessed a strong free radical scavenging activity when compared to standard antioxidants such as butylated hydroxytoluene (BHT) and α-tocopherol (Kim et al. 2005). However, its metal chelating capacity was relatively weak. VO (10 µL/mL) dissolved in methanol exhibited about 93 % free radical scavenging activity in the DPPH* assay and about 34 % Fe^{2+} chelating activity in the metal chelating assay. Among the complex constituents in the crude vetiver oil, β-vetivenene, β-vetivone and α-vetivone, which had shown strong antioxidant activities, were isolated and identified.

KS1 genotype of *V. zizanioides* showed higher ferric reducing antioxidant power (FRAP), 1,1-diphenyl-2-picrylhydrazyl (DPPH), total phenolic content (TPC) and reducing power potential compared to Gulabi genotype, and the antioxidant activity increased with the concentration of the extract (10–1000 µg/mL) (Luqman et al. 2009). A significant protective effect of cv KS1 (100 µg/mL) extract was also observed in reduced glutathione (GSH) and malondialdehyde (MDA) concentrations of erythrocytes subjected to oxidative stress by tert-butyl hydroperoxide (t-BHP) and hydrogen peroxide. The ethanolic extract and ethyl-acetate extract of vetiver showed DPPH radical scavenging activity of 40.7 % and 59.3 % and IC_{50} values of 157.38 & 112.79 µg/ml respectively (Tarai et al. 2010). The generation of free radicals O_2, H_2O_2, OH and NO were effectively scavenged in-vitro by vetiver root ethanolic extract (Subhadradevi et al. 2010). Vetiver extract showed strong antioxidant activity in a dose-dependent manner. The results obtained indicated that *V. zizanioides* scavenged free radicals, ameliorating damage imposed by oxidative stress in different disease conditions, and may serve as a potential source of natural antioxidant.

The water-soluble alkaline extract of vetiver grass representing the cell wall-bound fraction contained the highest amount of total phenolic acids (2.62 µM/g FW GA equivalent) and exhibited the highest antioxidant activity of 65.2 % TEAC value obtained by ABTS assay (Prajna et al. 2013). The water-soluble acidic fraction contained 2.03 µM/g FW GA equivalent total phenolic content and 54.73 % TEAC antioxidant, while methanol-soluble acidic fraction contained the lowest total phenolic content of 0.97 µM/g FW GA equivalent and lowest antioxidant activity of 21.45 % TEAC. The compounds *p*-coumaric acid, *p*-dihydroxybenzoic acid and ferulic acid were detected in the acidic extracts. Antioxidant property expressed as percentage TEAC value obtained by ABTS assay was correlated with the amount of phenolic acids and showed a Pearson's coefficient of 0.988.

Anti-inflammatory Activity

Vetiver oil was reported to suppress the inflammatory responses of LPS-stimulated RAW 264.7 macrophages, including nitric oxide production and cell apoptosis, by regulating the expression of the inflammation-related enzymes heme oxygenase-1, inducible nitric oxide synthase and cyclooxygenase-2 (inducible cyclooxygenase) and the inflammatory cytokines tumour necrosis factor-α, interleukin-1β and interferon-β (Chou et al. 2012). Additionally, the anti-inflammatory activity of vetiver oil correlated with its antioxidant activity of decreasing LPS-induced superoxide anion production and malondialdehyde levels. The vetiver oil inhibited the carrageenan-induced leukocyte migration to the peritoneal cavity in a dose-dependent manner (34.7, 35.4 and 62.5 % at doses of 25, 50 and 100 mg/kg, respectively) (Lima et al. 2012). In the paw oedema test, vetiver oil (100 mg/kg) inhibited all three phases of the oedema equally well, suggesting that the EO had a non-selective inhibitory effect on the release or actions of these mediators.

A polyherbal formulation containing *Vetiveria zizanioides*, *Aegle marmelos*, *Coriandrum sativum*

and *Cyperus rotundus* exhibited significant inhibitory activity against inflammatory bowel disease in two different experimental animal models of inflammatory bowel disease, namely, acetic acid-induced colitis in mice and indomethacin-induced enterocolitis in rats (Jagtap et al. 2004).

Antidiabetic Activity

Studies showed that ethanol extract of *V. zizanioides* root possessed antihyperglycaemic activity (Karan et al. 2012). It was observed that ethanol extract of *V. zizanioides* (100, 250, 500 and 750 mg/kg body weight) significantly reduced the blood-glucose level at the end of 28 days in alloxan-induced diabetic rats.

Anticancer Activity

At 100 ppm in cancer cell lines, Vetiver oil at 100 ppm inhibited in-vitro growth up to 89 % of SiHa and 88 % of CaSki cervical cancer cells and 89 % of MCF-7 breast cancer cells (Chen et al. 2003).

Sedative Activity

The sedative effect of vetiver oil upon inhalation in rats was observed in rearing (standing upright on hind legs) motilities in the open field test (Thubthimthed et al. 2003). The results showed that vetiver oil decreased rearing motility when compared to the positive control lavender oil group.

Antidiuretic Activity

The sesquiterpene alcohol khusimol isolated from *Vetiveria zizanioides* root was found to competitively inhibit the binding of vasopressin to rat liver V1a receptors (Rao et al. 1994).

Antimicrobial Activity

The hexane extracts of intact roots and spent roots after distillation of *Vetiveria zizanioides* varieties (Gulabi and KS-1) were found to show potent activity in-vitro against the drug-resistant strains of *Mycobacterium smegmatis* and *Escherichia coli* (Luqman et al. 2005). The minimum inhibitory concentration of the intact and spent root extracts of both varieties against *M. smegmatis* ranged from 62.5 to 250 μg/ml, and for *E. coli*, the range was from 0.5 mg/ml to 60 mg/ml. The variety Gulabi exhibited higher antibacterial activity than KS-1crude methanolic Vetiver root extract showed antimicrobial activity; its most active constituent vetiverin showed antifungal activity against *Trichophyton mentagrophytes* with minimum inhibitory concentration (MIC) value of 1628 μg/ml (Nantachit et al. 2010). Vetiver essential oil showed significant antimycobacterial activity against the drug-resistant strains of *Mycobacterium smegmatis* (Gupta et al. 2011). Purification of the bioactive fractions yielded six compounds: 5, 10-pentadecadiyn-1-ol, α-curcumene, hydroxy junipene, (+) cycloisosativene, valencine and selino 3,7 (11)-diene. All these compounds showed significant antimycobacterial activity against the drug-resistant strains (MDR-R and MDR-40) of *M. smegmatis*, and their MIC was in the range of 31.25–62.5 lg/ml. The ethanolic extract of intact as well as spent Vetiver root exhibited potent antituberculosis activity at a minimum concentration of 500 μg/mL (Saikia et al. 2012). The hexane fraction also showed antibacterial action by recording continuous decline in growth index (GI) of *Mycobacterium tuberculosis* at 50 μg/mL.

Vetiver leaf and root extracts exhibited antimicrobial activity (Sangeetha and Stell 2012). The order of antibacterial activity for the methanol, chloroform and hexane vetiver leaf extract based on minimum inhibitory concentration (MIC) values was as follows: *Staphylococcus aureus* (2.50, 5, 10 μg/ml), *Escherichia coli* (5, 10, 20 μg/ml),

Klebsiella pneumoniae (5, 10, 20 µg/ml), *Streptococcus faecalis* (10, 20, 40 µg/ml), *Pseudomonas aeruginosa* (10, 20, 40 µg/ml) and *Salmonella typhi* (20, 20, 40 µg/ml). The order of antifungal activity for the methanol, chloroform and hexane vetiver leaf extract based on minimum inhibitory concentration (MIC) values was as follows: *Aspergillus niger* (1.25, 5, 10 µg/ml), *Trichophyton mentagrophytes* (5, 10, 20 µg/ml), *Aspergillus flavus* (5, 10, 20 µg/ml), *Candida albicans* (10, 20, 20 µg/ml) and *Saccharomyces cerevisiae* (10, 20, 40 µg/ml). The order of antibacterial activity for the methanol, chloroform and hexane vetiver root extract based on minimum inhibitory concentration (MIC) values was as follows: *Staphylococcus aureus* (1.25, 2.5 µg/ml), *Escherichia coli* (2.5, 5, 5 µg/ml), *Klebsiella pneumoniae* (2.5, 5, 10 µg/ml), *Pseudomonas aeruginosa* (2.50, 5, 10 µg/ml), *Streptococcus faecalis* (5, 10, 20 µg/ml) and *Salmonella typhi* (5, 10, 20 µg/ml). The order of antifungal activity for the methanol, chloroform and hexane vetiver root extract was as follows: *Aspergillus niger* (1.25, 5, 10 µg/ml), *Trichophyton mentagrophytes* (5, 10, 20 µg/ml), *Aspergillus flavus* (10, 10, 20 µg/ml), *Candida albicans* (10, 20, 40 µg/ml) and *Saccharomyces cerevisiae* (10, 20, 40 µg/ml).

Vetiver extracts were found to be more potent against the gram negative *Escherichia coli* in comparison to *Bacillus subtilis* and *Micrococcus luteus*, except for the alkaline methanol-soluble fraction which was more potent against *M. luteus* and the methanol-soluble acid extract which was more active against *B. subtilis* (Prajna et al. 2013). The water-soluble and methanol-soluble alkaline extract showed the lowest LC_{50} values and hence the highest activity against *E. coli*. Alkaline extract dissolved in methanol showed the highest activity against *B. subtilis* and *M. luteus*. In contrast, the methanol-soluble alkaline fraction consistently showed better antifungal activity against *Aspergillus niger* and *Macrophomina phaseolina*. The water-soluble acidic fraction and the methanolic fraction were more effective against *Fusarium oxysporum*.

Recent studies showed that khusenic acid was 4 times more active than the standard drugs ciprofloxacin and nalidixic acid against the ciprofloxacin (CSC 101) and lomefloxacin (LOMR5)-resistant *Mycobacterium smegmatis* mutants, whereas khusimol was two times more active against the CSC 101 than nalidixic acid and ciprofloxacin (Dwivedi et al. 2013). Further, the virulent strain H37Rv of *Mycobacterium tuberculosis* khusenic acid was two times more active than nalidixic acid, while khusimol was equally active to nalidixic acid. In in-silico docking study, khusenic acid showed better binding affinity than khusimol with both subunits of the bacterial DNA gyrase, which was further confirmed from the in-vitro bacterial DNA gyrase inhibition study. Also, khusenic acid and khusimol showed better intestinal absorption, aqueous solubility and ability to penetrate the blood–brain barrier. Finally, khusimol was found safe at the highest dose of 2000 mg/kg body weight. Being edible, fragrant natural products, khusenic acid and khusimol from vetiver oil could have an advantage over the existing synthetic drugs.

Anticonvulsant Activity

Studies by Gupta et al. (2013) demonstrated that oral administration of *V. zizanioides* extract exerted significant anticonvulsant activity in mice with an LD_{50} of 600 mg/kg body weight. Vetiver ethanol extract at a dose of 400 mg/kg significantly reduced flexion (l5.98–3.73 s), extension (13.73–0.96 s), clonus (14.07–4.93 s) and stupor (6.29–1.22 s) in the maximal electroshock stimulation model. Further, it increases onset of clonic (88.25–708.32 s/30 min) and tonic (139.52–1126.39 s/30 min) in the pentylenetetrazol model. Vetiver oil exhibited anticonvulsant activity in both maximal electroshock (MES)- and pentylenetetrazol (PTZ)-induced seizure models in mice (Maignana Kumar et al. 2014). Vetiver oil exhibited equivalent efficacy as that of sodium valproate in PTZ model and comparatively lesser

effect in MES model, and thus it had a potential to be used as a sole antiepileptic/adjuvant drug in epilepsy. Its antiepileptic activity could be attributed to its rich content of sesquiterpenes that had anticonvulsant action.

Hepatoprotective Activity

Vetiver methanolic root extract exhibited hepatoprotective activity against 20 % ethanol (3.76 g/kg/d, p.o. for 18 days) induced liver damage in rats (Parmar et al. 2008). Treatment with methanolic vetiver extract (300 and 500 mg/kg/d, p.o. for 18 days) and silymarin significantly prevented the functional, physical, biochemical and histological changes induced by ethanol, indicating the recovery of hepatic cells.

Cognitive Stimulating Activity

Studies by Matsubara et al. (2012) found that volatile compounds emitted from vetiver roots under low-dose (0.25 μg) conditions may help subjects to maintain performance in visual discrimination tasks while maintaining high sympathetic nerve system activity. Participants who breathed the volatile compounds emitted under low-dose conditions showed faster reaction times during a visual display terminal task and stimulation of sympathetic nerve activity as measured by electrocardiography.

Antinociceptive Activity

Following intraperitoneal injection vetiver essential oil at 50 and 100 mg/kg significantly reduced the number of writhes (51.9 and 64.9 %, respectively) and the number of paw licks during phase 2 (56.7 and 86.2 %, respectively) of a formalin model when compared to control mice (Lima et al. 2012). However, vetiver oil-treated mice were ineffective at all doses in hot-plate and rotarod tests.

Antimelanogenesis Activity

Vetiveria zizanioides essential oil markedly decreased melanin production and tyrosinase activity in α-melanin-stimulating-hormone (α-MSH)-stimulated B16 cells (Peng et al. 2014). The results demonstrated that the activity of vetiver oil on melanogenesis might be the result of its potent antioxidative ability, which was reflected in the decreased cellular oxidant and malondialdehyde (MDA) levels and the restored activities of superoxide dismutase (SOD), glutathione peroxidase (GPX) and catalase (CAT) in α-MSH-stimulated B16 cells. Vetiver oil also exhibited potent lipid peroxidation inhibitory activity to moderate the bleaching of β-carotene and to maintain the cellular glutathione (GSH) levels. The most abundant compound in VZ-EO was cedr-8-en-13-ol (12.4 %), which has a strong capability to inhibit lipid peroxidation.

Mosquito Repellent/Insecticidal Activity

Zizanal and epizizanal, two new insect-repelling aldehydes, were isolated from Javanese vetiver oil (Jain et al. 1982). Essential oil-loaded nanoemulsions composed of citronella oil (10 % w/w), hairy basil oil (5 % w/w) and vetiver oil (5 % w/w) with mean droplet sizes ranging from 150 to 220 nm were found to have improved physical stability and prolonged mosquito repellent time to 4.7 h (Nuchuchua et al. 2009). Vetiver essential oil was found to be larvicidal and repellent to *Anopheles stephensi* adults (Aarthi et al. 2014). The LC_{50} value at 24 h post-treatment for larval instars 1–4 were, respectively, 281, 356, 389 and 475 mg/L. The repellency of topically applied vetiver oil tested at rates of 0.5 mg/cm^2, 1 mg/cm^2 and 1.5 mg/cm^2 was 100 % for 2, 4 and 5 h, respectively. After 12 h, the level of protection from mosquito bites provided by vetiver essential oil was 52 % at the 0.5 mg/cm^2 rate, 62 % at the 1 mg/cm^2 rate and 76 % at the 1.5 mg/cm^2 rate.

Source of Xylitol

Studies by Chuntranuluck et al. (2013) showed that xylitol, one of the most expensive polyol sweeteners with specific health claims, could be obtained from the hemicelullosic fraction of lignocellulosic materials containing xylose, such as vetiver grass. The chemical analysis of the dry vetiver grass indicated that the amounts of extractive, lignin, holocellulose, cellulose, pentosan and ash were 9.12, 9.97, 59.85, 30.71, 29.13 and 2.89 %, respectively. After hydrolysis by steam explosion and sulfuric acid, the chemical composition of the hydrolysate obtained was glucose, xylose,aceticacid,furfural,5-hydroxymethyfurfural and phenolic compounds with amounts of 0.749, 6.528, 3.397, 1.117, 0.120 and 0.077 g/L, respectively. Removal of inhibitory substances, namely, acetic acid, furfural, 5-hydroxymethyfurfural and phenolic compound, produced a detoxified hydrolysate with a yield of 6.528 g/L of xylose. Fermentation of the detoxified hydrolysate by *Candida guilliermondii* afforded a xylitol yield per amount of xylose and productivity was 0.359 g/g and 0.110 g/L/hr, respectively.

Traditional Medicinal Uses

Vetiver roots are stimulant, tonic, cooling, stomachic, diuretic, antispasmodic and emmenagogue and used in fevers, inflammations and irritability of stomach (Bhuiyan et al. 2008). Essence of the root is used to check vomiting in cholera. Smoke of vetiver grass is inhaled to relieve headache (Ghani 2003). Apart from its use as insect repellent and soil erosion management tool, vetiver grass has numerous traditional uses such as root paste for headaches and leaf paste for rheumatism and sprains. Various tribal people in the subcontinent use different parts of the grass for many of their ailments such as mouth ulcer, fever, boil, epilepsy, burn, snakebite, scorpion sting, rheumatism, headache, etc. (Singh and Maheshwari 1983; Jain 1991). The root paste is used for headache and toothache; the leaf paste is used for lumbago, sprain and rheumatism; the stem decoction for urinary tract infection; the leaf juice as an anthelmintic; the vapours for malarial fever; and the root ash is given for acidity relief. *Vetiveria zizanioides* is widely used as a traditional plant for aromatherapy, to relieve stress, anxiety, nervous tension and insomnia (Subhadradevi et al. 2010). Vetiver oil possesses sedative property and has been traditionally used in aromatherapy for relieving stress, anxiety, nervous tension and insomnia (Jain 1991). Vetiver drug has been reported to be used as liquid, oil or capsule and to be effective for treating prostate cancer, diabetes, hernia, incontinence, stomach ailments, skin diseases and irritations (Berudep 2003). This plant is used extensively in Indian folklore medicine and is used in treatment for a wide range of disorders including seizures (Gupta et al. 2013). Vetiver grass has been prescribed in the Indian system of medicine for a number of diseases: as decoction in high fever, inflammation and sexual disorder, as paste in diarrhoea, chronic dysentery and in Ayurvedic preparations and as anthelmintic juice (Bhushan et al. 2013). Ayurvedic literature mentioned that the plant is used for its carminative, stomachic, constipating, haematinic, expectorant, antispasmodic, antiasthmatic, antigout, anthelmintic, antimicrobial and diuretic properties. The roots are used for cooling the brain and also used in treatment of ulcers. In addition to these, the plant is used for anaemia, amenorrhea and dysmenorrhoea.

In Trinidad and Tobago, *Vetiveria zizanioides* has been employed to treat kidney ailments (Lans 2006) and for childbirth and infertility (Lans 2007). According to Burkill (1966), the Malays use the roots to scent a lotion and powder applied moist to body after childbirth; in the Philippines, a root decoction is lithotriptic and used to break up gall bladder stones, and in India, a weak infusion of the roots is given as febrifuge and a powder for bilious complaints, and a paste is applied for fever.

Other Uses

The uses of vetiver grass have been comprehensively reviewed by Chomchalow and Chapman (2003). Conventional uses of live vetiver grass

include: soil and water conservation, slope stabilisation, erosion control (road slopes and banks of reservoir), environmental protection (hedges to keep off dust and heat), absorption of heavy metals, water purification, disaster mitigation and waste-water treatment. Non-conventional uses of live vetiver plant include as forages for livestock grazing, fish feed, ornaments (landscape plants, hedge and potted plants for gardens, patios and decks) and field boundary markers. Dried or partially dried plant (leaves, culms and roots) by-products from non-processed plant materials are used as roof thatch, compost, mulch, potting medium, mushroom medium (for shiitake and oyster mushrooms), animal fodder and bouquet displays; semi-processed products include handicraft, botanical pesticides, pots, low-cost silo, energy sources (ethanol, green fuel), furniture, botanical pesticides and some industrial products. Fully processed products include essential oil and its derived products, herbal medicine, pulp and paper, fibreboard, pozzolana cement and industrial products, etc.

Construction Material

VGA (vetiver grass ash) mortar was found to be suitably adopted as a construction material for foundations, marine structures, sewers and other chemically exposed structures (Nimityongskul et al. 2003). Test results revealed that the silica content of vetiver grass ash was approximately 7 % higher and potassium oxide (K2O) content about seven times higher than in fly ash, and according to ASTM requirement VGA could be classified as class C pozzolana. Paddy storage silo could be made from vetiver grass and clay. Studies by Hengsadeekul and Nimityongskul (2004) found vetiver–grass–clay composite provided good insulation material that could reduce the effects of temperature and relative humidity outside of the silos and extend the storage period and maintain the quality of paddy. Vetiver grass could be used with clay to substitute bricks for housing construction (Hengsadeekul and Nimityongskul 2005). Due to the prefabricated vetiver–clay block wall having a rather low thermal conductivity, the house is more comfortable and energy saving. Moreover, both vetiver and clay are an abundant indigenous material, and construction using this composite is inexpensive and requires local-based skills, which can be considered as labour-based appropriate technology (LBAT) for the community.

Perfumery and Aromatherapy

It is the major source of the well-known oil of vetiver, which is used in medicine and in perfumery (Rao and Suseela 2000). Vetiver grass is also cultivated for the production of a commercially important essential oil used in perfumery and aromatherapy (Weyerstahl et al. 1996; Chowdhury et al. 2009). Vetiver oil and its constituents are used extensively for blending oriental type of perfumes and floral compounds, as well as in other cosmetic and aromatherapy applications (Lavania 2003). Vetiver oil is a main ingredient in 36 % of all Western-quality perfumes and 20 % of all men's fragrances. It is very persistent and one of the finest fixatives known. Dried roots are used as sachets/stuffing material to prepare ventilating screens that provide cool air effect and pleasant aroma when moistened.

Erosion Control

The Vetiver system is the premier soil erosion method outside of temperate zones (Anonymous 2014). Narrow hedgerows of Vetiver grass will spread out rainfall runoff across the slope, act as a filter to trap erosion sediment, create natural terraces and reduce the velocity of rainfall runoff. It is used on farm soil and for water conservation, rehabilitation of eroded lands and prevention of erosion on sloping lands. The Vetiver system when applied to such slopes significantly reduces the probability of land slippage and reduces the need for 'hard solutions'. Applications include highway, railway, riverbanks, public utility right of ways, canal, dikes and levee slopes.

In north Queensland, the establishment of vetiver grass has been shown to control channel

bank erosion, lower frequency of drain maintenance, trap sediments in runoff water and reduce acidic loading by exposing less acid sulphate soil in the drain wall to oxidisation and leaching (Troung et al. 2003).

Biofuel/Bioethanol/Biocoal Production

Broken vetiver culms and leaves that cannot be utilised for other purposes can be mixed with water hyacinth, as a mixer, in a proportion of 3:2 as green fuel (Babpraserth et al. 1996). Of 11 types of grasses selected as feedstocks for the ethanol production by simultaneous saccharification (using cellulase, xylanase) and co-fermentation with yeasts, *Saccharomyces cerevisiae* and *Pichia stipitis*, the highest yield of ethanol, 1.14 g/L or 0.14 g/g substrate equivalent to 32.72 % of the theoretical values, was obtained from Sri Lanka ecotype vetiver grass (Wongwatanapaiboon et al. 2012). On dry matter yield basis, Sri Lanka ecotype vetiver grass gave the yield of ethanol at 1091.84 L/ha/year, whereas the leaves of dwarf napier grass showed the maximum yield of 2720.55 L/ha/year (0.98 g/L or 0.12 g/g substrate equivalent to 30.60 % of the theoretical values). Among six tested plant species grown on floating beds in eutrophic water, *Miscanthus sinensis* and *Vetiveria zizanioides* were dominant in growth, annual biomass production, nitrogen phyto-uptake, phosphorus phyto-uptake, sulphur phyto-uptake and carbon sequestration (Zhao et al. 2012). Neutral-detergent fibre, acid-detergent fibre, acid-detergent lignin, cellulose and hemicellulose contents of these species were similar to switchgrass. The large amounts of above-ground biomass produced from the water treatment processes could be valuable resources for bioenergy production. Both species were most promising as bioenergy plants for biomass production and nutrient removal grown on floating beds in eutrophic water.

Biocoal samples prepared from aromatic plant waste of two perennial grasses, i.e. *Cymbopogon flexuosus* (lemongrass) and *Vetiveria zizanioides* (khus) after oil extraction, root of *Rosa damascena* (rose) and bark of *Eucalyptus citriodora* afforded biocoals with good calorific values (Yadav et al. 2013). Owing to their similar fuel properties as high sulphur sub-bituminous coal, they could be good candidates for cofiring. Blending of these biocoals with high sulphur coals will serve a dual purpose: (1) alternate fuel and (2) reduction in SO_2 emission.

Land Rehabilitation and Phytoremediation

Studies in South Vietnam found that planting of vetiver grass greatly improves bank stability and reduces bank erosion in acid sulphate soils (Du and Truong 2003). Vetiver grass could improve the quality of water in drainage channels by removing considerable amount of some toxic elements leaching from the ASS embankment. Vetiver grass system was found to be an outstanding option for sand dune and road batter stabilisation, stream bank erosion control and fishpond stabilisation in Central Vietnam (Van et al. 2003).

Studies showed that first vetiver strip on the slope accumulated 98 % more soil than lower vetiver strips in the first year (Babalola et al. 2003). Vetiver strips increased cowpea seed, stover and yields by 11.1 %, 20.6 % and 50 %, respectively, and increased soil moisture storage by a range of 1.9–50.1 % at various soil depths. Soil loss and runoff water were 70 % and 130 % higher on non-vetiver plots than vetiver plots. Eroded soils on non-vetiver plots were consistently richer in nutrient contents than on vetiver plots. Nitrogen use efficiency was enhanced by about 40 %. Studies in Turkey found that Vetiver grass could be used to prevent severe erosion on steep slopes in Yusufeli arid regions as it had proven successful in holding the soil (Demirel and Demirel 2005). Vetiver was found to tolerate crude-oil contamination in a concentration of 5 % (w/w), but its specific root surface area was reduced under the effects of petroleum (Brandt et al. 2006). Concerning total oil and grease content in soil, no significant decrease under the influence of vetiver was detected when compared

to the unplanted control. Thus, there was no evidence of vetiver enhancing the biodegradation of crude oil in soil under the conditions of the trial. However, uses of vetiver grass in relation to petroleum-contaminated soils are promising for amelioration of slightly polluted sites, to allow other species to get established and for erosion control. Glass house studies demonstrated that vetiver grass may promote the biodegradation of benzo[a]pyrene (B[a]P) under flooded conditions by plant roots by stimulating the microbial biomass (Li et al. 2006). Microbial biomass was the main factor affecting dissipation of B[a]P under flooded conditions.

Liao et al. (2005) found that the below-ground biomass of *V. zizanioides* was greater than that of *Cyperus alternifolius*. In contrast, the above-ground biomass of *C. alternifolius* was greater than that of *V. zizanioides*. The annual biomass yield of *C. alternifolius* (3406.47 g/m^2) was 2.3 times higher than that of *V. zizanioides* (1483.88 g/m^2). The removals of N, P, Cu and Zn by harvesting vegetation were 4–7 times higher in *Cyperus alternifolius* wetland than in *V. zizanioides* wetland.

As a species of land reclamation, vetiver grass possesses various kinds of superior characteristics and functions, such as rapid growth, huge biomass, massive and long roots, strong abilities to control erosion and stabilise slopes and huge capacities for phytoremediation (Xia and Shu 2003). Applications around the globe as well as in China of vetiver grass include reclamation of barren mountains or hills, contaminated water and soil, garbage landfills, mined lands, quarries, etc. From their series of experiments, a three-pronged strategy was suggested for an integrated vetiver technique (IVT) for phytoremediation of heavy metal contamination: use of vetiver for phytostabilisation of heavy metals, use of vetiver for phytoextraction of heavy metals and/or its potential use with chemical chelators and use of vetiver for phytofiltration of heavy metals (Shu and Xia 2003). They suggested that IVT could be used as an integrated technique for environmental management of mining activities. Vetiver had a very high capacity to purify waste water when used as a vetiver bamboo float (Kong et al. 2003). The purifying effects of Vetiver to heavy metals, N and P from pig farms were ranked as Zn > Cu > As > N > P > Pb > Hg. The Vetiver system has been identified to be an efficient, sustainable and cost-effective system for effluent and solid-waste product treatment (Smeal et al. 2003). Computer modelling output based on an assumed maximum annual effluent output of 475 ML/year, and N concentration of 300 mg/L and P of 1 mg/L, indicated that among the three grasses, vetiver required the least land for sustainable irrigation in both N and effluent volume: 72.5, 104 and 153 ha for vetiver, Kikuyu (*Pennisetum clandestinum*) and Rhodes grass (*Chloris gayana*) respectively. The study of Hart et al. (2003) reported on the efficacy of Vetiver growing under hydroponic conditions to treat motel effluent, which has been primary treated in septic tanks and to surface irrigate the motel gardens with the treated effluent in a sustainable way. The best method trialled was effluent flow at 20 L/min through Vetiver roots, a method that was highly successful in reducing nitrogen concentrations. The vetiver grass system to treat sewerage effluent on wetlands in southeast Queensland had already shown itself to be a suitable alternative to more expensive solutions to upgrade existing sewage treatment plants (Ash and Truong 2003). Singh et al. (2008) found in hydroponic studies that *Vetiveria zizanioides* had potential for phytoremediation of phenol.

The amount of arsenic removal was higher in *Vetiveria zizanioides* (Surat Thani ecotype) than *Vetiveria nemoralis* (Balansa, Prachuabkirikhan ecotype) (Srisatit et al. 2003). Arsenic accumulation was higher in the roots than in the leaves. Both ecotypes grew well in arsenic soils. The number of clumps and diameter of clumps were higher for *V. zizanioides* than *V. nemoralis*. Free water surface for tannery waste-water post-treatment with Surat Thani ecotype vetiver grass at 0.1 m water level was the most efficacious for chromium removal with 89.29 % efficiency.

Vetiver grass possesses special characteristics that make it a good choice for phytoremediation of heavy metals and organic wastes (Danh et al. 2009). Vetiver can accumulate heavy metals, particularly lead (shoot 0.4 % and root 1 %) and zinc

(shoot and root 1 %). The majority of heavy metals are accumulated in roots thus suitable for phytostabilisation and for phytoextraction with addition of chelating agents. Vetiver can also absorb and promote biodegradation of organic wastes (2,4,6-trinitroluene, phenol, ethidium bromide, benzo[a]pyrene, atrazine). Studies by Datta et al. (2013) showed that vetiver grass can be used as an in-situ phytoremediation agent to remove tetracycline from waste water. Studies by Danh et al. (2011b) showed that vetiver grass could be used for revegetation of lead-contaminated soils. They found that a level of applied CaCO3 about half of the lead concentration in soils was sufficient to improve vetiver growth and survival and accumulate high concentrations of lead in the roots. Danh et al. (2011a) showed that phytoremediation of Cu and Zn contaminated soils by vetiver could generate revenue from the commercialisation of vetiver essential oil extracts. Studies showed that inoculation of vetiver grass with a functional endophytic bacterium, *Achromobacter xylosoxidans* F3B, enhanced its phytoremediation potential in the removal of aromatic pollutants (Ho et al. 2013).

Antiochi et al. (2007) found vetiver grass to be have good phytoremediation activity for heavy metals like lead and zinc but not chromium and copper. Andra et al. (2009a) found vetiver grass to have a mechanism of high Pb tolerance, suggesting its potential usefulness for the remediation of lead-contaminated residential sites. Vetiver grass could accumulate up to 19,800 and 3350 mg Pb/kg dry weight in root and shoot tissues, respectively, in a hydroponics set-up. In the presence of 15 mM/kg EDTA, vetiver accumulated 4460 and 480 mg Pb/kg dry root and shoot tissue, respectively, that were 15- and 24-fold higher compared to those in untreated controls (Andra et al. 2009b). Paz-Alberto et al. (2007) found that vetiver grass possessed many beneficial characteristics to uptake Pb from heavily PB-contaminated soil. It can be used to phytoremediate urban soil with various contaminations by planting these grasses in lawns and public parks. Vetiver grass was found to be effective in the phytoremediation of endosulfan in two cotton soils, a vertisol and a lixisol, from Burkina Faso (Abaga et al. 2014). Six months after vetiver planting treatment, endosulfan was not detected in soils indicating the effectiveness of vetiver in promoting adsorption and the disappearance of endosulfan in both soils.

Successful rehabilitation of mine tailings and landfills with elevated levels of heavy metals in Australia, China and South Africa indicates that the Vetiver system should provide a powerful phytoremedial tool for the attenuation of the mercury pollution problem in Yolo and Lake counties by trapping and containing both the air- and water-borne insoluble mercury at sources and by reducing the soluble fraction in acid mine drainage (Truong 2003). Studies in Tanzania found Vetiver grass performed better than *Phragmites mauritianus* in removing pollutant in the wastewater treatment in horizontal subsurface flow constructed wetlands (Njau and Mlay 2003). For instance, it was found from the treatment plant that the organic removal BOD (biological oxygen demand) was on average 61.85 % and 67.47 % and COD (chemical oxygen demand) of 37.9 % and 46.2 % by *Phragmites mauritianus* and Vetiver grass respectively. Studies in Guangzhou, China, found that vetiver grass constructed wetland has great potential in treatment of highly concentrated landfill leachate after pretreatment to reduce its ammonium nitrogen concentration to 383 mg/L or even lower (Lin et al. 2003). Vetiver grass was found to be highly tolerant to adverse conditions such as acid mine leachate, containing high concentrations of Zn, Mn, Pb, Cd, Cu and sulphates and could be useful in the design of full-scale constructed wetland for treatment of acid mine leachates (Shu 2003).

Water Treatment

Studies by Kantawanichkul et al. (2013) showed that domestic waste water could be treated by vertical flow constructed wetland systems planted with *Cyperus alternifolius* (umbrella sedge) and *Vetiveria zizanioides* (Vetiver grass). The former was found to be more efficient than vetiver grass in terms of removal efficiency of COD (chemical

oxygen demand) and nitrogen in terms of total Kjeldahl nitrogen (TKN) was 76 and 65 % respectively at 20 cm/d hydraulic loading rates for umbrella sedge compared to only 67 and 56 % for Vetiver grass. Studies showed that *V. zizanioides* cultivated on floating beds had a great ability to remove total nitrogen, ammonium nitrogen, total phosphorus, phosphates, COD and BOD and had a significant effect on purifying eutrophicated water (Si et al. 2003). Liao and Luo (2002b) that *Vetiveria zizanioides* and *Cyperus alternifolius* had very stable effects on the removal of COD and BOD in waste water from pig farm. There was no significant difference between the two in the removal of COD, BOD and soluble solids. High removal rates of ammonium nitrogen and phosphate sulphur from piggery waste water were found for both species in spring and significant removal of total nitrogen in waste water by both species in autumn, while significant removal of total phosphorus in waste water was obtained only in *V. zizanioides* constructed wetlands (Lia and Luo 2002a). Studies by Xiong et al. (2011) found that using an integrated constructed treatment system (CTS) with vetiver growing in vertical constructed wetland and *Coix lacryma-jobi* in floating beds had excellent efficacy in removal of COD and phosphorus from secondary effluents.

Carbon Sequesterisation

Vetiver grass, a non-invasive C_4 grass with fast growing tufted root system reaching 3 m in one year, could be an ideal global candidate to facilitate long-term locking of atmospheric carbon below plough layer with reduced chances of being recycled into the atmosphere and replenish soil carbon sink (Lavania and Lavania 2009). It afforded a holding potential of 1 kg atmospheric carbon sequestered annually deep in the soils pool from one m^2 surface area. Strategic establishment of vetiver in crop field, tree line, river, road and rail line embankments as hedge rows could potentially contribute to carbon sequestering and as a source of biomass and bioenergy. *V. zizanioides* was found to have a very high photosynthetic capacity, fast growth rate and relatively high contents of cellulose and hemicellulose in leaf and to grow well in the marginal land and be considered as a potential lignocellulosic energy plant (Zhou and Yu 2012).

Production of Activated Carbon

Gas and liquid adsorption studies showed that large quantities of lignocellulosic residues derived from the industrial production of essential oil from vetiver grass roots could be used for the production of activated carbon (Gaspard et al. 2007).

Animal Feed

The leaves of vetiver are a useful by-product to feed cattle, goats, sheep and horses (Truong et al. 2008). It is also used as cattle fodder in Tanzania. Studies by Liu et al. (2003) found that digestibilities of gross energy, dry matter, crude protein, ether extract, crude fibre, calcium, phosphorus and nitrogen-free extract in Vetiver grass hay were 29.65 %, 46.09 %, 23.15 %, 28.79 %, 46.44 %, 61.00 %, 66.60 % and 36.25 %, respectively. 1 kg dry matter of Vetiver grass hay could provide 1.47 Mcal digestible energy, 13.4 g digestible crude protein and 4.17 g ether extract, which indicated that Vetiver grass is a promising feed resource for Donghsan goats.

Insect Pest Control

Khusitoneol, a keto alcohol from vetiver oil, exhibited considerable juvenile hormone activity against *Lipaphis erysmi* (mustard aphid) (Kalsi et al. 1985a). Of eight essential oils (vetiver grass, cassia leaf, clove bud, cedarwood, *Eucalyptus globulus*, *Eucalyptus citriodora*, lemongrass and geranium) evaluated against the Formosan subterranean termite, *Coptotermes formosanus*, vetiver oil proved the most effective repellent because of its long-lasting activity (Zhu et al. 2001a). Nootkatone, a sesquiterpene ketone, isolated

from vetiver oil was found to be a strong repellent and toxicant to Formosan subterranean termite *Coptotermes formosanus* (Zhu et al. 2001b). The lowest effective concentration tested was 10 µg/g substrate. Among eight valencenoid derivatives evaluated for their repelling activity against Formosan subterranean termites, *Coptotermes formosanus*, 1,10-dihydronootkatone was the strongest repellent, and valencene was the weakest (Zhu et al. 2003). Maistrello et al. (2001b) found that sand treated with vetiver oil or nootkatone at 100 µg/g disrupted termite tunnelling behaviour. As a consequence, after 21 days, wood consumption and termite survival were significantly lower compared with cedrene-treated or untreated sand treatments. Maistrello et al. (2001a) found that nootkatone acted as a feeding deterrent, inducing starvation that resulted in a complete loss of the termite symbiont protozoa *Pseudotrichonympha grassii*, the most important flagellate species of cellulosic digestion in *Coptotermes formosanus*.

In subsequent studies, they found that Vetiver oil and especially its constituent nootkatone affected Formosan subterranean termites and their protozoa, acting as arrestants, repellents and feeding deterrents, and represent a promising natural alternative for the control of this invasive pest (Maistrello et al. 2003). Ibrahim et al. (2004) reported that in sand barrier assays, a concentration of 100 ppm of nootkatone and two of its derivatives, 1,10-dihydronootkatone and tetrahydronootkatone, significantly reduced *Coptotermes formosanus* survival, tunnel building and food consumption after a 12-day exposure. Termites preexposed to 100 ppm nootkatone-treated sand and placed in containers without nootkatone for 15 days continued to exhibit abnormal feeding and digging behaviours; survivorship, tunnelling and feeding activities were significantly reduced by 83.5, 63.2 and 95.4 %, respectively.

Vetiver oil was found to possess strong termiticidal activity against the Formosan subterranean termite, *Coptotermes formosanus* (Chen et al. 2003). Vetiver oil decreased termite tunnelling at concentration as low as 5 µg/g sand and entirely inhibited termites' tunnelling and paper consumption at concentrations higher than 25 µg/g sand. Two-choice preference bioassays and stem borer larval survival experiments were conducted to determine the suitability of vetiver, napier grass (*Pennisetum purpureum*) and maize for survival of stem borer, *Chilo partellus* (Van den Burg et al. 2003). Results indicated that vetiver grass was highly preferred for oviposition but that larval survival on vetiver grass was extremely low. Thus, vetiver has potential as trap crop component of an overall 'push–pull' strategy to concentrate *C. partellus* oviposition away from the maize crop and reduce subsequent population development. This technology may also have application in rice stem-borer pest management.

Landscaping

The Vetiver system can be applied for urban landscaping including beautification, slope stabilisation, traffic dividers, demarcation of walkways and prevention of urban erosion (Anonymous 2014). Vetiver can make a city greener as a road boundary, at roundabouts and in landscaping parks and resorts. It can make a city cleaner through (1) its pond embankment filtration; various techniques in domestic, industrial and agricultural waste-water treatments; and water purification; (2) rehabilitation of contaminated or polluted water with the treatment of eutrophicated water, removal of effluents, heavy metals and toxic substances; (3) treatments of landfills and garbage dumps with the removal of agrochemicals and pesticides and absorption of heavy metals—a new approach of phytoremediation—and (4) dust reduction (Chomchalow 2012). It can make a city cooler using its evapotranspiration function, heat reduction and the cooling and refreshing effects of its dried massive roots. It can make a city safer serving as a windbreak and utilising its ability to stabilise slopes of the road, riverbanks, ponds and shorelines. And, finally, being a grass with a beautiful form and

aesthetic value, it can make a city more beautiful when used as an ornamental plant in landscaping or as a decorative potted plant. Vetiver-based Green City employs simple and low-cost technology, which is sustainable and has low maintenance cost effective. Vetiver grass ceramic pot, composed of vetiver grass and clay at the proportion of 1:10 and fired at 1200 °C, was found to be good for the cultivation of orchids and ornamental plants (Thiramonmgkol et al. 2003). The pots were lightweight with good aeration on the surface, thus enhancing maximum benefit for growing orchids and other ornamental plants.

Miscellaneous Uses

In Malacca vetiver roots are used for making fans and roofs of palanquins (Burkill 1966). In the Philippines, flower stalks are made into hats and brooms. In northern India, roots are used to make a pleasant screen through which water is poured and air-blown creating a refreshing shelter called khas-kahas tatti (Burkill 1966). In some Asian countries the roots are woven into coarse mats and hung in front of doors; they are moistened to cool and scent the air blowing through them. In India, the roots have been used in matting to give fragrance to a room; they also yield a heavy essential oil, khas-khas or cuscus, for perfumery. The matted roots are made into fans. In the Central African Republic they are used for stuffing mattresses.

Comments

Vetiver grass is grown for its oil mainly in Haiti, West Java, India, Réunion, China and Brazil (De Guzman and Oyen 1999). Indonesia and Haiti export the largest quantities of vetiver oil, about 50–100 tonnes/year each, while China exports about 20 tonnes/year. The best quality, called Bourbon oil, comes from Réunion. World production is estimated at about 250 tonnes of oil per year. The main importing countries are the United States and western Europe.

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Eleusine indica

Scientific Name

***Eleusine indica* (L.) Gaertner**

Family

Poaceae

Synonyms

Agropyron geminatum Schult. & Schult.f., *Chloris repens* Steud. (inv.), *Cynodon indicus* (L.) Raspail, *Cynosurus ara* Buch.-Ham. ex Wall. (inv.), *Cynosurus indicus* L., *Cynosurus pectinatus* Lam., *Eleusine distachya* Trin. ex Steud. (inv.), *Eleusine distans* Moench (illeg.), *Eleusine distans* Link., *Eleusine domingensis* Sieber ex Schult. (inv.), *Eleusine glabra* Schumach., *Eleusine gonantha* Schrank, *Eleusine gouinii* E.Fourn., *Eleusine inaequalis* E.Fourn., *Eleusine indica* subsp. *indica*, *Eleusine indica* var. *major* E.Fourn., *Eleusine indica* var. *monostachya* F.M.Bailey, *Eleusine indica* var. *oligostachya* Honda, *Eleusine japonica* Steud., *Eleusine macrosperma* Stokes, *Eleusine marginata* Lindl., *Eleusine polydactyla* Steud., *Eleusine rigidifolia* E.Fourn., *Eleusine scabra* E.Fourn., *Eleusine textilis* Welw. (inv.), *Juncus loureiroana* Schult. & Schult.f., *Leptochloa pectinata* (Lam.) Kunth, *Paspalum dissectum* Kniph. (illeg.), *Poa spicata* Willd. ex Steud. (inv.), *Triticum geminatum* Spreng.

Common/English Names

Bullgrass, Crabgrass, Crow's Foot, Crowfoot Grass, Crowsfoot Grass, Dog Grass, Foul Foot, Fowl Foot Grass, Fowl-Foot Grass, Goose Grass, Goosegrass, India Goosegrass, Indian Goose Grass, Indian Goosegrass, Iron Grass, Silver Crabgrass, Wire Grass, Wire Grass, Yard Grass, Yardgrass

Vernacular Names

Arabic: Kalassindra (Chad)
Bangladesh: Binna Chall, Chapra, Gaicha, Malangakuri
Benin: Gamatori, Gomateri (Bariba), Tchouan (Berba), Torohundo (Yom)
Brazil: Ca-A Pi-1, Capim Criador, Capim Pe Da Galinha, Capim-Da-Cidade, Capim-De-Burro, Grama-De-Coradoura, Grama-De-Coradouro, Grama De Sapo (Portuguese)
Burmese: Myet-Thakwa, Se-Gwa, Sin Ngo Let Kya, Sin Ngo Myet

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
DOI 10.1007/978-3-319-26062-4_17

Cambodia: Smao Choeng Tukke
Cameroon: Esinge-Singe, Woh
Central African Republic: Ndili (Manja)
Chad: Kalassindra (Arabic)
Chamorro: Umog
Chinese: Niu Jin Cao
Chuukese: Fatil
Cook Islands: Mārōki'Aki'A, 'Ātangaroa, Matie, Matie Tūtae-Kuri, Mauku (Maori)
Côte D'ivoire: Assumoamata, Essouéma (Aboure), Kama (Ashanti), Siganzi (Baoule), N'tema (Ebrie), Kpédé, Kwédé (Shien)
Cuba: Grama De Caballo, Pata De Gallina
East Africa: Ekitu (Ateso), Orutar-Atari (Ankole), Ribanchore (Ekegusii), Malulu (Kiswahili), Bek (Kipsigis), Enguruma (Masai), Kasibauti (Ruganda)
Egypt: Negil (Arabic)
Fijian: Kavoronaisivi, Vorovoroisivi
French: Chiendent Patte De Poule, Pied De Poule De L'inde, Eleusine D'Iindes, Eleusine Des Indes, Pied De Poule, Pied Poule Vrai
Germany: Indische Indica
Ghana: Nsensan (Asante-Twi)
Hawaiian: Mānienie Ali'I
India: Binna Challa, Chapra, Gaicha, Malangakuri (Bengali), Bajari (Gujarati), Ghoraya, Jangali Marua, Jhingari (Hindu), Ragi (Kannada), Mahaar, Naachni (Maharashtra), Nachani (Marathi), Nandimukha, Nandiaa (Orissa), Mandiaa (Oriya), Bajra (Punjabi), Kelvaraku, Kevuru, Thippa Ragi (Tamil), Ragi (Telugu), Chhota Madhana, Madhani Cheera (Urdu), Kodai, Mandla
I-Kiribati: Te Uteute, Te Uteute Na Banabana
Indonesia: Jukut Jampang, Jukut Jampang Ede, Jukut Jampang Munding, Jukut Charulang (Sundanese), Godong Ula, Rumput Welulang, Suket, Lulangan, Sukut Chelulang, Suket Welulang (Javanese), Sambau, Sarut (Sumatra)
Italian: Panico Indiano
Japanese: Ohi Shiba, Ohi Jiwa, Chikaragusa
Kosraean: Mahkwekwe
Laotian: Nya Phak Kole
Libya: Negil (Arabic)
Madagascar: Tsiavotraombilahy, Tsimpignipgny, Tsipihipihina
Malawi: Chinsanwi, Chigombe, Chipikamongu, Kanggodza
Malaysia: Godong Ula, Rumput Sambari, Rumput Sambau
Marshallese: Katejukjuk
Nepalese: Kode, Kode Vanso, Kodo Ghans
Nicaragua: Yerba De Camino
Niger: Tuji (Gwandara)
Nigeria: Ichite (Igbo), Gbegin (Yoruba)
Niuean: Mosie Fahitalo, Mosie Fuhitalo, Mosie Fuhitalotalo
Palauan: Deskim, Kelelamalk, Keteketarmalk
Papua New Guinea: Hiroi (Agenehembo, Northern Province), Kiroi (Kurereda, Northern Province), Iquazi (Quaqua, Morobe Province)
Paraguay: Yerba De Camino
Philippines: Barañgan (Bikol), Bugtusan, Palagtiki (Bisaya), Palad (Cebu Bisaya), Dinapaiuk (Ifugao), Parañgis (Iloko), Parañgis-Sabuñgan, Sabung-Sabuñgan (Pampangan), Bila-Bila (Panay Bisaya), Bikad-Bikad (Sulu), Bakis-Bakisan, Gagabutan, Kabit-Kabit, Paragis, Sabung-Sabuñgan, Sabung-Sabuñgan Sabung-Sabuñgan, Sambali (Tagalog)
Pohnpeian: Reh Takai
People's Republic of the Congo (Brazzaville): Kimboundia (Doondo), Kimbandzia (Koongo), Kimbandza (Lari)
Portuguese: Pata De Galinha, Capim De Caradouro. Capim De Caradouro, Capim-Da-Cidade, Capim-De-Burro, Capim-Pé-De-Galinha, Grama-De-Coradouro, Grama-Sapo, Pata De Galinha, Pe-De-Galo
Pukapukan: Veyaveya
Rakahanga-Manihiki: Mauku Vai-Rakau
Reunion: Chiendent, Siendan
Russian: Elevzina Indiiskaia
Samoan: Fahitalo, Fahitalo, Lau Ta'A Ta'A, Sefa, Ta'A Ta'A
Satawalese: Puker
Senegal: Gondirima, Ratam Fa Mbe, Vodvod
Shona: Makha
Sierra Leone: Ngetaewuli (Kpaa Mende)

South Africa: Indiese Osgras, Jongos Gras
Spanish: Eleusine, Grama De Caballo, Grama De Orqueta, Grama Dulce, Guarataro, Olotillo, Hierba Dulce, Natajo Dulce, Pata De Gallina, Pata De Gallo, Pata De Ganso, Yerba De Camino, Yerba Dulce
Swedish: Gåshirs
Tahitian: Tamamau, Tamaomao
Taiwan: Nui Chin Tsao
Thailand: Yaa Teen-Ka
Tongan: Mohuku Siamane, Takataka, 'A Leala, A Le Ala
Togo: Adon'doulé, Tchama (Kabiyé)
Tongarevan: Mauku
Uganda: Kasbanti
Ulithian: Fathil
Vietnam: Cỏ Mần Trầu, Tết Suất Thảo, Ngưu Cần Thảo, Cỏ Vườn Trầu, Màng Trầu, Thanh Tâm Thảo, Cỏ Chỉ Tía, Ngưu Cân Thảo, Hang Ma (Tày), Co Nhả Hút (Thái), Hìa Xú Xan (Dao), Cao Day (Ba Na), Hất T'rớ Lạy (K'ho), R'day (H'dong)
Zambia: Rapoka
Zimbawe: Mu Kha

Origin/Distribution

The plant is indigenous to Africa, but long naturalised elsewhere, including South America, Asia, Micronesia, American Samoa and most of the rest of the Pacific Islands from the tropical to subtemperate regions.

Agroecology

It is a major invasive weed of disturbed places, irrigated fields and canals, including cultivated crops, pastures, gardens and roadsides, and also occurs in plantations and nurseries in the tropics and subtropics (Plates 1 and 2). It is found from near sea level to 2000-m elevation. It grows best in moist, fertile, cultivated soil in full sunlight. It is prevalent in disturbed areas, especially in sandy soil. It is quick growing, long lived and partial to wetter locations.

Edible Plant Parts and Uses

The small seed is used as famine food and it can be cooked whole or ground into a flour and used in making cakes, gruels and alcoholic beverages (Kunkel 1984; Facciola 1990; Harris 1995). Young plants are eaten raw or cooked and used as a side dish with rice (Uphof 1968; Tanaka 1976; Kunkel 1984; Facciola 1990). Roots are edible raw (Kunkel 1984; Facciola 1990).

Botany

Eleusine indica is branching, erect or prostrate annual or short-lived perennial, and its culms are tuft forming and branching from the base (Plate 3). Leaves are narrow and arranged in two rows; the blade is glabrous, and sheath is hairy. Leaf blades are flat or folded, 15–30 cm long and 4–6 mm wide. Inflorescence is in a whorl of 2–7 (usually 5) digitate spikes from apex of culm, with single spikelet or two spikelets separated below (Plate 4). Spikelets are 3–5 flowered, up to 4 mm long, awnless and dark green. Glumes are membranous, with the lower part which is 1–1.5 mm long, pointed, rough on the keel and one-nerved and the upper part 3 mm long, sharply pointed or tapering gradually to a point, with smooth keel, one- to five-nerved; lemmas are similar in texture and shape to the glumes, ovate and sharply pointed; palea is somewhat rough on the keels. Grain is reddish brown to black, oblong-ovate, ridged and striated.

Nutritive/Medicinal Properties

Twenty phenolic compounds were detected in the leaves of *Eleusine coracana* subsp. *coracana*, *E. coracana* subsp. *africana*, *Eleusine indica*, *E. multiflora*, *E. tristachya*, *E. floccifolia* and *E. compressa* (Hilu et al. 1978). The leaf flavonoids identified were orientin, isoorientin, vitexin, isovitexin, saponarin, violanthin, lucenin-1 and tricin. The morphologically well-defined *E. coracana–africana–indica* group formed a unit in

Plate 1 Extensive stand of *Eleusine indica* (GF Chung)

Plate 2 Mixed weedy growth of *E. indica*

respect of flavonoids. Subspecies *africana* exhibited a higher flavonoid similarity to subsp. *coracan*a (finger millet) than did *E. indica*. Sterol glucosides 3-*O*-β-D-glucopyranosyl-β-sitosterol and its 6′-*O*-palmitoyl derivative were isolated from the aerial parts (Nguyen et al. 1994). Schaftoside (6-C-β-glucopyranosyl-8-C-a-arabinopyranosylapigenin) and vitexin (8-C-β-glucopyranosylapigenin) were isolated from the aerial parts (De Melo et al. 2005).

Antioxidant Activity

The methanol extract of *E. indica* exhibited the highest total phenolic content and DPPH scavenging activity (77.7 %), followed by the ethyl acetate (64.5 %), hexane (47.19 %) and dichloromethane (40.83 %) extracts (Al-Zubairi et al. 2011). Ethanol extract of *E. indica* leaves showed strong antioxidant properties against both hydrogen peroxide and superoxide anion (Sagnia et al. 2014).

Anti-inflammatory Activity

Studies in Brazil supported the popular use of aerial parts of *E. indica* against airway inflammatory processes like influenza and pneumonia (De Melo et al. 2005). Pretreatment with 400 mg/kg of crude extract inhibited 98 % of lung neutrophil recruitment in mice exposed to aerosols of lipopolysaccharide (LPS) from Gram-negative bacteria, in a dose-dependent manner. At 400 μg/kg, schaftoside (6-C-β-glucopyranosyl-8-C-a-arabinopyranosylapigenin) and vitexin (8-C-β-glucopyranosylapigenin), isolated from *Eleusine indica*, inhibited 62 % and 80 % of lung neutrophil influx, respectively. Ethanol leaf extract of *E. indica* exhibited anti-inflammatory effect on γδ T cells and immature dendritic cells as evidenced by the dose-dependent reduction in TNF-α production (Sagnia et al. 2014).

Plate 3 Small clump, branching from the base

Antimicrobial Activity

The ethyl acetate extract of *E. indica* exhibited a broad-spectrum antibacterial activity against the Gram-positive bacterium, methicillin-resistant *Staphylococcus aureus* (MRSA) and two Gram-negative bacteria, *Pseudomonas aeruginosa* and *Salmonella choleraesuis*, except *Bacillus subtilis* (Al-Zubairi et al. 2011). The Gram-positive bacterium *Bacillus subtilis* was found to be resistant to all *E. indica* extracts. The hexane extract also exhibited remarkable antibacterial activity against MRSA and *Pseudomonas aeruginosa*, while the dichloromethane extract did not exhibit significant activity against *P. aeruginosa*. None of the extracts showed significant cytotoxic activity towards MCF-7, HT-29 and CEM-SS human cancer cell lines after 72-h incubation time ($IC_{50} > 30$ μg/ml).

Antidiabetic Activity

A dose-dependent reduction in blood glucose level was observed in alloxan-induced diabetic rats treated with *E. indica* leaf ethanol extract; however, the effect was less than that of the standard drug glibenclamide (Okokon et al. 2010).

Plate 4 Close-up of digitate inflorescence (GF Chung)

Antiplasmodial Activity

E. indica ethanol leaf extract (320–960 mg/kg) exhibited significant schizonticidal activity during early and established infections of *Plasmodium berghei* (Okokon et al. 2010). The effect was comparable to the standard drug chloroquine (5 mg/kg).

Eleusine indica extract showed significant dose-dependent, antiplasmodial activity in the 4-day, repository and curative tests and increased the survival times of the *Plasmodium berghei*-infected mice (Ettebong et al. 2012). All the fractions exhibited significant antiplasmodial activity with the highest being ethyl acetate fraction. The results confirmed the ethnobotanical use of this plant as a malarial remedy.

Hepatoprotective Activity

E. indica extract scavenged DPPH level radical in a dose-dependent manner with IC_{50} value of 2350 μg/ml (Iqbal and Gnanaraj 2012). Total phenolic content was found to be 14.9-mg/g total phenolic expressed as gallic acid equivalent per gram of extract. Rats pretreated with *E. indica* showed significantly increased activity of antioxidant enzymes compared to untreated CCl_4-intoxicated group. The increased levels of serum alanine aminotransferase (ALT) and aspartate aminotransferase (AST) were significantly prevented by *E. indica* pretreatment. The extent of malondialdehyde (MDA) formation due to lipid peroxidation was significantly reduced, and reduced glutathione (GSH) was significantly increased in a dose-dependent manner in the *E. indica*-pretreated groups as compared to the CCl_4-intoxicated group. The protective effect of *E. indica* was further evident through decreased histopathological alterations in the liver.

Traditional Medicinal Uses

Eleusine indica is used in traditional Vietnamese medicine for its diuretic, febrifuge and stomachic properties (Nguyen et al. 1994). The whole plant, but especially the root, is depurative, diuretic, febrifuge, laxative and sudorific (Chopra et al. 1986). It is also used in the treatment of liver complaints in India and Vietnam (Chopra et al. 1986; NIMM 1999). In Vietnamese traditional medicine, the plant is a component of the 'basic remedy' *toa căn bản*, a herbal mixture of several plants, commonly prescribed as a diuretic, laxative and stomachic and for influenza, oliguria, liver ailments and has depurative property (NIMM 1999). The plant is used as diaphoretic to treat fever, malaria and yellowish urine.

In Malaysia, the juice of the leaves has been prescribed to women after childbirth as a postpartum to help expel the placenta. In Sumatra fresh leaves decoction is used as anthelmintic (Burkill 1966). In Kampuchea, the whole plant has been used as a sudorific and for fevers and liver complaints especially the root. In the Philippines, whole plant mixed with gogo has been used for dandruff and to prevent hair loss (Stuart 2014). In India the plant decoction is used for hemoptysis, diuretic and dysentery. Poultice of the leaves has been used for sprains and injuries. A decoction of the roots is used for fever. In Guyana, decoction of plant is used to relieve pains from abdominal muscle strain and applied to wounds to stop the bleeding. Decoction of grass is used as tonic and to relieve bladder disorders. In Venezuela, seed decoction is given to infants suffering from black jaundice. In Colombia, decoction of plant is used for diarrhoea, dysentery and convulsions. The plant has been used for kidney problems in Trinidad and Tobago (Lans 2006).

In the Betsimisaraka region in the North East, Madagascar, the whole plant is boiled and used to treat sprains (Quansah 1988), and in the Agnalazaha littoral forest in southeastern Madagascar, the whole plant is used for stomach pain by women (Razafindraibe et al. 2006). In Madagascar, pounded leaves are used externally for sprains and strained joints (Novy 1997). In Babungo, Northwest Region, Cameroon, the leaves are pounded with palm oil and taken orally for side pains; the paste from pounded leaves is applied on fractures and tied with a bandage (Simbo 2010). In the southwest slopes of Mount

Cameroon, the whole plant is used for haemorrhagic cough (Sandberg et al. 2005). In Nigeria, the plant is used as an anti-inflammatory and for convulsion in children (Obute 2005). Leaves of *Tetracera alnifolia* and *Eleusine indica* are pounded and the poultice rubbed on skin for scabies and skin eruption in Sierra Leone (Lebbie and Guries 1995). *Eleusine indica* leaves are macerated and the infusion is employed for treating urine retention. Whole plant of *Olax subscorpioidea* + *Eleusine indica* + *Eragrostis cilianensis* is made into semi-powder and is burned to fumigate non-violent mental patient by Gwandara tribe of Sabo Wuse in Niger state (Ibrahim et al. 2007). In Ghana, district of Gosomtwi-Atwima-Kwanwoma, a poultice of aerial parts of *Eleusine indica*, is used to treat new and old wounds (Agyare et al. 2009). In Central Nigeria (Kwara state), *Eleusine indica* leaves are crushed and mixed with shea butter (*Butyrospermum paradoxum*) to make an ointment used to massage the painful parts of the body (Bhat et al. 1990). In Benin, *E. indica* roots are employed to treat diarrhoea; pulped roots are used locally for fractures and *E. indica* roots and *Aframomum melegueta* are used for treating antalgic (Adjanohoun et al. 1989). A decoction of *E. indica* plant is used as a wash for boils and abscesses. An aqueous decoction of leaves of *Commelina benghalensis*, *Eleusine indica* and *Cleome viscosa* is taken orally for treating female infertility. In the People's Republic of the Congo (Brazzaville), aqueous decoction of the whole plant is sued for treating urogenital infections (Adjanohoun et al. 1988). The same decoction is taken orally as a mouth wash for influenza. In Togo, leaves and shoot of *E. indica* and ripe fruit of *Aframomum melegueta* are powdered diluted in lemon juice and taken orally for tachycardia (cardiac pain), and aqueous decoction of the roots is used taken orally to treat urethral infection (Adjanohoun et al. 1986). Pounded seeds of *Aframomum melegueta* and *E. indica* roots are taken orally for fever and convulsion. In Côte d'Ivoire, *E. indica* sap is applied on cuts, wound and injuries and is used for headache, for rib pain and as nose drop (Bouquet and Debray 1974). Pulped roots are used as plaster for lymph gland disease and to treat menorrhagia. A decoction of the plant is used as cardiotonic. In Central African Republic (Oubangui), pounded plant is used as a bath for malaria in children (Vergiat 1969).

Other Uses

The stems are used to make mats, baskets and hats. The plant is suitable for paper manufacture. The plant is sued in magic rituals where Malays hold the grain in their hand in spirit-summoning rituals. In Bontoc, Philippines, the plant is used in *mangmang* rituals. Its strong roots make it a good plant to prevent soil erosion. The plant is used for silage and hay.

Crabgrass or crowfoot grass is considered in some regions to be a good fodder grass.

Eleusine indica, *Cynodon dactylon*, *Cyperus rotundus* and *Equisetum ramosissimum* showed promising potential for phytoremediation of heavy metal pollution soil (Anh et al. 2011). The plants accumulated very high Pb (0.15–0.65 %) and Zn (0.22–1.56 %) concentration in their roots.

Comments

E. indica is ranked the 5th worst weed in the world and in Southeast Asia and an important weed in over 60 countries (Holm et al. 1977).

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Morinda officinalis

Scientific Name

***Morinda officinalis* F.C. How**

Synonyms

Gynochthodes officinalis (F.C. How) Razafim. & B. Bremer, *Morinda officinalis* var. *hirsuta* F.C. How, *Morinda officinalis* var. *officinalis*

Family

Rubiaceae

Common/English Names

Chinese Herbal Morinda, Medicinal Indian Mulberry, Morinda Root

Vernacular Names

Chinese: Ba Ji, Ba Ji Tian, Chi-Yen-T'eng, Ji-Yan-Teng, Pa-Chi-Tian
Japanese: Hagekiten
Korean: P'agukch'on
Latin: Radix Morindae Officinalis
Vietnamese: Ba Kich, Ba Kích Thiên, Chẩu Phóng Xì, Dây Ruột Gà, Liên Châu Ba Kích, Sáy Cáy (Thái), Thao Tày Cáy (Tày), Chồi Hoàng Kim, Chày Kiàng Đòi (Dao)

Origin/Distribution

The species is native to China in Fujian, Guangdong, Guangxi and Hainan and North Vietnam in Bac Giang, Cao Bang, Hoa Binh, Lang son, Phu Tho, Vinh Phuc and Yen Bai.

Agroecology

The species is shade tolerant and hygrophilous and occurs in fertile, acidic, moist sandy loam soil rich in humus. In its native range, it occurs in secondary forests of hills, low mountains and midlands at altitudes of 200–600 m and thrives best in cool temperatures of 21–23 °C.

Edible Plant Parts and Uses

In China, fresh or dried roots are cooked with pork for a broth as health food called Chinese bupin (Hu 2005). Another recipe consists of

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cooking the roots of *Morinda officinalis* and *Pueraria* with pumpkin, ginger, leek, salt and pepper in a stew. In South China, Hong Kong and Macao, this plant has been developed into various health foods, such as 'Ba-ji-tian wine', 'Ba-ji-zi-bu Gao' (Li et al. 2009).

Botany

A perennial slender climbing shrub, several m long with greyish bark and angular twigs. Roots cylindrical 0.5–2 cm diameter, with longitudinal wrinkles and transverse cracks, dark grey or yellowish grey (Plate 1). Young shoots are violet when young, tomentose becoming glabrous. Leaves on short petioles are opposite, simple, entire, lanceolate to obovate, 6–14 cm long by 2.5–6 cm wide, base obtuse or rounded, apex acuminate, glossy dark green above, pale violet and hairy on both sides especially the lower surface below, stipule tubular thin, compressed, petiole short. Inflorescence in terminal umbellate panicles; 0.3–1.5 cm long, flowers are small, white to pale yellowish, calyx tubular-cyathiform with unequal sepals, corolla tube short. Fruit is globose, drupe, scarlet when ripe and two seeded.

Nutritive/Medicinal Properties

Morinda officinalis roots were found to contain: anthraquinones, iridoids, oligosaccharides, polysaccharides (Wu et al. 2009, 2013; Choi et al. 2005; Zhu et al. 2008, 2009a, b); organic acids, sugars, resins, vitamin C, an essential oil (NIMM 1999), anthraglucosides (*1*-hydroxyanthraquinone) and phytosterols, *β*-sitosterol, *2*-methyl-anthraquinone, rubiadin-*1*-methyl ether and *24*-ethylcholesterol (Li et al. 1991); eight anthraquinones rubiadin; rubiadin-*1*-methyl ether; *1*-hydroxyanthraquinone; *1*-hydroxy-*2*-methylanthraquinone; *1,6*-dihydroxy-*2,4*-dimethoxyanthraquinone; *1,6*-dihydroxy-*2*-methoxyanthraquinone; *1*-hydroxy-*2*-methoxyanthraquinone and physcion (Yang et al. 1992); an iridoid lactone, morindolide, and an iridoid glucoside, morofficinaloside, together with five anthraquinones (tectoquinone, alizarin *1*-methyl ether, lucidin ω-methyl ether, *1*-hydroxyl-*2,3*-dimethylanthraquinone and *1*-hydroxy-*3*-hydroxymethylanthraquinone), four iridoid glucosides (asperuloside, asperulosidic acid, desacetyl asperulosidic acid and monotropein), a monoterpene glycoside (*l*-borneol *6-O-β*-D-apiosyl-*β*-D-glucoside), two sterols (*β*-sitosterol and oxositosterol), an ursane-type triterpene (rotungenic acid) and a lactone compound (*4R,5S*)-*5*-hydroxyhexan-*4*-olide (Yoshikawa et al. 1995); succinic acid, nystose, *1F*-fructofuranosylnystose, inulin-type hexasaccharide and an heptasaccharide I (Cui et al. 1995); *3*-hydroxy-*1,2*-dimethoxy-anthraquinone (Xu et al. 2009); five anthraquinones including alizarin-*1*-methylether; *1,2*-dimethoxy-*3*-hydroxyanthraquinone; *1*-hydroxy-*3*-hydroxymethyl-anthraquinone; rubiadin-*1*-methylether and anthragallol-*2*-methylether (Zhu et al. 2009a); *2*-hydroxy-*1*-methoxy-anthraquinone monohydrate (Liu and Jiao 2009); physicion, rubiadin-*1*-methyl ether, *2*-hydroxy-*1*-methoxy-anthraquinone, *1,2*-dihydroxy-*3*-methylanthraquinone, *1,3,8*-trihydroxy-*2*-methoxy-anthraquinone, *2*-hydroxymethyl-*3*-hydroxyanthraquinone, *2*-methoxyanthraquinone and scopoletin (Wu et al. 2009); four anthraquinones *2*-hydroxy-*3*-hydroxymethylnthraquinone, *2*-hydroxy-*1*-methoxy-anthranquinone, rubiadin-*1*-methyl ether, rubiadin (Bao et al. 2010); three anthraquinones, *1,2*-dimethoxy anthraquinone, alizarin-*2*-methyl ether and rubiadin-*1*-methyl ether (Liu et al. 2012); four anthraquinone compounds, namely, *2*-hydroxy-*3*-hydroxymethyl-anthraquinone, *2*-hydroxy-1-methoxy-anthraquinone, rubiadin-*1*-methyl ether and rubiadin (Wu et al. 2013). *Morinda officinalis* root was found to contain 89.5 % oligosaccharides and 0.19 % proteins and 12 mineral elements including Zn, Fe, Ca, K, P and Na but did not contain As, Cd and Pb (Li et al. 2008).

Anthraquinones in *M. officinalis* root were found to be distributed in parenchymatous cells, and the content of anthraquinones in the root gradually increased with plant age (Yao et al. 2004).

The iridoid glycoside monotropein and deacetylasperulosidic acid were isolated from the

Plate 1 Dried morinda roots

roots (Choi et al. 2005). Seven anthraquinones and one coumarin were isolated upon further fraction of the ethanol root extract; these compounds were identified as physcion, rubiadin-*1*-methyl ether, *2*-hydroxy-*1*-methoxyanthraquinone, *1,2*-dihydroxy-*3*-methyl anthraquinone, *1,3,8*-trihydroxy-*2*-methoxyanthraquinone, *2*-hydroxymethyl-*3*-hydroxyanthraquinone, *2*-ethoxyanthraquinone and scopoletin (Wu et al. 2009).

Seventeen compounds were identified in *M. officinalis* roots: physcion, *1*-hydroxy-*2*-methylanthraquinone, *2*-Hydroxy-*1*-methoxyanthraquinone, rubiadin, rubiadin *1*-methylether, 1,3-dihydroxy-*2*-methoxyanthraquinone, 3-hydroxy-*2*-methylanthraquinone, digiferruginol, 1,2-dimethoxy-*3*-hydroxyanthraquinone, 1,3-dihydroxy-2-hydroxymethylanthraquinone, lucidin *ω*-ethyl ether, anthraquinone-*2*-carboxyllic acid, 7-hydroxy-*6*-methoxy-coumarin, fumaric acid, stigmasterol, daucosterol and *β*-sitosterol (Zhang et al. 2010)

Polysaccharides of *M. officinalis* consisted mainly of glucose and fructose in the molar ratio of 1.29:2.71 (Zhu et al. 2009b). Six oligosaccharides were isolated from *M. officinalis* roots and identified as sucrose, inulin-type trisaccharide, inulin-type hexasaccharide, inulotriose, inulotetraose and inulopentaose (Feng et al. 2012). Five oligosaccharides were found in *M. officinalis* root: 2.128–21.28 μg sucrose, 1.864–18.64 μg 1-kestose, 1.92–19.2 μg nystose, 1.912–19. 12 μg *1F*-fructofuranosylnystose and 2.368–23.68 μg bajijiasu (Deng et al. 2012). Inulin-type oligosaccharides with different DPs (degree of polymerisations) were isolated from the roots with purities of >98 % (Yang et al. 2010). An acidic polysaccharide APMO was isolated from *Morinda officinalis* (Zhang et al. 2013). It predominantly consisted of galacturonic acid, arabinose and galactose. Galacturonic acid was assigned to be 1→4 glycosyl linkage in its skeleton. Seven inulin-type oligosaccharides (DP = 3–9) were analysed using double-development performance thin-layer chromatography and scanning densitometry in *Morinda officinalis* (Zhou et al. 2014).

Thirty-four compounds representing 77.4 % of the volatile oil of *M. officinalis* root were identified (Liu et al. 2005). The main constituents (>2 %) were: borneol L 29.28 %, *α*-zingiberene 4.88 %, ar-curcumene 4.49 %,*1*-hexanol 3.40 %,*β*-sesquiphellandrene 3.34 %, *2*-amylfuran 3.32 %, *n*-nonanal 2.17 %, *L*-camphor 2.07 % and *β*-bisabolene 2.06 %. Forty-six volatile components were identified from 15-year-old *M. officinalis* roots, which accounted for 89.98 % in the

peak area of total ion chromatogram. Nineteen volatile components were identified from 10-year-old *M. officinalis* roots, which accounted for 70.01 %. Fourteen volatile components were identified from 6 to 8-year-old *M. officinalis* roots, which accounted for 63.23 %. The volatile components extracted from *M. officinalis* root mainly included acids, aldehydes, alcohols, alkenes, etc. Organic acids were the most abundant, accounting for 65.28 % of volatile components with palmitic acid accounting for 45.75 % followed by oleic acid. Twenty-six volatile components were identified from *M. officinalis*, comprising mainly of hexadecanoic acid (highest), followed by linoleic acid, oleic acid, diisobutyl phthalate, *3*-methyl-benzaldehyde and borneol (Yin et al. 2009).

The contents of monotropein from the different processed products of *M. officinalis* root, namely, crude drugs, woody part, salt processed and conventionally processed, were found to be 13.92 mg/g, 9.10 mg/g, 9.21 mg/g and 12.86 mg/g, respectively (Xu et al. 2007).

In traditional oriental medicine, the roots are reported to exert a tonic effect on kidneys, improving yang, especially for shengyangxu (kidney yang deficiency) that causes impotence, lack of libido, infertility, premature ejaculation, frequent urination, incontinence, irregular menses, cold and painful lower abdomen and chronic inflammation of nerves (especially the sciatica nerves). They are useful in treating impotence, spermatorrhoea, delayed menstruation, hypertension, rheumatism, musculoskeletal atrophy, arthritis and fatigue and ridding of damp cold. Roots are described as having the following properties: antibacterial, hypotensive, adrenocortical stimulant, antidepressant, aphrodisiac, androgenic, cerebral restorative, urogenital astringent, analgesic, musculoskeletal restorative, antirheumatic and interferon inducent.

Scientific studies showed that the roots have antioxidant, hypoglycaemic, hyperglycaemic, antidepressant, antifatigue, cardiovascular protective, renoprotective, anti-inflammatory, antinociceptive, antitumour, anti-impotence and antiosteoporotic attributes.

Antioxidant Activity

Studies showed that a 10-day oral administration of *M. officinalis* extract reduced the fasting serum glucose, hepatic and renal thiobarbituric acid reactive substances (TBARS) level and significantly increased the hepatic superoxide dismutase (SOD) and catalase (CAT) activities as well as glutathione (GSH) levels in streptozotocin-induced diabetic rats (Soon and Tan 2002). *Morinda officinalis* extract was found to scavenge superoxide anion and hydroxyl radicals in the chemiluminescence reaction of luminol–H2O2–CuSO4 system (Wu et al. 2006). *M. officinalis* root extract showed a 47.8 % *2,2*-diphenyl-*1*-picrylhydrazyl (DPPH) radical scavenging effect in TM3 Leydig cells with no significant cytotoxicity (Chang et al. 2008). The treatment of the cells with 250 μg/mL extract showed the most significant protective effect (64 %) in the cell viability assay with a decreased lipid peroxidation level (1.75 nmol/mg protein), increased testosterone production (43.5 pg/mL), and improved superoxide dismutase (SOD) activity (7.49 units of SOD/mg protein) and catalase (CAT) activity (74.6 units of CAT/mg protein). The findings indicated that *M. officinalis* root, as an antioxidant, protected functions of cultured mouse TM3 Leydig cells from H2O2-induced oxidative stress. Studies showed that *M. officinalis* polysaccharide supplementation resulted in (a) increased antioxidant enzyme activities and (b) decreased malondialdehyde level in rats (Zhu et al. 2009b). An acidic polysaccharide APMO of *M. officinalis* exhibited excellent capability in scavenging DPPH radicals, chelating ferrous ions and inhibiting haemolysis of rats' erythrocyte induced by hydrogen peroxide, which was stronger than those of vitamin C at high concentration (Zhang et al. 2013).

Hypoglycaemic and Hyperglycaemic Activities

Scientific studies confirmed the dried roots of *Morinda officinalis* possessed both hypoglycaemic and hyperglycaemic properties (Soon and Tan 2002). In the 3-h dose response study, the crude ethanolic root extract reduced the fasting serum glucose levels of streptozotocin-induced diabetic rats significantly at 150 mg/kg but increased those of the normal rats significantly at 600 mg/kg only. The water fraction demonstrated a dose-dependent hypoglycaemic effect in the diabetic rats whereas the *n*-butanol fraction increased the fasting serum glucose levels of the diabetic rats significantly at 50 mg/kg only within 3 h after administration.

Anthraquinones from *Morinda officinalis* roots were found to enhance adipocyte differentiation in 3T3-L1 cells (Liu et al. 2012). Among them, alizarin-*2*-methyl ether showed the strongest enhancing activity, followed by rubiadin-*1*-methyl ether and *1,2*-dimethoxyanthraquinone. At a concentration of 100 μM, alizarin-*2*-methyl ether enhanced adipocyte differentiation by up to 131 % (compared to insulin-treated cells). Thus, these compounds could be beneficial in the treatment of diabetes.

Antidepressant Activity

Five compounds, succinic acid, nystose, *1F*-fructofuranosylnystose, inulin-type hexasaccharide and heptasaccharide, isolated from *Morinda officinalis* roots were found to have antidepressant activity (Cui et al. 1995).

Studies showed that chronic stress resulted in diffuse hyperplasia of the adrenal cortex and atrophy of the adrenal medulla in mice, which suggested that stress-adaption failure of the adrenal gland occurred, while adrenal gland of the mice pretreated with *Morinda officinalis* (Chinese medicine 'Ba ji tian') oligosaccharides (MW-97) (100 mg/kg, ip) prior to each stressor for 15 days did not produce any pathologic changes (Li et al. 2001). In addition, chronic stress also significantly reduced the WBC count and relative WBC percentages in the peripheral blood, including the percentage of lymphocytes, monocytes and neutrophils; however, MW-97 (25 and 100 mg/kg) reversed these changes and raised WBC count, along with relative WBC percentages significantly. Further, the serum concentration of testosterone was decreased and corticosterone was increased significantly in chronically stressed animals. MW-97 also lowered the serum level of corticosterone and raised the level of testosterone. MW-97 had no effects on the spontaneous motor activity in the stressed mice. The data indicated that MW-97 had antistress effect against chronic stress; moreover, MW-97 had no excitatory or inhibitory effects on the CNS, which suggested that MW-97 might become a new kind of antistress agent. Separate animal studies showed that *M. officinalis* extract possessed the antidepressant effect (Zhang et al. 2002). In the forced swimming test in mice, the plant extract (50 mg/kg), like the effect of desipramine (20 mg/kg), elicited a significant reduction in the duration of immobility. In the DRL 72-s schedule in rats, the plant extract (25–50 mg/kg), similar to clinically effective antidepressant drug desipramine (5–10 mg/kg), significantly reduced response rate and efficiency ratio while at the same time increasing reinforcement rate.

The roots were found to contain oligosaccharides, P_6, that significantly antagonised the apoptosis induced by corticosterone in PC12 cells, which may be one of the cellular mechanisms of their antidepressant effects (Li et al. 2003). Studies found that inulin-type hexasaccharide (IHS) at the doses of 0.625, 1.25 μM or desipramine (DIM) 0.25, 1 μM protected the PC12 cells from the lesion induced by corticosterone (Li et al. 2004b). High concentration of corticosterone (Cort), 0.2 mM, was incubated with PC12 cells to simulate the lesion state of brain neurons in depressive illness. The data indicated that IHS attenuated the intracellular Ca2+overloading and thereby upregulated the NGF mRNA expression in corticosterone-treated PC12 cells, which may consist at least part of the cytoprotective effect of IHS. These results supported the hypothesis that neuroprotective action may be one of the common mechanisms for antidepressants.

Antinociceptive Activity

Pretreatment of mice with the butanol root extract (100, 200 mg/kg, p.o. daily for 7 d) more significantly inhibited nociceptive or inflammatory response than the chloroform and ethyl acetate extracts by acetic acid writhing and hot-plate testing in mice (Choi et al. 2005). The administration of its active constituent, monotropein, significantly reduced the number of writhings and stretchings caused by 0.7 % acetic acid. The percentage reductions in the writhing response afforded by monotropein were 36.6 % and 47.5 %, respectively, at 100 mg/kg and 200 mg/kg, and latencies by hot-plate testing were prolonged by 64.3 % and 96.1 %, respectively. The results suggested that monotropein possessed centrally and peripherally mediated antinociceptive properties. In separate studies, the methanol root extract exhibited antinociceptive effects in mice in the acetic acid-induced abdominal constriction test and the hot-plate test (Kim et al. 2005).

Anti-inflammatory Activity

Pretreatment of rats with the methanol root extract and butanol root extract (100, 200 mg/kg, p.o. daily for 7 days) more significantly inhibited inflammatory response than the CHCl3 and EtOAc extracts in carrageenan-induced edema testing rats (Choi et al. 2005). It bioactive constituent monotropein was found to have an anti-inflammatory effect 1 h after the carrageenan injection, and maximal oedema inhibition was observed at 3 h after oedema induction. In particular, treatment with monotropein (30 mg/kg, p.o.) reduced the oedema by 39.6 % at 3 h. When subjected to acute toxicity test using mice, any lethality was not observed up to 2000 mg/kg dose (p.o.). This result indicated that monotropein was safe for clinical use. In separate studies, the methanol root extract potently inhibited the production of nitric oxide (NO), prostaglandin E2 and tumour necrosis factor-α (TNF-alpha) in lipopolysaccharide (LPS)-stimulated RAW 264.7 macrophages (Kim et al. 2005). The expression of inducible nitric oxide synthase (iNOS) and cyclooxygenase-*2* (COX-2) at the protein level, and of iNOS, COX-2 and TNF-alpha at the mRNA level, was also inhibited by the root extraction, a concentration-dependent manner. Furthermore, MEMO inhibited the nuclear factor kappa B (NF-kappaB) activation induced by LPS, and this was associated with the prevention of degradation of the inhibitor kappa B (IkappaB) and subsequently with attenuated p65 protein in the nucleus. The anti-inflammatory effect of MEMO was examined in rats using the carrageenan-induced oedema model.

Monotropein, from *M. officinalis*, was found to inhibit the expressions of inducible nitric oxide synthase (iNOS), cyclooxygenase-2 (COX-2), tumour necrosis factor-α (TNF-α) and interleukin-1β (IL-1β) mRNA in LPS-induced RAW 264.7 macrophages (Shin et al. 2013). Treatment with monotropein decreased the DNA binding activity of nuclear factor-κB (NF-κB). Monotropein also suppressed phosphorylation and degradation of inhibitory κB-α (IκB-α) and consequently the translocations of NF-κB. In the dextran sulphate sodium-induced colitis mouse model, monotropein reduced disease activity index (DAI), myeloperoxidase (MPO) activity and inflammation-related protein expressions by suppressing NF-κB activation in the colon mucosa. The findings suggested that the anti-inflammatory effects of monotropein were mainly related to the inhibition of the expressions of inflammatory mediators via NF-κB inactivation and supported its possible therapeutic role in colitis.

Antiosteoporotic Activity

Studies demonstrated that ethanol root extract had significant antiosteoporotic activity (Li et al. 2009). The administration of the extract for 12 weeks significantly increased trabecular bone mineral content and bone mineral density of the tibia; improved the levels of phosphorus, calcium and osteoprotegerin; decreased the levels of deoxypyridinoline/creatinine, tartrate-resistant acid phosphatase (TRAP), adrenocorticotropin

and corticosterone; but did not reverse the levels of alkaline phosphatase (ALP), TNF-α (tumour necrosis factor-α) and interleukin IL-6 in serum of ovariectomised rats. The findings demonstrated that the root extract reduced bone loss in ovariectomised rats, probably via the inhibition of bone resorption, but was not involved with bone formation. Anthraquinones and polysaccharides from *Morinda officinalis* could be responsible for their antiosteoporotic activity.

Bioactivity-guided fractionation led to the successful isolation of antiosteoporotic components, i.e. physicion (1), rubiadin-*1*-methyl ether (2), *2*-hydroxy-*1*-methoxy-anthraquinone (3), *1,2*-dihydroxy-*3*-methylanthraquinone (4), *1,3,8*-trihydroxy-*2*-methoxy-anthraquinone (5), *2*-hydroxymethyl-*3*-hydroxyanthraquinone (6), *2*-methoxyanthraquinone (7) and scopoletin (8) from an ethanolic extract of the roots of *Morinda officinalis* (Wu et al. 2009). Among them, compounds 2 and 3 promoted osteoblast proliferation, while compounds 4 and 5 increased osteoblast alkaline phosphatase activity. All of the isolated compounds inhibited osteoclast tartrate-resistant acid phosphatase (TRAP) activity and bone resorption, and the inhibitory effects on osteoclastic bone resorption of compounds 1 and 5 were stronger than that of other compounds. The results suggested that *M. officinalis* and its anthraquinones may have therapeutic potential against osteoporosis.

Pharmacological studies showed that *M. officinalis* root extract enhanced the expression of core-binding factor α1 (cbfα1), a key transcription factor for osteoblast differentiation (Wang et al. 2004), and increased the proliferation, alkaline phosphatase activity and osteocalcin (Li et al. 2004a). Animal preventive and therapeutic studies showed that *M. officinalis* aqueous root extract administered to sciatic neurectomised significantly and dose-dependently suppressed the decrease in hind limb thickness, tibia failure load, bone mineral density and tibia Ca and P contents with an increase in serum osteocalcin levels (Seo et al. 2005). Further, the root extracts also significantly and dose-dependently suppressed the decrease in histomorphometrical parameters of the tibia such as volume, length and thickness of trabecular bone and thickness of cortical bone with an increase in osteoclast cells. The findings suggested that the root extracts may act as both a suppressor of bone resorption and an enhancer of bone formation in vivo and may have some favourable effects for preventing and treating the osteoporosis induced by sciatic neurectomy. The administration of *M. officinalis* polysaccharides (MOP) to osteoporotic rats induced by ovariectomy resulted in an increase in bone mineral density and mineral element concentration and a decrease in serum cytokine level, indicating that MOP administration may play an important role in thwarting development of osteoporosis (Zhu et al. 2008).

Compounds *1,3,8*-trihydroxy-*2*-methoxy-anthraquinone (1), *2*-hydroxy-*1*-methoxy-anthraquinone (2) and rubiadin (3) decreased the formation of bone resorption pits, the number of multinucleated osteoclasts and the activity of tartrate-resistant acid phosphatase (TRAP) and cathepsin K in the coculture system of osteoblasts and bone marrow cells in the presence of *1,25*-dihydroxyvitamin D(3) and dexamethasone (Bao et al. 2011). They also enhanced the apoptosis of osteoclasts induced from bone marrow cells with M-CSF and RANKL. Further, they improved the ratio of mRNA and protein expression of OPG and RANKL in osteoblasts, interfered with the JNK and NF-κB signal pathway and reduced the expression of calcitonin receptor (CTR) and carbonic anhydrase II (CA II) in osteoclasts induced from bone marrow cells with M-CSF and RANKL. The findings indicated that the anthraquinone compounds from *M. officinalis* were potential inhibitors of bone resorption and bone loss. *Morinda officinalis* capsules at all doses (90, 270 and 810 mg/kg/day) were able to significantly prevent the ovariectomised-induced loss of bone mass due to diminishing serum tartrate-resistant acid phosphatase (TRAP), and alkaline phosphatase (AKP), levels while elevating osteocalcin level in the plasma (Li et al. 2014). *Morinda officinalis* capsules also enhanced the bone strength and prevented the deterioration of trabecular microarchitecture. The results suggested that *Morinda officinalis* capsules possessed potent antiosteoporotic activity which could be an effective treatment for postmenopausal osteoporosis.

Renoprotective Activity

The administration of *M. officinalis* extract alleviated hydrocortisone-induced 'kidney yang deficiency syndrome' in rats (Gong et al. 2012). The extract effectively alleviated the disruption of energy and amino acid metabolism and enhanced transmethylation but could not modulate the gut microflora environment.

Pretreatment of rats with WKY2, an aqueous extract from an herbal formula containing *Astragalus membranaceus, Lycium barbarum, Morinda officinalis, Taraxacum mongolicum* and *Cinnamomum cassia*, protected rats against kidney yang deficiency syndrome induced by hydrocortisone injection (Zhao et al. 2013). The changes of serum metabolic profiles indicated that significant alterations of key metabolic pathways in response to abrupt hydrocortisone perturbation, including decreased energy metabolism (lactic acid, acetylcarnitine), lipid metabolism (free fatty acids, *1*-monolinoleoylglycerol and cholesterol), gut microbiota metabolism (indole-*3*-propionic acid) and biosynthesis of catecholamine (norepinephrine), and elevated alanine metabolism, were attenuated or normalised with different degrees by the pretreatment of WKY2. Also, WKY2 could ameliorate biochemical markers of serum cortisone, adrenocorticotropic hormone (ACTH) and urine *17*-hydroxycorticosteroids (*17*-OHCS). In a separate study, administration of *M. officinalis* could alleviate the hydrocortisone-induced 'kidney-yang deficiency syndrome' in rats using the established metabonomic method and the regulated metabolic pathways involving energy metabolism, transmethylation and transportation of amine (Zou et al. 2013). Eight potential biomarkers including citrate, succinate, alpha-ketoglutarate, lactate, betaine, sarcosine, alanine and taurine were definitely up- or downregulated.

Studies found that four processed products of *M. officinalis*, namely, *M. officinalis* extract, morinda pulp, salt-steamed *M. officinalis* and liquorice-processed *M. officinalis*, could improve the symptoms of the kidney yang-deficient mice (Cui et al. 2013). Among them, salt-steamed *M. officinalis* had the most significant effect, which was followed by liquorice-processed *M. officinalis*, morinda pulp and *M. officinalis*.

Central Nervous System/ Neuroprotective Activity

In-Vitro Studies

In-vitro studies showed that 'bajijiasu' (*β*-D-fructofuranosyl (*2–2*) *β*-D-fructofuranosyl), a dimeric fructose isolated from *M. officinalis* root, exhibited neuroprotective activity against beta-amyloid peptide $A\beta_{25–35}$-induced neurotoxicity in PC12 cells likely by protecting against oxidative stress and ensuing apoptosis (Chen et al. 2013a). Further, reversed $A\beta_{25–35}$ induced changes in the expression levels of p21, CDK4, E2F1, Bax, NF-κB p65 and caspase-*3*. Using rat hippocampal slices, Chen et al. (1998) found that Ba-Ji-Su could enhance long-term potentiation, improve memory and protect neurons from anoxic injury.

Animal Studies

Oral administration of *M. officinalis* root aqueous extract increased body weight, thymus weight and blood leukocyte content, prolonged swimming times of the young mice and decreased Rt of M-receptor in the brains of the hypothyroidic mice (Qiao et al. 1991). The results indicate that *M. officinalis* had antifatigue activity, improved the immunological action of the young mice and reduced the excitability of the parasympathetic nervous system of the hypothyroidic mice by decreasing the Rt of M-receptor in their brains.

Treatment of D-galactose-induced senile rats with Ba ji tian improved their spatial learning and memory ability (Tan et al. 1999). The results showed that the escape latency of senile rats was shortened, the proplateau quadrant and the 40-cm circle swimming times lengthened, the proplateau quadrant swimming path percentage increased and the long-term potentiation effect of hippocampal synapse transmission increased significantly in a dose-dependent manner. Studies demonstrated that treatment with Ba ji tian increased the activity of superoxide dismutase

and glutathione peroxidase, reduced the content of lipid peroxide and raised the glucose content in the brain tissue of senile mice with acute cerebral ischemia but had no obvious influence on the NO content (Chen et al. 2000). The results suggested that the mechanism of Ba ji tian's protective effect on acute cerebral ischemic injury was related to the counteraction of lipid peroxidation and the improvement of glucose metabolism in brain tissue.

The administration of *M. officinalis* oligosaccharides to rats with beta-amyloid-induced dementia ameliorated dementia by enhancing oxidation resistance, activating brain energy metabolism and improving the injury of cholinergic system (Chen et al. 2013b). All administered groups showed higher superoxide dismutase, catalase and glutathione peroxidase levels and lower malondialdehyde in the brain tissues. Additionally, they also showed increases in the activities of acetylcholine and Na^+/K^+-ATPase.

Bajijiasu, a dimeric fructose isolated from *Morinda officinalis* root, ameliorated $A\beta_{25-35}$-induced learning and memory dysfunction, enhanced antioxidative activity and energy metabolism and attenuated cholinergic system damage in rats (Chen et al. 2014b). The findings suggested that bajijiasu could enhance antioxidant capacity and prevent free radical damage. It could also enhance energy metabolism and monoamine neurotransmitter levels and inhibit neuronal apoptosis.

Angiogenesis-Promoting Activity

The medium and high doses of serum containing *Morinda officinalis* oligosaccharides when added to chick embryo chorioallantoic membrane elicited a significant increase in the number of new blood vessels (Yang et al. 2012). The results suggested that *M. officinalis* oligosaccharides could promote angiogenesis.

Antifatigue Activity

Polysaccharides of *M. officinalis*, when tested in mice weight-loaded swimming model, were found to have antifatigue activity (Zhang et al. 2009). The administration of *M. officinalis* extract improved the physical ability of swimming mice through its antioxidation activities (Long et al. 2013). The activity of myocardium SOD and GSH-Px was enhanced and MDA lowered compared to the untreated control group; free radicals were efficiently eliminated.

Anti-ageing Activity

Five anti-ageing compounds, rubiadin-*1*-methyl ether, *2*-hydroxy-*1*-methoxy anthraquinone, scopoletin, isofraxidin and anthraquinone-*2*-aldehyde, were isolated (Li et al. 2011). Seven active anti-ageing compounds isolated were digiferruginol, *1*-hydroxy-*6*-hydroxymethyl anthraquinone, *1*-hydroxy-*7*-hydroxymethyl anthraquinone, *3*-hydroxy-*1,2*-dimethoxyanthraquinone, *2*-hydroxy-*3*-methyl anthraquinone, *2*-carbomethoxy anthraquinone and *1,2*-dihydroxy-*3*-methyl anthraquinone (Wang et al. 2011).

Cardiovascular Protective Activity

Treatment of rats with *M. officinalis* oligosaccharides (1.4 and 2.8 g/kg/day) could protect myocardium against ischemia reperfusion injury via inhibition of free radical and subsequent lipid peroxidation (Wang et al. 2010). The scores of ventricular arrhythmia and the infarct size of the myocardium were significantly reduced, and the activities of SOD, CAT and GSH-Px significantly increased, while MDA content significantly reduced in myocardium of the treated group compared to myocardial ischemia reperfusion animals.

Oral treatment of acutely stressed blood stasis rats with *M. officinalis* root ethanol extract (3, 6, 12 g/kg bw/day) for 5 days eliminated blood stasis, inhibited rate of platelet aggregation and improved haemorheological indexes and blood flow (Fu et al. 2007).

Anticancer Activity

Studies showed that Equiguard, a dietary supplement comprised of standardised extracts from nine herbs, viz. Herba *Epimedium brevicornum* (stem and leaves), Radix *Morinda officinalis* (root), Fructus *Rosa laevigata* (fruit), *Rubus chingii* (fruit), *Schisandra chinensis* (fruit), *Ligustrum lucidum* (fruit), *Cuscuta chinensis* (seed), *Psoralea corylifolia* (fruit) and *Astragalus membranaceus* (root), significantly reduced prostate cancer cell growth, induced apoptosis, suppressed expression of the androgen receptor (AR) and lowered intracellular and secreted prostate-specific antigen (PSA), and almost completely abolished colony-forming abilities of prostate cancer cells (Hsieh et al. 2002). The data indicated that this herbal formulation contained ingredients that collectively may be efficacious in preventing or treating androgen-dependent (AD) and androgen-independent states of prostate carcinoma.

Fertility Enhancement Activity

Treatment of isolated human sperm with *M. officinalis* root extract (0.25, 0.5 mg/ml) significantly inhibited lipid peroxidation in sperm membrane by its antioxidative effects (augmenting superoxide dismutase activity and reducing MDA (malondialdehyde) level) and protected the structure and function of sperm membrane from ROS injury (Yang et al. 2005). The data elucidated one of the mechanisms for treating male's infertility and asthenospermia with *M. officinalis*. Studies showed that oligosaccharides extracted from *Morinda officinalis* could be used to treat infertility by protecting the DNA of human sperm from being damaged by H_2O_2 (Chen et al. 2014a). It was also demonstrated that *Morinda officinalis* as a tonifying and replenishing natural herb medicine could be used to enhance reproductive functions and that Raman spectroscopy could be an applicable technology for screening active components in-vitro from herbs.

Traditional Medicinal Uses

Morinda officinalis is one of the 'top four south authentic traditional Chinese medicines' and is a commonly used Chinese herb distributed in the south of China, and its roots are widely used for the treatment of sexual impotence, spermatorrhoea, irregular menstruation and female infertility (National Pharmacopoeia Commission of China 2005; Zhang et al. 2010). The root is used to treat rheumatoid arthritis and impotence in the traditional Oriental medicine (Choi et al. 2005). The roots of *Morinda officinalis* continue to be traditionally used to treat rheumatoid arthritis, diabetes and hypertension in Northeast Asia rather than *M. citrifolia*, which is also used in traditional medicine and said to have similar pharmacologic effect.

Therapeutic uses of *M. officinalis* roots include the therapy of sexual hormonal deficiency in males; treatment of fatigue, general debility and loss of appetite in old people; cure for kidney yang debility, rheumatoid diseases, lumbago, dizziness, ringing in ears, weakness of tendons and bones and spermatorrhoea; and tonic for treatment of impotency in man and for menstrual disorders in women (NIMM 1999; Lu 2005). In clinical therapy, it is often used with other herbs or on its own. The root is used to treat beriberi, tendon and bone ailments, premature ejaculation, impotence, lumbago, hernia and excessive or involuntary discharge of urine, to strengthen the kidneys and to increase menstrual flow (Wee and Hsuan Keng 1990).

Other Uses

Fleshy roots are mainly used for medicinal purposes; the roots are sold dried or further processed into liquorice-impregnated or salted-dried drugs.

Comments

The plant is propagated from seeds and stem cuttings.

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Eurycoma longifolia

Scientific Name

***Eurycoma longifolia* Jack**

Synonyms

Eurycoma latifolia Ridl., *Eurycoma longifolia* var. *cochinchinensis* Pierre, *Eurycoma merguensis* Planch., *Eurycoma tavoyana* Wall. (inval.)

Family

Simaroubaceae

Common/English Names

Ali's Umbrella, Ali's Walking Stick, Tongkat Ali, Long Jack, Longjack, Malaysian Ginseng, Manotes Asiatica, Picroxylon Siamese

Vernacular Names

Chinese: Ali Zhi Zhang
Czech: Malajský Ženšen
French: Canne D'ali, Ginseng De Malaisie
German: Tongkat Ali
Japanese: Nagaekasa
Indonesia: Bidara Laut, Pasak Bumi, Babi Kurus (Javanese)
Laotian: Tho Nan
Latvian: Garlapu Eurikoma
Malaysia: Tongkat Ali, Wonod Mondou, Umpudumaidu (Sabah), Sengkayap (Iban, Sarawak), Tongkat Ali, Akar Pasak Bumi, Batang Pasak Bumi, Kayu Dali, Muntah Bumi, Tongkat Ali, Penawar Pahit, Penawar Bias, Bendera Merah, Bendera Putih, Lempedu Pahit, Payong Ali, Petala Bumi, Tongkat Baginda
Polish: *Eurycoma*, Żeńszeń Malezyjski
Thai: Lan-Don, Hae Phan Chan, Phiak, Plaa Lai Phuenk, Tung Saw
Vietnamese: Cây Bá Bệnh

Origin/Distribution

The species is found in Indonesia and Malaysia and, to a lesser extent, Thailand, Vietnam and Laos. In Indonesia, this species only occurs naturally in Sumatra and Kalimantan.

Agroecology

E. longifolia prefers well-drained acid and sandy soils and is found at low altitude up to 1200 m above sea level. The species occurs in beach for-

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
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ests, primary and secondary forests, secondary mixed dipterocarp, Kerangas and submontane forests and also in heath forests.

In Riau Province, Sumatra, the plants were reported to grow in areas with an average temperature of 25 °C and 86 % humidity (Hadiah 1996). The soils in this area were found to be poor in nutrients, but mycorrhizal fungi were found growing near the plants and may indicate an association. Seedlings require shade, during which time they develop an extensive root system. Following juvenile stages, plants need stronger light to develop vegetative and reproductive parts. *E. longifolia* flowers and fruits throughout the year.

Edible Plant Parts and Uses

In Malaysia, the common use of *E. longifolia* root and trunk base (apart from traditional medicine and dietary supplements) is as food and drink additive (Plates 4 and 5). Specifically, it is a common ingredient for coffee and functional beverage positioned as energy drinks. Traditional users of 'Tongkat Ali' brew tea from the dried chips of the tree's root. In Malaysia alone, over 300 popular tonics, coffees and candies contain Tongkat Ali. Presently, many tea, coffee and carbonated beverages, premixed with the root extract, are available commercially for the improvement of general health and libido (Low et al. 2013a).

Botany

Eurycoma longifolia are small trees to 10 m (Plates 1 and 2), rarely shrubs, monoecious or dioecious. Its leaves are imparipinnately compound and are 20–40 cm long with 13–41 leaflets. Leaflets are lanceolate to ovate-lanceolate, 5–20 cm long, 1.5–6 cm wide, much paler on the ventral side, opposite to sub-opposite, sessile to sub-sessile and entire, glabrous and without glands (Plates 1 and 2). Flowers in axillary determinate thryses have multiple reddish axes with thick and capitate glandular hairs. Petals 5(6) are indusate–valvate pubescent with capitate glandular hairs; stamens 5(6). Filaments with small

Plate 1 Tongkat Ali sampling

appendages have anthers dorsifixed, staminodes 5(6) alternating with stamens in staminate flowers and inconspicuous disc; carpels 5(6) are distinct, and stylodia are connate or cohering; stigma is lobed and peltate. Fruits 1–5 are nut-like mericarps, ovoid, bicarinate, 10–20 mm by 5–12 mm and yellowish brown when young and brownish red when ripe (Plate 3).

Nutritive/Medicinal Properties

The plant had been reported to contain a series of quassinoids (Ang et al. 2000a, b; Ang and Lee 2002a, b, c; Bedir et al. 2003; Chan et al. 1989, 1992; Miyake et al. 2009; Chua et al. 2011), canthin-6-one alkaloids, β-carboline alkaloids (Chan et al. 2004; Kuo et al. 2004; Chua et al. 2011), tirucallane-type triterpenes (Kuo et al. 2004), squalene derivatives (Kuo et al. 2004; Morita et al. 1993a; Chua et al. 2011) and biphenylneolignans (Kuo et al. 2004; Chua et al. 2011)

Plate 2 Foliage and fruits

Plate 3 Cluster of ripe red fruits

Wood/Root Phytochemicals

E. longifolia roots from Perak and Pahang were found to contain 0.3868 and 0.9573 mg/mL of crude protein, respectively (Chua et al. 2013). The crude proteins were separated into two (49.8 and 5.5 kD) and four (49.8, 24.7, 21.1 and 5.5 kD) protein spots for Tongkat Ali Perak and Pahang, respectively. The roots contained significantly high level of isoleucine and high levels of calcium, magnesium and potassium. Toxic metals such as arsenic and lead were not detected. The water-soluble fraction of the methanolic extract of *E. longifolia* roots afforded three quassinoid diterpenoids eurycomalide A, eurycomalide B and 13β, 21-dihydroxyeurycomanol, carbohydrates glucose and fructose and twenty-five amino acids (Kuo et al. 2003a). The predominant amino acids were alanine, proline, arginine and serine amounting to 53.39 % of the total amino acids. *E. longifolia* was reported to contain a bioactive 4.3 kDa peptide which was present in most parts of the plant including root, bark, callus and tissue-cultured plantlets (Nurhanan et al. 2004; Asiah et al. 2007).

From *Eurycoma longifolia* roots, two highly oxygenated quassinoids, named eurycomanone and eurycomanol, were isolated (Darise et al. 1982). Two new C_{18}quassinoids laurycolactones A and B were isolated from *E. longifolia*, and the structure of eurycomalactone, a C_{19} quassinoid, was revised (Nguyen et al. 1982). 10-Hydroxycanthin-6-one, eurycomalactone, eurycomanone and eurycomanol were isolated from *Eurycoma longifolia* (Chan et al. 1986). A new quassinoid glycoside, eurycomanol-2-*O*-β-D-glycopyranoside, and eurycomanol have been isolated as antimalarial components of *Eurycoma longifolia* roots (Chan et al. 1989). A new C_{19}-skeleton quassinoid, named longilactone, and three new quassinoids, 13,21-dihydroeurycomanone, 13β,21-dihydroxyeurycomanone and 14,15β-dihydroxyklaineanone were isolated from *Eurycoma longifolia* roots (Morita et al. 1990). Four canthin-6-one alkaloids, namely, 9-methoxycanthin-6-one, 9-methoxycanthin-6-one-N-oxide, 9-hydroxycanthin-6-one and

Plate 4 (**a**) Trunk base and root with bark removed, (**b**) Tongkat ali processed product

Plate 5 Slices of Tongkat Ali sold for herbal tea

9-hydroxycanthin-6-one-N-oxide, and one quassinoid, eurycomanone, were isolated from *E. longifolia* roots and found to be cytotoxic principles (Kardono et al. 1991). A new quassinoid, 13β,18-dihydroeurycomanol, and 14,15p-dihydroxyklaineanone were isolated from the roots (Chan et al. 1991). On the basis of NOE and ^{1}H-^{1}H COSY measurements, the previous ^{1}H NMR assignment for the C-4 and C-10 methyl groups of eurycomanol-2-*O*-β-D--glycopyranoside and eurycomanol was reversed. Two additional acids, the β-carboline alkaloids β-carboline-1-propionic acid and 7-methoxy-β-carboline-1-propionic acid, were also isolated. Four C_{20} quassinoids, pasakbumins A (eurycomanone), B, C and D, were isolated from *Eurycoma longifolia* (Tada et al. 1991). A new cytotoxic squalene-type triterpene, named eurylene, was

isolated from *E. longifolia* (Itokawa et al. 1991b). New cytostatic quassinoids, 6α-hydroxyeurycomalactone, longilactone and 14,15β-dihydroxyklaineanone, were isolated from the wood of *Eurycoma longifoli*a with three cytotoxic quassinoids, 11-dehydroklaineanone, eurycomalactone and 5,6-dehydroeurycomalactone, and with seven cytotoxic tirucallane-type triterpenes, niloticin, dihydroniloticin, piscidinol A, bourjotinolone A, 3-episapelin A, melianone and hispidone (Itokawa et al. 1992). A new C_{19} quassinoid, 6α-hydroxyeurycomalactone, and eurycomalactone were isolated from the roots (Chan et al. 1992). Two new 1,2-seco-1-nor-6(5 → 10)abeo-picrasan-2,5-olide skeleton quassinoids, eurylactones A and B, and two new C_{18} skeleton quassinoids 3 and 4 were isolated from *Eurycoma longifiola* together with two known C_{18} quassinoids 5 and 6 (Itokawa et al. 1993a). A new 1, 2-seco-1-nor-6(5–10)-abeo-picrasan-2, 5-olide skeleton quassinoid named eurylactone and two new C_{19}- and C_{20}-skeleton quassinoids were isolated from *Eurycoma longifolia* wood (Itokawa et al. 1993b). One compound was found to have a longilactone-type C_{19}-skeleton, and the others a klaineanone-type13β,18-dihydroeurycomanol, eurycomanol-2-*O*-β-D-gluco-pyranoside, eurycomanol and eurycomanone were identified in *E. longifolia* (Ang et al. 1995a, b). Eurycomanone (1),longilactone(2),14,15β-dihydroxyklaineanone (3), 15β-acetyl-14-hydroxyklaineanone (4), 6α-hydroxyeurycomalactone (5) and eurycomalactone (7) were isolated together with β,12α,15β-triacetyleurycomanone from *Eurycoma longifolia* (Chan et al. 1998). Eurycomanone was recovered with the highest concentration, being about 16.8–39.6-fold higher than the other quassinoids 2, 3, 5 and 7 but 145.3-fold higher than 4 which showed the lowest concentration. Three novel quassinoids, eurylactones A–C, were isolated from the roots (Ang et al. 2000b). Three major canthinone alkaloids, 9-methoxycanthin-6-one, 3-methylcanthin-5,6-dione and its 9-methoxy analogue, were detected in *Eurycoma longifolia* (Choo and Chan 2002). Quassinoids, eurycolactone D, eurycolactone E, eurycolactone F, laurycolactone B and eurycomalactone were isolated from *E. longifolia* roots (Ang et al. 2002). Eurycomanone, 13,21-dihydroeurycomanone, eurycomanol, longilactone, 14,15β-dihydroxyklaineanone and eurycomanol-2-*O*-β-glucopyranoside were identified in the *n*-butanol fraction (Chan and Choo 2002). Three new [n-pentyl β-carboline-1-propionate, 5-hydroxymethyl-9-methoxycanthin-6-one and 1-hydroxy-9-methoxycanthin-6-one] and 19 known β-carboline alkaloids including 9-methoxycanthin-6-one and canthin-6-one were isolated from *E. longifoli*a roots (Kuo et al. 2003b). A new C19-quassinoid-type glycoside named eurycomaoside was isolated from the roots (Bedir et al. 2003). Sixty-five compounds were isolated from *E. longifolia* roots including four quassinoid diterpenoids including new ones eurycomalide A, eurycomalide B, 13β,21-dihydroxyeurycomanol and 5α,14β,15β-trihydroxyklaineanone (Kuo et al. 2004). A quassinoid compound, 4,5,7,8,17-penta-hydroxy-14,18-dimethyl-6-methylene-3,10-dioxapenta-cyclo-[9.8.0.0.0.0] nona-dec-14-ene-9,16-dione methanol solvate dihydrate, a natural eurycomanone, was isolated from *Eurycoma longifolia* roots (Teh et al. 2009). A novel 2,3-dehydro-4α-hydroxylongilactone and two known phenyl propanoids, 2,3-dihydroxy-1-(4′-hydroxy-3′-methoxyphenyl)-propan-1-one and scopolin, were isolated from the roots (Teh et al. 2010). Five compounds were obtained from *E. longifolia* and identified as scopoletin, 9-methoxycanthin-6-one, 7-methoxy-β-carbolin-1-propionic acid, laurycolactone A and 7-methoxyinfractin (Han et al. 2011). Five new quassinoids, eurylactone E, eurylactone F, eurylactone G, eurycomalide D and eurycomalide E, along with ten known quassinoids including 13β-methyl,21-dihydroeurycomanone, were isolated from *E. longifolia* roots (Park et al. 2014).

The volatile compounds identified in the headspace of *E. longifolia* extracts were as follows: curcumene; (*R*)-(−)-massoilactone; 3-phenoxy-1-propanol; octanoic acid; benzoic acid; acetic acid; 2-phenoxyethanol; 4 ethynyl-4-hydroxy-3,5,5-trimethyl-2-cyclohex-1-enone; butanol, 3 –methyl; 1-butanol; 1-pentanol; 2-hexadecanol; acetol; nonanal; 2-methylhexanol, benzaldehyde; 2,3-butanediol, [*S*-(*R**,*R**)]-; butyrolactone;

2-furanmethanol; 3-methylbutanoic acid; 2(5H)-furanone; hexanoic acid; butylated hydroxytoluene; ethanone,1-(1H-pyrrol-2-yl)-; 1H-pyrrole-2-carboxaldehyde; menthol,1′-[butyn-3-one-1-yl]-, [1R,2S,5R]-; ethyl-*p*-ethoxybenzoate; nonanoic acid; 2,4-bis(1,1-dimethylethyl)phenol; diethyl phthalate; and 4α,8α-butano-[1,4]dioxino[2,3-β]-1,4dioxin,tetrahydro (Shafiqul Islam et al. 2006).

Thirteen known compounds including five canthin-6-one alkaloids, three anthraquinones and five anthraquinone glucosides were isolated from the roots of *E. longifolia* (Lin et al. 2001). Ethanol extract of *E. longifolia* roots was found to contain 14.631 % terpenoids and 5.117 % alkaloids (Rahmalia et al. 2011). Terpenoids included 5-(hydroxymethyl)-2-furancarboxaldehyde (3.04 %), vanillin (2.57 %), 1H-2-benzopyran-1-one, 3,4-dihydro-8-hydroxy-3-methyl (5.79 %), 3-ethoxy-benzaldehyde (4.63 %), 4-((1*E*)-3-hydroxy-1-propenyl)-2-methoxyphenol (5.12 %), 2-H-1-benzopyran-2-one, 3-phenyl-(coumarin derivative) (21.44 %) and 2-methyl-*Z*,*Z*-3,12-octadecadienol (4.46 %) and alkaloids identified were 6-ter-butyl-2,3-dicayanonaphthalen (3.59 %), 6,7-dimethoxy-1,4-dihydro-2,3-quinoxalinedione (10.90 %), 1-amino-9-fluorenone (2.50 %), 3-methyl-1-oxo-2,3-dihydro-1H-pyrazolo[4,3-c][1,10]phenanthroline (27.83 %) and 2,2′-(1,4-phenylene)bis[4-methyl]-5-phenyl-oxazole (2.31 %)

Metabolites detected in *E. longifolia* aqueous root extracts from Perak and Pahang included quassinoids which were detected in the highest concentration, canthine-6-one alkaloids, β-carboline alkaloids, squalene-type triterpenes and biphenylneolignans (Chua et al. 2011). The concentration of canthin-6-one and β-carboline alkaloids was significantly increased when the roots of the plant samples were extracted at 100 °C. A small peptide of leucine (m/z 679) and a new hydroxyl methyl β-carboline-propionic acid have been identified to differentiate *E. longifolia* extracts that were prepared at 35 °C and 100 °C, respectively. From the targeted metabolite identification, it was found that 3,4ε-dihydroeurycomanone (quassinoid) and eurylene (squalene-type triterpene) could only be detected in the Pahang extract, whereas canthin-6-one-3-N-oxide could only be detected in the Perak extract. The quassinoids included eurycolactones A, B, C, D, E; eurycomalides A and B; eurycomalactone, 6α-hydroxyeurycomalactone; 7α-hydroxyeurycomalactone; eurycomanone; 3α(21)-epoxyeurycomanone; 12,15-diacetyl-13α(21)-epoxyeurycomanone; 12-acetyl-13,21-dihydroeurycomanone; 15-acetyl-13α(21)-epoxyeurycomanone;3,4ε-dihydroeurycomanone; 13,21-dihydroeurycomanone; eurycomanol; 13β,18-dihydroeurycomanol, 13β,21-dihydroeurycomanol, eurycomanol-2-*O*-β-D--glycopyranoside; 11-dehydroklaineanone; 15β-hydroxyklaineanone; 14,15β-dihydroxyklaineanone; 5α,14b,15β-trihydroxyklaineanone; 15β-*O*-acetyl-14-hydroxyklaineanone; 6α-acetoxy-14,15β-dihydroxyklaineanone; 6α-acetoxy-15β-hydroxyklaineanone; laurycolatones A, B; longilactone; dehydroxylongilactone; 2,3-dehydro-4α-hydroxylongilactone; ailanthone, (α/β-epoxide) ailanthone; chaparrinone (α-methyl); 3,4 ε-dihydrochaparrinone; picrasinoside B; klaineanolide B, iandonoside B; 16-α-*O*-methylneoquassin; samaderin B; and glaucarubolone. The canthine-6-one alkaloids included canthin-6-one; 9-methoxycanthin-6-one; 5,9-dimethoxycanthin-6-one; 9,10-dimethoxycanthin-6-one; 11-hydroxycanthin-6-one; 1-hydroxy-11-methoxycanthin-6-one; 10-hydroxy-9-methoxycanthin-6-one; 11-hydroxy-10-methoxycanthin-6-one; bruceolline G (11-*O*-β-D-glucopyranosylcanthin-6-one); canthin-6-one-3N-oxide; 9-methoxycanthin-6-one-3N-one; and 9-methoxy-3-methylcanthin-5,6-dione. The β-carboline alkaloids included 7-hydroxy-β-carboline-1-propionic acid, β-carboline-1-propionic acid and 1-methoxymethyl-β-carboline. The squalene-type triterpenes were eurylene and 11/14-deacetyl eurylene, and the biphenylneolignans included 2,2′-dimethoxy-4-(3-hydroxy-1-propenyl)-4′-(1,2,3-trihydroxypropyl) diphenyl ethers (isomer); 2-hydroxy-3,2′,6′-trimethoxy-4′-(2,3-epoxy-1-hydroxypropyl)-5-(3-hydroxy-1-propenyl)-biphenyl; and 2-hydroxy-3,2′-dimethoxy-4′-(2,3-epoxy-1-hydroxypropyl)-5-(3-hydroxy-1-propenyl)-biphenyl.

Four compounds, β-carboline-propionic acid, eurycomanone, 18-dehydro-6α-hydroxyeurycomalactone and eurycomanol, were isolated from the roots (Yusuf et al. 2013). The following compounds were isolated from the methanol root extract: eurycomalide C (1); eurycomalactone (2); 7α-hydroxyeurycomalactone (3); 5,6-dehydroeurycomalactone (4); eurycolactone E (5); longilactone (6); 14,15β-dihydroklaieanone (7); 11-dehydroklaieanone (8); eurycomanone (9); 13,21-dehydroeurycomanone (10); laurycolactone A (11); laurycolactone B (12); 1-methoxycarbonyl-β-carboline (13); 9-hydroxycanthin-6-one (14); 9-methoxycanthin-6-one (15); 9,10-dimethoxycanthin-6-one (16); 5-methoxycanthin -4-hydroxycanthin-6-one (17); canthin-6-one 9-*O*-β-D-glucoside (18); scopoletin (19); fraxidin (20); eurylene (21); pedunculoside (22); vanillic acid (23); vanillic aldehyde (24); syringic acid (25); 1,1′-biphenyl-3,3′-dicarboxylic acid (26); isoloeresin D (27); and 3,5,6,7,8,3′,4′-heptamethoxyflavone (Tran et al. 2014). Eight compounds were isolated from the roots and identified as scopoletin, 9-methoxycanthin-6-one, laurycolactone A, eurylene, *β*-carboline-l-propionic acid, 3*β*-hydroxy-stigmast-5,22-dien-7-one, 13*β*,21-dihydroxyeurycomanone and iandonol (Zhang et al. 2014). Seven compounds were isolated from the roots, including four new quassinoids, and three of them were diastereomers for each other (Meng et al. 2014).

A new squalene-type triterpene with cytostatic activity, named as longilene peroxide, was isolated from the wood of *Eurycoma longifolia* (Itokawa et al. 1991a). Two novel isomeric 2,2′-dimethoxy-4-(3-hydroxy-1-propenyl)-4′-(1,2,3-trihydroxypropyl) diphenyl ethers, and two novel biphenyls, 2-hydroxy-3,2′,6′-trimethoxy-4′-(2,3-epoxy-1-hydroxypropyl)-5-(3-hydroxy-1-propenyl)-biphenyl and 2-hydroxy-3,2′-dimethoxy-4′-(2,3-epoxy-1-hydroxypropyl)-5-(3-hydroxy-1-propenyl)-biphenyl, were isolated from *Eurycoma longifolia* wood (Morita et al. 1992). Three novel cytotoxic squalene-type triterpenes, eurylene, 14-deacetyl eurylene and longilene peroxide, together with teurilene, were isolated from the wood (Morita et al. 1993b). Five new canthin-6-one alkaloids, 9,10-dimethoxycanthin-6-one, 10-hydroxy-9-methoxycanthin-6-one, 11-hydroxy-10-methoxycanthin-6-one, 5,9-dimethoxycanthin-6-one and 9-methoxy-3-methylcanthin-5,6-dione, were isolated from the bark and wood of *Eurycoma longifolia*, along with six known canthin-6-one alkaloids and two known β-carboline alkaloids (Mitsunaga et al. 1994).

Using liquid chromatography–mass spectrometric method, five bioactive quassinoid markers, namely, eurycomanone, 13α(21)-epoxyeurycomanone, eurycomanol, eurycomanol-2-*O*-β-D-glucopyranoside and 13,21-dihydroeurycomanone, were simultaneously analysed from manufactured batches of *Eurycoma longifolia* extract used as antimalarial medicaments (Teh et al. 2011b). The batches were found to contain 5.65–9.95 % of eurycomanone, 5.21–19.75 % of eurycomanol and 7.59–19.95 % of eurycomanol-2-*O*-β-D-glucopyranoside as major quassinoids, whereas 13α(21)-epoxyeurycomanone, and 13,21-dihydroeurycomanone were much lower in concentrations of 0.78–3.90 % and 0.47–1.76 %, respectively.

The commercial *E. longifolia* product Physta® from Phytes Biotek Sdn Bhd, Malaysia, is a standardised aqueous extract prepared by a water extraction of *Eurycoma longifolia* roots using the patented high-pressure water extraction technology (Patent no. US 7,132,117 B2, Athimulam et al. 2006) comprising the steps of (a) subjecting the dried root to hot water extraction by percolation, (b) filtering, (c) followed by concentration by condensation, (d) freeze-drying without any carrier and (e) size reduction obtaining the dry extract powder. The dry extract powder was standardised for content of (1) >22 % of protein, (2) >35 % of glycosaponin and (3) 0.8–1.5 % eurycomanone (Yee et al. 2014).

Leaf/Stem Phytochemicals

Two steroids, β-sitosterol and campesterol, 2,6-dimethoxybenzoquinone and a bitter principle eurycomalactone were isolated from the leaves (Le and Nguyen 1970).

Eurycomalactones 5,6-dehydroeurycomalatone; 7α-hydroxyeurycolalactone; 13α(21)-epoxyeurycomanone; 15-acetyl-13α(21)-epoxyeurycomanone; 12,15-diacetyl-13α(21)-epoxyeurycomanone; 12-acetyl-13,21-dihydroeurycomanone; 15β-acetyl-14-hydroxyklaineanone; 6α-acetoxy-14,15β-dihydroxyklaineanone; and 6α-acetoxy-15β-hydroxyklainenone (Morita et al. 1993a) and seven quassinoids including lasilactone; 6-dehydrolonilactone; 11-dehydroklaineanone, 12-*epi*-11-dehydroklaineanone, 14,15β-dihydroxyklaineanone; 15-B-hydroxylklaianeanone; and 15-B-O-acetyl-14-hydroxyklaineanone (Jiwajinda et al. 2001) were isolated from the leaves.

Ten new structurally diverse quassinoids (1–10) and 14 known compounds were isolated from *Eurycoma longifolia* stems (Miyake et al. 2009). The new compounds were two eurycomanone-type C_{20} quassinoids (1, 2), one klaineanone-type C_{20} quassinoid (3), one C_{19} quassinoid (4) with a 1,2-seco-1-nor-6(5 → 10)-abeo-picrasan-2,5-olide skeleton and six eurycomalactone-type C_{19} quassinoids (5–10). Two new canthin-6-one alkaloids, 4,9-dimethoxycanthin-6-one and 10-hydroxy-11-methoxycanthin-6-one, and a new tirucallane-type triterpenoid, 23,24,25-trihydroxytirucall-7-en-3,6-dione, along with 37 known compounds, were isolated from the stem (Miyake et al. 2010b). These included an oxasqualenoid; 9,10-dimethoxycanthin-6-one; 10-hydroxy-9-methoxycanthin-6-one; dihydroniloticin; and 14-deacetyleurylene.

Ethanol extract of *E. longifolia* stem was found to contain 7.781 % terpenoids and 1.785 % alkaloids (Rahmalia et al. 2011). Terpenoids included (*S*)-2-cyclohexen-1-one, 2-methyl-5-(1-methylethenyl) (0.94 %), (*S*)-2,7-octadien-4-ol, 2-methyl-6-methylene (1.15 %), dibutyl phthalate (6.73 %), *trans*-3,4-dimethoxy-2-ethoxy-β--methylstyrene (1.64 %), 1,2-benzenedicarboxylic acid, 2-butoxyethyl butyl ester (2.63 %), campesterol (4.85 %), stigmasterol (50.54 %), D-homoandrosta-4,17-dien-3-one,17a-dihydroxy (1.76 %), 22,23-dihydro-stigmasterol (7.25 %) and 4,2, stigmastadiene-3-one (8.58 %); the alkaloids included 9H-pyrido[3,4-b]indole-1-carboxylic acid, methyl ester (2.37 %), 6H-indolo[3,2,1-de][1,5]naphthyridn-6-one (1.79 %) and 3-methyl-1-oxo-2,3-dihydro-1H-pyrazolo[4,3-c][1,10]phenanthroline (9.77 %).

Four alkaloids, 9-methoxycanthin-6-one, 9-hydroxycanthin-6-one, 5,9-dimethoxycanthin-6-one and 9-methoxycanthin-6-one-N-oxide, were isolated from the callus cultures of *Eurycoma longifolia* (Kanchanapoom et al. 2002). Callus and cell suspension cultures initiated from leaves of *E. longifolia* were found to produce canthin-6-one alkaloids 9-methoxycanthin-6-one and 9-hydroxycanthin-6-one (Siregar et al. 2004). The highest amount of alkaloids, 9-hydroxycanthin-6-one and 9-methoxycanthin-6-one, could be obtained from *E. longifolia* cells cultured in modified MS (Murashige and Skoog) liquid medium containing macronutrients: 21.50 mM NH_4NO_3, 14.25 mM KNO_3, 7.50 mM $CaCl_2•2H_2O$, 2.50 mM $MgSO_4•7H_2O$ and 1.45 mM KH_2PO_4, while content of micronutrients was 0.233 mM FeNa-EDTA, 0.215 mM $MnSO_4•4H_2O$ and without $CuSO_4•5H_2O$ (Siregar et al. 2009). Maziah and Rosli (2009) reported on the production of 9-methoxycanthin-6-one from *E. longifolia* explants derived from callus cultures.

Antitumour Activity

The methanol, n-butanol, chloroform root extracts of *E. longifolia* root produced significant cytotoxic effect on KB, DU-145, RD, MCF-7, CaOV-3 cancer cell lines (Nurhanan et al. 2005). However, no significant cytotoxic effect was detected on MDBK (kidney) normal cell line. 9-methoxycanthin-6-one, an alkaloid, was detected in each extract with different intensities. Of three medicinal plants tested, *Eurycoma longifolia* extract was found to be the most cytotoxic with IC_{50} of 11 μg/ml and 13 μg/ml on human Hep2 and human foetal lung fibroblast HFL1 cell lines, respectively (Mohd-Fuat et al. 2007). Also, combined extract of *E. longifolia* and *Helmintostachys zeylanica* was more cytotoxic than single extract on Hep2 cell lines.

Four canthin-6-one alkaloids, namely, 9-methoxycanthin-6-one, 9-methoxycanthin-6-one-N-oxide, 9-hydroxycanthin-6-one and 9-hydroxycanthin-6-one-N-oxide, and one quassinoid, eurycomanone, isolated from *E. longifolia* roots, exhibited cytotoxicity on human breast, colon, fibrosarcoma, lung, melanoma, KB and murine lymphocytic leukaemia (P-388) cell lines (Kardono et al. 1991). Eurycomanone was inactive against murine lymphocytic leukaemia (P-388) but was significantly active against the human cell lines tested including KB-V1 (a multidrug-resistant cell line derived from KB). The two β-carboline alkaloids β-carboline-1-propionic acid and 7-methoxy-β-carboline-1--propionic acid were not significantly active. Beta-carboline alkaloids 9-methoxycanthin-6-one and canthin-6-one isolated from the roots demonstrated significant cytotoxicity in-vitro against human lung cancer (A-549) and human breast cancer (MCF-7) cell lines (Kuo et al. 2003b). Quassinoids, 6α-hydroxyeurycomalactone,longilactoneand14,15β-dihydroxyklaineanone; 11-dehydroklaineanone, eurycomalactone and 5,6-dehydroeurycomalactone; and seven cytotoxic tirucallane-type triterpenes, niloticin, dihydroniloticin, piscidinol A, bourjotinolone A, 3-episapelin A, melianone and hispidone isolated from the roots, exhibited potent cytotoxic activity against murine lymphocytic leukaemia P388 and human KB cancer cells (Iotakawa et al. 1992).

Eurycomalactone; 5,6-dehydroeurycomalatone; 7α-hydroxyeurycolalactone; 13α(21)-epoxyeurycomanone;15-acetyl-13α(21)-epoxyeurycomanone; 12,15-diacetyl-13α(21)-epoxyeurycomanone; 12-acetyl-13,21-dihydroeurycomanone; 15β-acetyl-14-hydroxyklaineanone; 6α-acetoxy-14,15β-dihydroxyklaineanone; and 6α-acetoxy-15β-hydroxyklainenone, from *E. longifolia* leaves, exhibited moderate antileukemic against human P338 cell lines with IC_{50} values of 14, 6.6, 7.2,0.94, 7.8, 12 and 15 μg/ml, respectively (Morita et al. 1993a). *Eurycoma longifolia* methanol extract was found to exhibit antiproliferative activity in-vitro against human HT-1080 fibrosarcoma cells (Ueda et al. 2002). The methanolic *E. longifolia* root extract showed significant cytotoxic effect ($IC_{50} \leq 20.0$ μg/ml) against pelvic cancer (RD) and epidermoid carcinoma (KB) cell lines; however, it did not show any significant cytotoxic effect against prostate DU-145 cancer cell line ($IC_{50} = 33.0$ mg/ml) (Nurhanan et al. 2002). Petroleum ether and aqueous extracts showed insignificant cytotoxic effect ($IC_{50} > 20.0$ μg/ml) against all the cancer cell lines tested. No toxic effect was observed for these extracts when treated on the normal Chang's liver cell line. *E. longifolia* root extracts and fractions exerted a direct antiproliferative activity on human breast cancer cell line MCF-7 (Tee and Azimahtol 2005). Three active fractions, F5, F6 and F7, displayed IC_{50} values of 6.17, 4.40 and 20 μg/ml, respectively. The resultant from F7 purification, F16, exhibited a higher cytotoxic activity towards MCF-7 ($IC_{50} = 15.23$ μg/ml) and a certain degree of selectivity against a normal breast cell line MCF-10A ($IC_{50} = 66.31$ μg/ml). F16 significantly increased apoptosis in MCF-7 cells through the modulation of Bcl-2 protein levels. In-vitro studies showed that the F16 fraction from *E. longifolia* exerted antiproliferative action and growth inhibition on human breast cancer MCF-7 cells by apoptosis induction through Bcl-2 protein pathway and was independent of caspase-9 and p53 pathways (Tee et al. 2007). Among the tested quassinoid compounds from *E. longifoli*a, eurycomalactone displayed the most potent activity against all the tested cell lines: murine colon carcinoma colon 26-L5 ($IC_{50} = 0.70$ μM), murine B16–BL6 melanoma ($IC_{50} = 0.59$ μM), Lewis lung carcinoma LLC ($IC_{50} = 0.78$ μM) and human lung adenocarcinoma A549 ($IC_{50} = 0.73$ μM) (Miyake et al. 2010a). These activities were comparable to clinically used anticancer agent doxorubicin (colon 26-L5, $IC_50 = 0.76$ μM; B16–BL6, $IC_{50} = 0.86$ μM; LLC, $IC_{50} = 0.80$ μM; A549, IC50 = 0.66 μM).

Jiwajinda et al. (2002) found the most active quassinoid compound isolated from the leaf, for inhibition of tumour promoter-induced Epstein–Barr virus activation (antitumour promotion) was 14,15β-dihydroxyklaineanone (5, $IC_{50} = 5$ μM). Of 65 compounds, isolated from the roots, compounds 12, 13, 17, 18, 36, 38, 59 and 62 demonstrated strong cytotoxicity towards human lung cancer (A-549) cell lines; however, 12, 13, 17,

38, 57, 58 and 59 exhibited strong cytotoxicity towards human breast cancer (MCF-7) cell lines (Kuo et al. 2004). Several quassinoid compounds 11, 23 and 24 exhibited cytotoxicity towards the highly metastatic HT-1080 human fibrosarcoma cell line and showed potent cytotoxicity (IC_{50} values 0.93–1.1 μM) (Miyake et al. 2009). Among the compounds isolated from *E. longifolia* stem, 9,10-dimethoxycanthin-6-one (IC_{50} = 5.0 μM), 10-hydroxy-9-methoxycanthin-6-one (IC_{50} = 7.2 μM), dihydroniloticin (IC_{50} = 8.2 μM) and 14-deacetyleurylene (IC_{50} = 3.2 μM) displayed stronger cytotoxic activity against a HT-1080 human fibrosarcoma cell line than the positive control 5-FU (IC_{50} = 9.2 μM) (Miyake et al. 2010b).

Eurycomanone, from *E. longifolia*, was found to be cytotoxic on cancerous cells (CaOv-3, HeLa, HepG2, HM3KO, MCF-7) by inducing apoptosis through upregulation of p53 and Bax and downregulation of Bcl-2 independently of functional E6 and E6-AP activity (Mahfudh and Pihie 2008). The characteristics of apoptosis including chromatin condensation, DNA fragmentation and apoptotic bodies following eurycomanone treatment were observed. Eurycomanone was less toxic on normal cells (MDBK, Vero). Similarly, Zakaria et al. (2009) found that eurycomanone was cytotoxic on cancerous liver cell, HepG2 by inducing apoptosis through the upregulation of p53 and Bax and downregulation of Bcl-2. It was less toxic on normal cells Chang's liver and WLR-68. Wong et al. (2012) reported that eurycomanone inhibited A549 lung cancer cell proliferation in a dose-dependent manner at concentrations ranging from 5 to 20 μg/ml with IC_{50} value of 5.1 μg/ml. Eurycomanone at viable therapeutic concentrations of 5–20 μg/ml exhibited significant antiproliferative and anti-clonogenic cell growth effects on A549 lung cancer cells. The treatment also resulted in suppression of the lung cancer cell tumour markers (heterogeneous nuclear ribonucleoprotein (hnRNP) A2/B1, p53 tumour suppressor protein) and several known cancer cell growth-associated genes (prohibitin, annexin 1 and endoplasmic reticulum protein 28). Cytotoxic compounds 2 and 5 from the roots exhibited the lowest IC_{50} values of 24.9 μM, 11.8 μM and 44.1 μM, 14.1 μM towards MCF-7, MGC-803 cancer cell lines, respectively, while compound 6 exhibited moderate cytotoxicity towards HT-29, MCF-7, LOVO, BGC-823, MGC-803, HepG2, HeLa and A549 cancer cell lines (Meng et al. 2014).

A partially purified quassinoid (eurycomanone, 13α(21)-epoxyeurycomanone and eurycomanol)-rich fraction (TAF273) of *E. longifolia* root extract exhibited antiangiogenic activity (Al-Salahi et al. 2013). It caused significant suppression in sprouting of microvessels in rat aorta with IC_{50} 11.5 μg/ml. TAF273 (50 μg/ml) showed remarkable inhibition (63.13 %) of neovascularization in chorioallantoic membrane of chick embryo. In-vitro, TAF273 significantly inhibited the major angiogenesis steps such as proliferation, migration and differentiation of human umbilical vein endothelial cells (HUVEC). The results demonstrated that the antiangiogenic activity of TAF273 may be due to its inhibitory effect on endothelial cell proliferation, differentiation and migration which could be attributed to the high content of quassinoids in *E. longifolia.*

Antimalarial Activity

Eurycoma longifolia aqueous extract exhibited antiplasmodial activity against chloroquine-resistant *Plasmodium falciparum* strain (W2) with IC_{50} value ≤ 4 μg/ml (Hout et al. 2006).

Hydroxycanthin-6-one, eurycomalactone, eurycomanone and eurycomanol isolated from *Eurycoma longifolia* and 6-hydroxy-5,6-dehydroeurycomalactone exhibited in-vitro antimalarial activities against a multidrug-resistant Thailand strain (K-1) of *Plasmodium falciparum* (Chan et al. 1986). The two β-carboline alkaloids β-carboline-1-propionic acid and 7-methoxy-β-carboline-1-propionic acid, isolated from the roots, demonstrated significant antimalarial activity as judged by studies conducted with cultured *Plasmodium falciparum* strains (Kardono et al. 1991). The antimalarial activity of *Eurycoma longifolia* extract (containing 13β,18-dihydroeurycomanol, eurycomanol-2-*O*-β-D-gluco-pyranoside, eurycomanol and

eurycomanone) against six Malaysian chloroquinone-resistant *Plasmodium falciparum* isolates was dose dependent and reached a maximum of < 50 % at 0.07–5.00 μg/m after 1 day post-treatment (Ang et al. 1995a). However, complete inhibitions were observed at 1.25–5.00-μg/ml extract after 3 days post-treatment and 0.62 and 0.31 μg/ml after 4 and 6 days post-treatment, respectively. Three quassinoids from the roots of *Eurycoma longifolia* eurycomanol, eurycomanol 2-*O*-β-D-glucopyranoside and 13 β,18-dihydroeurycomanol exhibited antimalarial activity against nine *Plasmodium falciparum* isolates with IC_{50} values of 1.231–4.899 μM, 0.389–3.498 μM and 0.504–2.343 μM, respectively, compared with 0.323–0.774 μM for chloroquine (Ang et al. 1995b). 11-Dehydroklaineanone (3) and 15β-O-acetyl-14-hydroxyklaineanone, isolated from the leaf, showed potent plasmodiacidal activity (IC_{50} = 2 μg/ml) (Jiwajinda et al. 2002). Quassinoid compounds 57 and 58 from the roots displayed potent antimalarial activity against the resistant *Plasmodium falciparum* (Kuo et al. 2004). Four quassinoids from *E. longifolia* roots, eurycomanone (1), 13,21-dihydroeurycomanone (3), 13α(21)-epoxyeurycomanone (4), eurycomalactone (6) and an alkaloid, 9-methoxycanthin-6-one (7) displayed higher antiplasmodial activity against chloroquine-resistant Gombak A isolate of *Plasmodium falciparum* but were less active against the D10 strain when compared with chloroquine. Among the compounds tested, 1 and 3 showed higher selectivity indices obtained for the cytotoxicity to antiplasmodial activity ratio than 14,15β-dihydroxyklaineanone (2), eurycomanol (5), 6 and 7(Chan et al. 2004). Several diacylated derivatives of eurycomanone, 1,15-di-*O*-isovaleryleurycomanone, 1,15-di-*O*-(3,3-dimethylacryloyl)-eurycomanone and 1,15-di-O-benzoyleurycomanone were synthesised by direct acylation with the respective acid chlorides (Chan et al. 2005). The diacylated eurycomanones exhibited lower antiplasmodial activity against the Gombak A isolates of *Plasmodium falciparum* and lower toxicity in the brine shrimp assay when compared to eurycomanone. In contrast, the monoacylated derivative displayed comparable antiplasmodial potency to eurycomanone, but its toxicity was reduced. Results of in-vitro studies showed that about 95–100 % growth inhibition of *P. falciparum*-infected erythrocyte was observed when treated with *E. longifolia* methanol extract (TA164) and L-buthionine(*S*,*R*)-sulfoximine (BSO) at 16 g/ml and 64 g/ml, respectively (Mohd Ridzuan et al. 2005). The IC_{50} and IC_{75} values of TA164 are to be 0.17 g/ml and 6 g/ml, respectively, while for BSO were 25.5 g/ml and 46.5 g/ml, respectively. Treated trophozoite-infected erythrocyte (10 % parasitemia) showed decreased glutathione (GSH) content. TA164 did affect the GSH content of non-infected erythrocyte at 24 h, as well as the parasite compartments (trophozoite-infected erythrocyte and parasite itself) but failed to affect the GSH content of enriched trophozoite-infected erythrocyte.

Sholikhah et al. (2008) found that fraction 4 of *E. longifolia* root methanol extract exhibited the most potent antiplasmodial activity at the trophozoite stages of *P. falciparum*. The antiplasmodial activity (inhibition of *Plasmodium falciparum* schizont maturation) of the *E. longifolia* extract was higher than that expected from the three quassinoids eurycomanone, 13,21-dihydroeurycomanone and 13α(21)-epoxyeurycomanone isolated from the plant, suggesting synergism between the quassinoids or the presence of other unidentified compounds (Wernsdorfer et al. 2009). The ethanol and methanol–ethanol extracts of roots of *E. longifolia* showed higher antiplasmodial activities than those of the other solvent extracts, but their activities were about 10-fold lower than those of extracts from *B. javanica* fruit (Sriwilaijaroen et al. 2010). In drug combination tests, *B. javanica* and *E. longifolia* extracts did not appear to antagonise antiplasmodial activity of chloroquine and quinine. The use of such drug combinations could delay the onset of parasite drug resistance.

Four isolated compounds from *E. longifolia* root extract exhibited in-vitro antimalarial activity against the chloroquine-sensitive *Plasmodium falciparum* strain TD7 (Yusuf et al. 2013).The compounds were identified as β-carboline-propionic acid, eurycomanone, 18-dehydro-6α-

hydroxyeurycomalactone and eurycomanol, and their IC_{50} values were 76,73 ng/mL; 2,04 ng/mL; 119,12 ng/mL; 171,39 ng/mL and chloroquine diphosphate 5.73 ng/mL, respectively.

Aphrodisiac/Reproductive Enhancement Activities

Clinical Studies

Testosterone replacement therapy (TRT) had been reported to be the conventional way of treating testosterone deficiency syndrome (TDS) characterised by numerous symptoms, including low libido, increased fat mass, fatigue, erectile dysfunction or osteoporosis, and up to 80 % of men would experience some kind of ageing males' symptoms (Geroge and Henkel 2014). *Eurycoma longifolia* (Tongkat Ali) is being touted as a natural alternative to testosterone replacement therapy (TRT) and had been shown to restore serum testosterone levels, thus significantly improving sexual health with significant positive effects on bone health and physical condition of patients (Geroge and Henkel 2014). In addition, a significant antihyperglycaemic effect and cytotoxicity against prostate cancer cells had been shown.

In a study of managing idiopathic male infertility, of 350 patients given 200 mg of *E. longifolia* extract daily for 9 months, 75 patients completed one full cycle of 3 months (Tambi and Imran 2010). Follow-up semen analyses in these patients showed significant improvement in all semen parameters. The proprietary extract of *Eurycoma longifolia* significantly improved the sperm quality in these patients, allowing for 11 (14.7 %) spontaneous pregnancies.

Treatment of male patients suffering from late-onset hypogonadism with 200 mg of a standardised water-soluble extract of Tongkat Ali for 1 month significantly improved the Ageing Males' Symptoms (AMS) score as well as the serum testosterone concentration (Tambi et al. 2012). *Eurycoma longifolia* was reported to stimulate dehydroepiandrosterone (DHEA), which functioned as an endogenous precursor to testosterone and dihydrotestosterone. In a randomised double-blind, placebo-controlled, parallel group 12-week study in 109 men between 30 and 55 years of age, the group treated with 300 mg of water extract of *E. longifolia* (Physta) had significant improvements in the domain physical functioning of SF-36 questionnaire, from baseline to week 12 compared to placebo (Ismail et al. 2012). The *E. longifolia* group showed higher scores in the overall erectile function domain in IIEF (International Index of Erectile Function), sexual libido (14 % by week 12), seminal fluid analysis—with sperm motility at 44.4 %—and semen volume at 18.2 % at the end of treatment. Subjects with body mass index (BMI) $\geq$ 25 kg/m^2 significantly improved in fat mass lost. All safety parameters were comparable to placebo. In a 12-week, randomised, double-blind, placebo-controlled study of healthy men aged 40–65 years old, supplementation of Physta (a freeze-dried water extract of *Eurycoma longifolia*) combined with *Polygonum minus* was found to enhance sexual performance (Udani et al. 2014). Significant improvements were noted in scores for the Sexual Intercourse Attempt diary, Erection Hardness Scale, Sexual Health Inventory for Men, and Ageing Male Symptom scale. No clinical abnormalities were observed and the supplementation was well tolerated.

Animal Studies

Administration of *E. longifolia* chloroform, methanol, water and butanol fractions for 10 days produced a dose-dependent increase (400 mg to 800 mg/kg) in mounting frequency of sexually experienced male rats, but there were no erections, intromissions, ejaculations or seminal emissions during the 20-minute observation period which allowed for the measurement of sexual arousal reflected by mounting frequency uninfluenced by other behavioural components (Ang and Sim 1997c). The study indicated *E. longifolia* to be a potent stimulator of sexual arousal in sexually vigorous male rats in the absence of feedback from genital sensation. Treatment with *E. longifoli*a increased the sexual performance of the treated sexually adult male rats by extending the duration of coitus and

decreasing the refractory period between the different series of copulation (Ang and Sim 1997b). Similar copulatory effects were observed on middle-aged male rats but the effect was much smaller (Ang and Lee 2002b). *E. longifolia* fractions produced a dose-dependent, recurrent and significant increase in the episodes of penile erection when compared with control male rats; 400 mg/kg of chloroform, methanol, water and *n*-butanol extracts exhibited respective penile erection indices of 28.32, 31.32, 39.25 and 36.49, while 800 mg/kg further increased the indices to 32.00, 35.32, 40.24 and 45.29 (Ang and Sim 1997a). However, none of the treated rats exhibited any homosexual mountings during the 1-hour observation period. They also found that chronic administration of *Eurycoma longifolia* exerted aphrodisiac effect on sexually naive male mice as shown by the slow and transient reduction in hesitation time and also a similar manner in the increase in the % of sexually naive male mice scoring right choice throughout the investigation period (Ang and Sim 1998a). In another study, *E. longifolia* modified the orientation activities of the treated male rats in that they significantly displayed more frequent and vigorous mounting, licking and anogenital sniffing towards the receptive females, and it further intensified self-orientation as indicated by the increased grooming of the genitals compared to the controls (Ang and Sim 1998c, 1999). In addition, rats treated with 800 mg/kg of methanol, water and butanol extracts of *E. longifolia* continued to show confinement to a particular area of the cage (around the female), thus showing restriction in movement as compared to the controls. However, the treated males possessed a lack of interest in the external environment as indicated by a reduction in exploration, raring and climbing on the cage wall. In sexually naïve male rats, *E. longifolia* treatment enhanced sexual motivation as evidenced by the high level of both the total number of successful crossovers, mountings, intromissions and ejaculations during the 9–12th week observation period (Ang and Sim 1998b). Studies with inexperienced castrated male rats showed that *E. longifolia* produced a dose-dependent increase in sexual performance of the treated animals, but the *E. longifolia*-treated groups showed lower sexual performance in mounting, intromission and ejaculation than the testosterone-treated group (Ang et al. 2000a). Also, *E. longifolia* promoted the growth of both ventral prostate and seminal vesicles as compared with the control, but the growth of sexual accessories at 800 mg/kg of butanol, methanol, water and chloroform fractions of *E. longifolia* Jack was less than that of the testosterone-treated group. In further studies 800 mg/kg of butanol, methanol, water and chloroform fractions of *E. longifolia* significantly increased the levator ani muscle to 58.56, 58.23, 60.21 and 62.35 mg/100-g body weight, respectively, when compared with the control (untreated) in the uncastrated intact male rats, and 49.23, 52.23, 50.21 and 52.35 mg/100-g body weight, respectively, when compared to control (untreated) in the testosterone-stimulated castrated intact male rats (Ang and Cheang 2001). Hence, the pro-androgenic effect as shown by this study further supported the traditional use of this plant as an aphrodisiac. Separate studies showed that *E. longifolia* root extracts produced a dose-dependent, recurrent and significant increase in the episodes of penile reflexes as evidenced by increases in quick flips, long flips and erections of the treated male rats during the 30-minute observation period (Ang et al. 2001). The results provided further evidence that *E. longifolia* increased the aphrodisiac potency activity in treated animals. Ang and Ngai (2001) found that fractions of *E. longifolia* decreased the hesitation time of noncopulator male rats, throughout the investigation period using an electrical age. Separate studies showed that a high dose (800 mg/kg) of *E. longifolia* methanol, chloroform, water and butanol fractions could increase libido in middle-aged male rats by increasing mount frequency (Ang and Lee 2002a). It was demonstrated that middle-aged male rats treated with 800 mg/kg of *E. longifolia* Jack increased orientation activities towards the receptive females (anogenital sniffing, licking and mounting), increased genital grooming towards themselves and restricted movements to a particular area of the cage but decreased interest in the external environment (climbing, raring, exploration) as

compared with the controls during the investigation period (Ang and Lee 2002c). Treatment with various fractions of *E. longifolia* 0.5 g/kg enhanced the sexual qualities of middle-aged male rats decreasing their hesitation time as compared to controls (3-ml/kg saline) (Ang et al. 2003a). More than 50 % of the male rats scored right choice after 2 weeks post-treatment. They found *E. longifolia* continued to enhance sexual motivation in adult, middle-aged male mice and in retired breeders (Ang et al. 2003b). They found a transient increase in the percentage of male mice responding to the right choice after chronic consumption of the fractions with 50 percent of the adult middle-aged male mice treated with *E. longifolia*.

Consumption of *E. longifolia* aqueous extract enhanced both sexual behaviour and sperm quality in rats (Mat Noor et al. 2004). The extract (150 mg/kg)-treated male rats exhibited the shortest period of time to reach the female rats compared to other doses and control. Oral administration of the aqueous extract resulted in increased sperm count, viability and motility. Oral administration of *E. longifolia* also elicited sexual arousal in sexually sluggish old male rats (Ang et al. 2004b). The results showed that 800 mg/kg of *E. longifolia* increased yawning by 50 % and stretching by 16.7 % in sexually sluggish old male rats, by 676–719 % and 31–336 %, respectively, in sexually active male rats, and by 22–44 % and 75–100 %, respectively, in middle-aged, 9-month-old and retired breeders. Zanoli et al. (2009) found that in sexually sluggish rats, both acute (dosed at 500 and 1000 mg/kg) and subacute treatments with *E. longifolia* root powder significantly reduced ejaculation latencies, increasing also the percentage of mounting and ejaculating animals. In addition, the subacute administration reduced post-ejaculatory interval. In impotent rats both subacute and subchronic treatments increased the percentage of mounting and ejaculating rats. The effect could be mainly ascribed to increased testosterone levels. The motivational behaviour of sluggish rats during the partner preference test was not affected by the treatments. Studies by Wahab et al. (2010) found that *E. longifolia* extract acted as a potential agent for reversing the effects of oestrogen by increasing spermatogenesis, sperm counts and sperm motility in estradiol-treated rats after fourteen consecutive days of treatment.

Oral treatment of rats with a standardised methanol extract of *E. longifolia* containing the major quassinoid constituents of 13α(21)-epoxyeurycomanone, eurycomanone, 13α,21-dihydroeurycomanone and eurycomanol, at doses of 50, 100 and 200 mg/kg, significantly increased sperm count by 78.9, 94.3 and 99.2 %, respectively, when compared with that of control (Chan et al. 2009).The low count, poor motility and abnormal morphology of the spermatozoa induced by the *Andrographis paniculata* fraction were significantly reversed by the standardised *E. longifolia* MeOH extract. The plasma testosterone level of the rats treated with the standardised MeOH extract at 200 mg/kg was significantly increased when compared with that of the control and infertile animals. Interestingly, eurycomanone alone was detected in the rat testis homogenates and may have contributed towards the improvement of sperm quality. Thus, it was concluded that *E. longifolia* may potentially be suitable for the management of male infertility.

Studies by Chiou and Wu (2012) found that 9-hydroxycanthin-6-one (9-HC-6-one), a β-carboline alkaloid isolated from *E. longifolia*, could induce penile erection and delayed ejaculation by antagonising the smooth muscle tone of the rat's corpus cavernosa as well as seminal vesicle probably through interfering with Ca^{2+} mobilisation.

Oral administration of a standardised extract F2 (25 mg/kg) of *E. longifolia* and the aqueous extract (250 mg/kg) to male rats significantly increased the sperm concentration when compared with that of the control animals; the effects were almost similar in concentration of eurycomanone, the major and most potent quassinoid (Low et al. 2013b). Following treatment with F2, there was a significant increase in the number of spermatocytes and round spermatids at stage VII of the spermatogenesis cycle when compared to that of the control. Plasma levels of testicular testosterone, luteinizing hormone (LH) and follicle-stimulating hormone (FSH) were higher

than those of control plasma, and the oestrogen level was significantly lower than that of the untreated control. The fertility index, fecundity index and the pup litter size delivered from the females after mating with the males treated with F2 were increased. Among the isolated quassinoids of F2, eurycomanone and 13α(21)-dihydroeurycomaone significantly increased the testosterone level from the Leydig cells of the testicular interstitial cells cultured in-vitro. The authors found that eurycomanone dose-dependently enhanced testosterone steroidogenesis at the Leydig cells by inhibiting aromatase conversion of testosterone to oestrogen and at a high concentration may also involve phosphodiesterase inhibition (Low et al. 2013a). The authors suggested that eurycomanone may be worthy for further development as a phytomedicine to treat testosterone-deficient idiopathic male infertility and sterility. Treatment of aqueous extract of Tongkat Ali root to male rats for 2 weeks decreased body weight by 5.7 % and omentum fat by 31.9 %, and no changes in organ weights were found for the prostate, testes and epididymides (Solomon et al. 2014). Testosterone concentration increased by 30.2 % and muscle weight also increased, but not significantly. While sperm concentration, total and progressive motility and vitality increased significantly, mitochondrial membrane potential improved markedly. No detrimental effect could be observed indicating Tongkat Ali to be safe for possible treatment of male infertility and ageing male problems.

Following intraperitoneal injections at similar doses of 2.44 μmol/kg/day for 3 consecutive days, eurycomanone displayed comparable potency with tamoxifen but was more potent than 13α,21-dihydroeurycomanone (quassinoid of *E. longifolia*) in the antiestrogenic effect against 17α-ethynylestradiol (EE)-induced uterotrophy of immature rats (Teh et al. 2011a).Treatment with a standardised quassinoid-rich extract (TAF 273) of *Eurycoma longifolia* root ameliorated testosterone-induced reproductive disorders in female rats (Abdulghani et al. 2012). Upon treatment with TAF 273, fewer animals showed irregular oestrous cycles and there was less follicular morphological damage. The reversal effect may be attributed to the antiestrogenic properties of *E. longifolia* quassinoids.

Combination treatment of the standardised extract (TA164) with artemisinin suppressed *P. yoelii* infection in the experimental mice. The 4-day suppressive test showed that *Eurycoma longifolia* standardised root extract (TA164) suppressed the parasitemia of *Plasmodium yoelii*-infected mice in a dose-dependent manner (10-, 30- and 60-mg/kg BW) by oral and subcutaneous treatment (Mohd Ridzuan et al. 2007). By oral administration, combination of TA164 at 10-, 30- and 60-mg/kg BW each with artemisinin, respectively, showed a significant increase in the parasitemia suppression to 63, 67 and 80 percent as compared to artemisinin single treatment (31 %). Using subcutaneous administration, at 10-mg/kg BW of TA164 in combination with 1.7-mg/kg BW of artemisinin, gave a suppression of 80 % of infection. Administration of a new herbal combination called Etana, composed of five herbal extracts including *Panax quinquefolius* (ginseng), *Eurycoma longifolia* (Tongkat Ali), *Epimedium grandiflorum* (horny goat weed), *Centella asiatica* (gotu kola) and flower pollen extracts, was found to enhance penile erection in male rats (Qinna et al. 2009). The penile erection index (PEI) of Etana was significantly higher than each single component or the sum of any two herbal components of Etana. When compared with sildenafil citrate, Etana induced more pronounced PEI than 0.36 mg/kg, but similar to 0.71 mg/kg of sildenafil. Further, full acute and subacute toxicity studies showed no toxic effects of Etana.

Antiosteoporotic Activity

Studies showed that both testosterone replacement and *E. longifolia* supplementation for six weeks to orchidectomised aged rats were able to restore the bone calcium level, with the former showing better effects (Shuid et al. 2011). The authors concluded that *E. longifolia* prevented bone calcium loss in orchidectomised rats and therefore had the potential to be used as an

alternative treatment for androgen-deficient osteoporosis. Further they found that supplementation with *E. longifolia* extract elevated the testosterone levels, reduced the bone resorption marker (CTx) and upregulated osteoprotegerin gene expression of the orchidectomised male Sprague-Dawley rats (Shuid et al. 2012). These actions may be responsible for the protective effects of *E. longifolia* extract against bone resorption due to androgen deficiency.

Eurycoma longifolia was reported to have potential as an alternative complementary treatment for male osteoporosis due to hypogonadism (androgen deficiency) (Mohd Effendy et al. 2012). It was reported to exert pro-androgenic effects that enhance testosterone level, as well as stimulate osteoblast proliferation and osteoclast apoptosis, thereby maintaining bone remodelling activity and reducing bone loss. Studies by Saadiah Abdul Razak et al. (2012) found that combination therapy of *Eurycoma longifolia* and low-dose testosterone therapy protected bone from androgen-deficient osteoporosis in orchidectomised male Sprague-Dawley rats. The lower testosterone dose was beneficial in reducing the side effects of testosterone therapy. Ramli et al. (2012) found that high dose of *E. longifolia* (90 mg/kg) may have potential in preserving the bone microarchitecture of orchidectomised rats, but lower doses may aggravate the osteoporotic changes. Studies by Tajul Ariff et al. (2012) found that testosterone replacement therapy was able to raise the testosterone level and restore the bone volume of aged orchidectomised rats, but *E. longiflora* supplementation failed to emulate both such testosterone actions. The inability of *E. longiflora* to do so may be related to the absence of testes in the androgen-deficient osteoporosis model for *E. longiflora* to stimulate testosterone production. Recent studies by Nadia and Shuid (2013) found that single supplementation of *E. longiflora* was better than combination with calcium in terms of the bone remodelling and strength of orchidectomised rats. *E. longiflora* supplementation was able to reduce bone resorptive activity as well as increase the bone strength of hypogonadal osteoporosis model. It possessed potential as an alternative agent to testosterone replacement therapy in treating hypogonadal osteoporosis in men.

Anti-inflammatory Activity

The following compounds were isolated from the methanol root extract: eurycomalide C (1); eurycomalactone (2), 7α-hydroxyeurycomalactone (3); 5,6-dehydroeurycomalactone (4); eurycolactone E (5); longilactone (6); 14,15β-dihydroklaieanone (7); 11-dehydroklaieanone (8); eurycomanone (9);13,21-dehydroeurycomanone (10); laurycolactone A (11); laurycolactone B (12); 1-methoxycarbonyl-β-carboline (13); 9-hydroxycanthin-6-one (14); 9-methoxycanthin-6-one (15); 9,10-dimethoxycanthin-6-one (16); 5-methoxycanthin-4-hydroxycanthin-6-one (17); canthin-6-one 9-*O*-β-D-glucoside (18); scopoletin (19); fraxidin (20); eurylene (21); pedunculoside (22); vanillic acid (23); vanillic aldehyde (24); syringic acid (25); 1,1′-biphenyl-3,3′-dicarboxylic acid (26); isoloeresin D (27); and 3,5,6,7,8,3′,4′-heptamethoxyflavone (Tran et al. 2014). C_{19}-type (1–6) and C_{20}-type quassinoids (7–10), alkaloids (13–16) and the flavonoid 28 exhibited >50 % NF-κB inhibition in TNF-α-stimulated HEK-293/NF-κB-luc cells. NF-κB is a key regulator of many pro-inflammatory pathways. Compounds 2, 7 and 10 were potent NF-κB inhibitors with IC_{50} values < 1 μm (0.5, 1.0 and 0.7 μm, respectively). Compounds 3–6, 8, 9, 14 and 15 exhibited IC_{50} values ranging from 1.5 to 7.4 μm. Less active were compounds 1 and 16 with IC_{50}s of 18.4 and 19.5 μm, respectively, and compounds 13 and 28 with IC_{50} > 20 μm. The order of activity was 2 > 10 > 7 > 3 > 8 > 9 > 5 > 14 > 6 > 4 > 15 > 1.16 > 28 > 13. C18-type quassinoids (11, 12), coumarins (19 and 20), phenolic compounds (23–27), the squalene derivative (21) and the triterpenoid (22) did not exhibit discernible inhibitory effects against NF-κB. Thus, C_{19}- and C_{20}-type quassinoids may be considered as the major anti-inflammatory principles of *E. longifolia*. Among the quassinoids, eurycomalactone (2) was the most potent and 9-hydrocanthin-6-one (14) was the most potent inhibitor of the alkaloids isolated.

Anxiolytic Activity

Eurycoma longifolia extract exerted anxiolytic effect in mice (Ang and Cheang 1999). In the open field test, fractions of *E. longifolia* produced a significant increase in the number of squares crossed (controls = 118.2 squares), but significantly decreased both the immobility (controls = 39.4 s) and faecal pellets (controls = 12.3 faecal pellets) when compared with control mice. In the elevated plus maze test, they significantly increased the number of entries (controls = 6.7 entries) and time spent (controls = 42.9 s) in the open arms, but decreased both the number of entries (controls = 13.2 entries) and time spent (controls = 193.4 sec) when compared with the control mice in the closed arms. The fractions decreased the fighting episodes significantly (controls = 18.0 fighting episodes) when compared with control mice. In addition, these results were found to be consistent with anxiolytic effect produced by diazepam and supported the medicinal use of this plant for anxiety therapy.

Antiparasitic Activity

Longilactone isolated from the leaf gave significant antischistosomal effect at a concentration of 200 μg/ml Jiwajinda et al. (2002). Several fractions (TAF 355, TAF 401) of the crude root extract of *E. longifolia* exhibited in-vitro antiparasitic activity against *Toxoplasma gondii* using Vero cells as host for *T. gondii* (Kavitha et al. 2012a). Significant anti-*T. gondii* activity was observed with clindamycin (EC_{50} = 0.016 μg/ml), followed by TAF 355 (EC_{50} = 0.369 μg/ml) and TAF 401 (EC_{50} = 0.882 μg/ml). After 36 hours of exposure to the *E. longifolia* fraction, the host Vero cells showed no visible intracellular *T. gondii* parasite and no remarkable morphological changes. Treatment with clindamycin and the fractions caused a decrease in cytoplasmic volume, leaving a state of structural disorganisation within the cell cytoplasm and destruction of its organelles as early as 12 hours of treatment, which indicated the rapid antiparasitic activity of the *E. longifolia* fractions (Kavith et al. 2012b).

Hepatoprotective Activity

Administration of the methanol-water fraction of *E. longifolia* roots to rats for three months protected against carbon tetrachloride induced hepatotoxicity (Panjaitan et al. 2013). It lowered the serum level of alanine transaminase and aspartate transaminase and restored hepatic morphology in male rats.

Adaptogenic and Ergogenic Activities

According to the review by Muhamad et al. (2012), there is a paucity of studies on *E. longifolia* as an ergogenic aid for enhancing endurance performance. *Eurycoma longifolia* had been reported to have adaptogenic property for maintaining men's health (Tambi 2006). *Eurycoma longifolia* was found to facilitate conversion of pregnenolone to progesterone, cortisol, 5-dehydroepiandrosterone (DHEA) and testosterone in rabbit corpus cavernosum tissues. Supplementation of 400-mg Tongkat Ali extract daily for 5 weeks to physically active male and female seniors (57–72 years) elicited significant increases in total and free testosterone concentrations and muscular force in both the men and women (Henkel et al. 2013). After treatment, haemoglobin, testosterone and dehydroepiandrosterone concentrations and the ratio of total testosterone/cortisol and muscle force remained significantly lower in female seniors than in male seniors. Haematocrit and erythrocyte count in male seniors increased slightly but was significantly higher than in female seniors. The increase in free testosterone in women was thought to be attributed to the significant decline in sex hormone-binding globulin concentrations. The results affirmed the ergogenic benefit of Tongkat Ali through enhanced muscle strength. In a randomised, double-blind, placebo-controlled clinical trial, involving 40 Malaysian men aged 30–55 years, daily ingestion of 300 mg of the freeze-dried water extract of *Eurycoma longifolia* root (Physta®) for 12 weeks did not change the normal ratio of testosterone to epitestosterone, indicating that *E. longifolia* did not exhibit

'doping'-like effects (George et al. 2013). Instead, muscular strength improved significantly in the back and leg with *E. longifolia* supplementation rendering this herb good for physical performance minus the doping effects.

In a study of moderately stressed subjects (men and women), daily supplementation with Tongkat Ali root extract for a month improved stress hormone profile (salivary cortisol and testosterone) and certain mood state parameters (tension 11 %, anger 12 % and confusion 15 %) (Talbott et al. 2013). The results suggested that this remedy may be an effective approach to shielding the body from the detrimental effects of 'modern' chronic stress, which may include general day-to-day stress, as well as the stress of dieting, sleep deprivation and exercise training. *E. longifolia* had been reported to contain a bioactive 4.3-kDa peptide as an aphrodisiac marker (Nurhanan et al. 2004; Asiah et al. 2007), which could increase testosterone level in rat's Leydig cell (Sambandan et al. 2004). The ethanolic extract of *Eurycoma longifolia* could decrease the basal level but increase the human chorionic gonadotropin (hCG)-induced production of testosterone by rat Leydig cells (Lin et al. 2001).

In a double-blind, placebo-controlled, crossover study of 12 Malaysian healthy male recreational athletes aged 23.3 (37) years old, supplementation of the *E. longifolia* product at a dosage of 150 mg/day for 7 days did not provide beneficial effects on endurance running capacity and physiological responses of recreational athletes in the heat (Muhamad et al. 2010). Results showed that the endurance running capacity of *E. longifolia* was not significantly different from that of the placebo trial. Similarly, oxygen uptake, heart rate, skin temperature, tympanic temperature, ratings of perceived exertion, haemoglobin concentration, haematocrit level, plasma glucose concentration and plasma-free fatty acid concentration were not significantly different between the trials.

Antiulcer Activity

Both pasakbumin-A (eurycomanone) and pasakbumin-B from *E. longifolia* root exhibited potent antiulcer activity (Tada et al. 1991).

Antihyperglycaemic Activity

Administration of aqueous extracts TA-a and TA-b of *E. longifolia* at 150-mg/kg BW exhibited antihyperglycaemic effect in streptozotocin-induced hyperglycaemic rats (Husen et al. 2004).

Antipyretic Activity

Several quassinoids of *E. longifolia* exhibited antipyretic activity (Chan et al. 1995).

Antimicrobial Activity

The alcoholic and acetone extracts of Tongkat Ali leaf and stem extracts were active on both Gram-positive bacteria *Staphylococcus aureus*, *Micrococcus luteus*, *Enterococcus faecalis* and *Bacillus subtilis* and Gram-negative bacteria *Proteus vulgaris* and *Serratia marcescens* in-vitro (Farouk and Benafri 2007). Aqueous leaf extract showed antibacterial activity against *Staphylococcus aureus* and *Serratia marcescens*. The root extracts had no antibacterial activity against Gram-positive and Gram-negative bacteria tested. Aqueous extracts of three common Malaysian herbs (*Andrographis paniculata*, *Eurycoma longifoli*a and *Garcinia atroviridis*) were found to differentially modulate hydrophobicity and attachment to surfaces of five food-related bacterial strains (*Bacillus cereus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella enteritidis*, *Staphylococcus aureus*) (Hui and dykes 2012). For specific combinations of bacteria, surface material and plant extract, significant correlations ($R^2 => 0.80$) between hydrophobicity and attachment were observed. The highest of these was observed for *S. aureus* attachment to stainless steel and glass after treatment with the *E. longifolia* extract ($R^2 = 0.99$). Such findings may be useful for the simple and practical control of food-borne pathogens. *E. longifolia* root extract did not show any antibacterial (methicillin-resistant *Staphylococcus aureus*, *Enterococcus faecium*, extended-spectrum beta-lactamase-producing *Klebsiella pneumoniae*, group 1 beta-lactamase-producing *Pseudomonas aeruginosa*, multidrug-resistant *Acinetobacter*

baumannii and *Salmonella typhi*) or antifungal (*Candida albicans*, *Candida glabrata* and *Candida krusei*) effect at concentrations of equal to or less than 50 mg/mL and 10 mg/mL, respectively (Tzar et al. 2011)

Herb–Drug Interaction Activity

Salman et al. (2010) found that the bioavailability of propranolol (a antihypertensive drug) was significantly decreased when consumed together with *E. longifolia* water-based extract in a placebo-controlled randomised single-blind crossover study of 14 healthy non-smoker young males. The interaction was due to a reduction in absorption, rather than an increase in propranolol's metabolism. Although the pharmacodynamics of propranolol was not affected in healthy volunteers, caution was still advisable with co-administration of the drug and the herb. Eurycomanone, an active constituent isolated from *Eurycoma longifolia*, was found not to inhibit cytochrome P450 (CYP) isoforms CYP1A2, CYP2A6, CYP2C8, CYP2C9, CYP2C19, CYP2E1 and CYP3A4 in in-vitro studies with IC_{50} values > 250 μg/ml, thus indicating the little likelihood of drug–herb interaction (Pan et al. 2013).

Pharmacokinetic Studies

Studies found that < 1 % of 9-methoxycanthin-6-one, an active compound of *Eurycoma longifolia*, was found to be absorbed orally (Tan et al. 2002). A quantification limit of approximately 1.6 ng/ml of the compound was detected in the rat and human plasma.

Relatively high plasma eurycomanone concentrations were detected after an intravenous injection of 10-mg/kg *E. longifolia* extract F2 containing 1.96 mg/kg of the quassinoid (Low et al. 2005). However, it declined rapidly to zero after 8 h. The plasma concentration of the quassinoid after oral administration was much lower than after intravenous application in spite of the oral dose being 5 times higher. The results indicated that eurycomanone was poorly bioavailable when given orally. Its poor oral bioavailability may be due to poor membrane permeability in view of its low P value and/or high first-pass metabolism.

Following intravenous administration of a standardised extract Fr 2 of *Eurycoma longifolia* containing 4.0 % 13α(21)-epoxyeurycomanone (EP), 18.5 % eurycomanone (EN), 0.7 % 13α,21-dihydroeurycomanone (ED) and 9.5 % of eurycomanol (EL), EP displayed a relatively longer biological half-life in rat plasma due primarily to its lower elimination rate constant when compared with those of EN (Low et al. 2011). Following oral administration, the absolute bioavailability of EP was 9.5-fold higher than that of EN, not because of chemical degradation since both quassinoids were stable at the simulated gastric pH of 1. In contrast, EL, being in higher concentration in the extract than EP, was not detected in the plasma after oral administration because of substantial degradation by the gastric juices after 2 hours. Similarly, ED, being unstable at the acidic pH and together with its low concentration in Fr 2, was not detectable in the rat plasma. Thus, upon oral administration of the bioactive standardised extract Fr 2, EP and EN may be the only quassinoids contributing to the overall antimalarial activity

Toxicity Studies

An evidence-based systematic review of Tongkat Ali (*Eurycoma longifolia*) by the Natural Standard Research Collaboration consolidated the safety and efficacy data available in the scientific literature (Ulbricht et al. 2013). The topics covered included written and statistical analysis of clinical trials, plus a compilation of expert opinion, folkloric precedent, history, pharmacology, kinetics/dynamics, interactions, adverse effects, toxicology and dosing.

Acute toxicity studies of each fraction of the 50 % aqueous ethanol extract of *Eurycoma longifolia* root on mice administered orally and brine shrimps revealed that the n-butanol fraction was the most toxic (Chan and Choo 2002). Eurycomanone was identified as the most toxic component in the n-butanol fraction.

13,21-Dihydroeurycoma-none, eurycomanol, longilactone, 14,15β-dihydroxyklaineanone and eurycomanol-2-O-β-glucopyranoside were 2.8, 33, 44, 88.9 and > 100 times less toxic on brine shrimps, respectively. A C-20-type quassinoid, an alpha,beta-unsaturated ketone in ring A, an exomethylene function at C-13 and an oxymethylene bridge connecting C-8 and C-11 of ring C contributed to increased toxicity. In-vitro studies showed that Tongkat Ali extract exhibited no deleterious effects on human sperm functions at therapeutically used concentrations (<2.5 μg/ml), but at very high concentrations, it may have harmful effects in-vitro (Erasmus et al. 2012).

Li et al. (2013) found neither mutagenicity nor clastogenicity in toxicity studies of Tongkat Ali powdered root extract, and the acute oral LD50 was more than 6 g/kg b.w. After 4-week subacute and 13-week subchronic exposure paradigms (0, 0.6, 1.2 and 2 g/kg b.w./day), adverse effects attributable to test compound were not observed with respect to body weight, haematology, serum biochemistry, urinalysis, macropathology or histopathology. However, the treatment significantly reduced prothrombin time, partial thromboplastin time, blood urea nitrogen, creatinine, aspartate aminotransferase, creatine phosphate kinase, lactate dehydrogenase and cholesterol levels, especially in males. These changes were judged as pharmacological effects, and they were beneficial to health. The calculated acceptable daily intake (ADI) was up to 1.2 g/adult/day

The reproductive toxicity, two generation of foetus teratology and the up-and-down acute toxicity were investigated in Sprague-Dawley rats orally treated with quassinoid-rich *E. longifolia* extract (TAF273) by Low et al. (2014). The results showed that the median lethal dose (LD_{50}) of TAF273 for female and male rats was 1293 and >2000 mg/kg, respectively. Fertility index and litter size of the TAF273-treated dams were significantly increased when compared with those of the non-treated animals. The TAF273-treated dams decreased in percentage of pre-implantation loss, post-implantation loss and late resorption. No toxic symptoms were observed on the TAF273-treated pregnant female rats and their foetuses were normal. The no-observed-adverse-effect level (NOAEL) obtained from reproductive toxicity and teratology studies of TAF273 in rats was 100 mg/kg body weight/day, being more than 10-fold lower than the LD_{50} value.

Eurycoma longifolia aqueous root extract was found to be non-toxic in the oral acute, subacute and subchronic 90-day toxicity studies conducted in male and female Wistar rats (Choudhary et al. 2012). In the acute toxicity test, oral administration of 2000 mg/kg of the aqueous extract produced neither mortality nor changes in behaviour or any other physiological activities. In the subacute study, no mortality or toxic signs were observed when three doses of 250, 500 and 100 mg/kg were given orally for 28 days. There were no significant differences in body and weight between treated and control animals of both sexes. Haematological analysis showed no significant changes in red blood cell, haemoglobin, haematocrit, white blood cell and platelet levels in both sexes compared to untreated control. No mortality and clinical abnormalities were recorded in the subchronic 90-day study. There were no significant difference between treated male and females and untreated animals in biochemical parameters, such as total protein, albumin, globulin, alkaline phosphatase, AST, AST, glucose, urea, urea nitrogen, creatine, total bilirubin, total cholesterol, triglycerides and levels of CA, P, Na and K. The NOAEL (no-observed-adverse-effect level) of *E. longifolia* aqueous extract for Wistar rats was determined to be > 1000-mg/kg body weight under the conditions of the investigation. The study by Yee et al. (2014) indicated that *Eurycoma longifolia* root aqueous extract was not mutagenic in the in-vitro *Salmonella*/microsome assay or clastogenic in the in-vivo mouse peripheral blood cell micronucleus test. Physta® was not toxic to *Salmonella* tester strains (TA 98, TA 100, TA 102, TA 1535 and TA 153) and did not increase the number of revertant colonies over the background incidence. In the mouse peripheral blood cell micronucleus assay, the extract did not alter the relative PCE, nor did it increase the incidence of micronucleated polychromatic erythrocytes. Based on these results, it was concluded that mammalian toxicity

of the standardised *Eurycoma longifolia* aqueous extracts (Physta®) was low and their use posed no genotoxic risks to individuals.

Results of analytical studies showed that 36 % of the 100 products of Tongkat Ali herbal preparations possessed 0.52 to 5.30 ppm of mercury and, therefore, did not comply with the quality requirement for traditional medicines in Malaysia (Ang et al. 2004a). Another study showed that 26 % of Tongkat Ali hitam herbal products possessed 0.53–2.35 ppm of mercury and, therefore, did not comply with the quality requirement (≤0.5 ppm) for traditional medicines in Malaysia (Ang and Lee 2006).

Traditional Medicinal Uses

Eurycoma longifolia is a herbal medicinal plant of Southeast Asian origin, popularly recognised as 'Tongkat Ali' (Bhat and Karim 2010). Its plant parts have been traditionally used for its antimalarial, aphrodisiac, antidiabetic, antimicrobial and antipyretic activities, which have also been proven scientifically. 'Tongkat Ali' is popularly taken as a traditional remedy by the ethnic population to improve the male libido, sexual prowess and fertility (Low et al. 2013a). It is traditionally used primarily as an aphrodisiac and for improving general health (Ang and Lee 2002a, b, c). Other traditional uses include the treatment of aches, persistent fever, malaria, dysentery, glandular swelling, bleeding, oedema, hypertension, syphilitic sores and ulcers (Kuo et al. 2004; Bedir et al. 2003). *Eurycoma longifolia* (Tongkat Ali) has been used in the Malay traditional medicine for osteoporotic fracture healing (Abd Jalil et al. 2012). The inhabitants of some regions of Sumatra and Kalimantan use the roots an antipyretic (Chan et al. 1995). In Lampung and Belitung, it is used as a medicine for dysentery. In Indonesia *E. longifolia* is used by both large and home industries in the preparation of jamu (Hadaiah 1996). As is the case with many other species used in the jamu industry, the collection of roots and other plant parts is directly from wild plants. One of the most unique uses for *E. longifolia* is that of the Sakai ethnic group in Sumatra who use the plant as an amulet to protect people from the smallpox virus (Hadiah 1996).

In Peninsular Malaysia and Thailand, the roots are used to cure fever, mouth ulcers and intestinal worms (Satayavivad et al. 1998; Jaganath and Ng 2000). It is used in Thai traditional medicine as a tonic, aphrodisiac, anticancer and antimalarial agent (Kanchanapoom et al. 2002). In Vietnam, besides the usual uses (malarial, dysentery, sexual insufficiency and glandular swelling), a decoction and alcoholic extract of the roots are used for treatment of rheumatism (NIMM 2004). In Vietnam, people use the flowers and fruits as a medicine for treating dysentery.

Fruits of *Brucea javanica* (L.) Merr. ('Ratchadad' in Thai) and roots of *Eurycoma longifolia* Jack ('Plalaipeag' in Thai) are used as traditional medicines for the treatment of malarial fever (Sriwilaijaroen et al. 2010).

Other Uses

Plant Growth Inhibitory Activity

Seven quassinoids from the leaves, including a new 12-epi-11-dehydroklaineanone, and longilactone, 11-dehydroklaineanone and 15β-*O*-acetyl-14-hydroxyklaineanone showed moderate growth inhibitory activity of cucumber seedling; the strongest activity was found in 14,15β-dihydroxyklaineanone (Jiwajinda et al. 2001, 2002).

Comments

A digital signal processing (DSP)-based electronic taste sensor was developed to authenticate claims of medicinal health food products that were enriched with the medicinal herb *Eurycoma longifolia* (Abdullah et al. 2004). The system was trained to detect *E. longifolia* into four different concentrations: 0.01 %, 0.03 %, 0.05 % and 0.08 %. Over 100 samples were tested, from

which the taste system was able to correctly classify the test mixtures at a greater than 90 % success rate.

Over the years several patents on the use of *Eurycoma longifolia* have been lodged with the US Patent Office.

- US Patent 7132117 B2 entitled 'Sexual dysfunction, male infertility; root extract; topical application' (Sambandan et al. 2006). This intervention provides new uses and products for treatment of sexual dysfunction and male infertility. The products include bioactive components of extracts from roots of the plant *Eurycoma longifolia* mixed in preparations for topical application and administration.
- US Patent 20070224302 A1 entitled 'Maintaining anabolic hormone profile during weight loss and intense exercise' (Talbot 2007). This intervention focuses on the use of *E. longifolia* in reducing cortisol levels and raising testosterone levels in persons under stress. It includes a method of promoting weight reduction with *E. longifoli*a and method for promoting improved endurance aerobic performance in a human with effective dose of *E. longifolia.*
- US Patent 20100221370 A1 entitled 'Polar organic extract of *Eurycoma longifolia*' (Chan et al. 2010). The invention provides a composition including a polar organic extract of *Eurycoma longifolia* and a fraction derived from the polar organic extract, said composition comprising of quassinoids, coumarins, their glycosides, analogues and derivatives, which exhibits bioactivity of increasing spermatozoa production and spermatozoa quality in terms of morphology and motility, as well as increasing testosterone synthesis and release from cells of males. The extraction method of *E. longifolia* plant to produce the polar organic extract; and the subsequent purification to produce the fraction of polar organic extract containing the quassinoids, coumarins, their glycosides, analogues and derivatives; and uses for manufacturing a preparation for infertility treatment are also provided.

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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 characterisation of antioxidants.

Abeta aggregation 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-Azinobis-3-ethylhenthiazoline-6--sulphonic acid, a type of mediator in chemical reaction kinetics of specific enzymes.

ACAT Acyl CoA: cholesterol acyltransferase.

ACE See Angiotensin-converting enzyme.

ACTH (adrenocorticotropic 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-catalyses 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 Adrenocorticotropic hormone (or corticotropin), a polypeptide tropic hormone produced and secreted by the anterior pituitary gland. It palys a role in the synthesis and secretion of gluco- and mineralo-corticosteroids and androgenic steroids.

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
DOI 10.1007/978-3-319-26062-4

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.

Actoprotective Increasing the body's physical performance.

Actoprotectors Preparations that increase the mental performance and enhance body stability against physical loads without increasing oxygen consumption. Actoprotectors are regarded as a subclass of adaptogens that hold a significant capacity to increase physical performance.

Acute otitis media (AOM) see Otitis media.

Acyl-CoA dehydrogenases A group of enzymes that catalyses 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.

Adenoidectomy Surgical removal of the adenoids.

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 anti-inflammatory 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 defence 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.

Adrenalectomised 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.

Aerophagia Excessive air swallowing.

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 centre 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.

Agoraphobia An anxiety disorder characterised by anxiety in situations where the sufferer perceives certain environments (openness or crowdedness) as dangerous or uncomfortable.

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 signalling pathway Akt are protein kinases involved in mammalian cellular signalling and inhibit apoptotic processes.

Akt/FoxO pathway Cellular processes involving Akt and FoxO transcription factors that play a role in angiogenesis and vasculogenesis.

Akt/GSK-3β/eNOS phosphorylation Amplifies serotonin 5-HT2B receptor blockade mediated anti-hypertrophic effects.

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.

Albuminaria Excessive amount of albumin in the urine, a symptom of severe kidney disease.

Alcohol dehydrogenase (ADH) An enzyme involved in the breakdown of alcohol.

Aldose reductase, aldehyde reductase An enzyme in carbohydrate metabolism that converts glucose to sorbitol.

Aldosterone Is a steroid hormone. Its main role is to regulate salt and water in the body, thus having an effect on blood pressure.

Aldosteronism A condition in which there is excessive secretion of aldosterone, which disturbs the balance of sodium, potassium and water in the blood and so leads to high blood pressure.

Aldosteronopenia Deficiency of aldosterone production with normal secretion of cortisol.

Alexipharmic An antidote, remedy for poison.

Alexiteric A preservative against contagious and infectious diseases and the effects of poisons.

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.

Alkalosis Is a condition in which the body fluids have excess base (alkali).

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.

Allodynia A painful response to a normally innocuous stimulus.

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 behavioural change.

Alopecia Is the loss of hair on the body.

Alopecia areata Type of hair loss that typically causes patches of baldness.

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, alpha-linked polysaccharides, such as starch and glycogen, yielding glucose and maltose.

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 matters. Also called coniophage or dust cell.

Alzheimer's disease A degenerative, organic, mental disease characterised 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.

Amygdalitis Inflammation of one or both tonsils, tonsilitis**.**

Amyloid beta (Aβ 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 sansation 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.

Anamnesis Patient's account of their medical history.

Anaphoretic An antiperspirant.

Anaphodisiac Or antiaphrodisiac is something that reduces or blunts the libido.

Anaphylaxis A severe, life-threatening allergic response that may be characterised by symptoms such as reduced blood pressure, wheezing, vomiting or diarrhoea.

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.

Androgenic alopecia Hair loss in men and women.

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.

Angioedema Rapid swelling of the dermis, subcutaneous tissues, mucosa and submucosal tissues caused by small blood vessels leaking fluid into these tissues.

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.

Anglioplasty Medical procedure used to open obstructed or narrowed blood vessel resulting usually from atherosclerosis.

Anguillulosis A parasitosis caused by the intestinal nematode *Strongyloides stercoralis* (round worm).

Anisakiasis A human parasitic infection of the gastrointestinal tract caused by the consumption of raw or undercooked seafood containing larvae of the nematode *Anisakis simplex*.

Anisonucleosis A morphological manifestation of nuclear injury characterised 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.

Anophthalmia Medical term for the absence of one or both eyes.

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.

Anorexia nervosa Is a psychiatric disorder characterised by an unrealistic fear of weight gain, self-starvation and conspicuous distortion of body image.

Anorexic Having no appetite to eat.

Anorexigenics See Anorectics.

Anosmia Inabity to perceive odour, reduced sense of smell.

Anoxia Absence of oxygen supply.

Antagonist A substance that acts against and blocks an action.

Antalgic A substance used to relive 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 ship that can be transmitted to man though 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 (fAβ) from amyloid β-peptide (Aβ) and destabilise fAβ.

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.

Antiasmathic 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.

Antiblennorrhagic 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 neutralise 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.

Antidipsotropic Antialcohol abuse; medication to reduce alcohol consumption.

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 diarrhoea.

Antidyslipidemic Agent that will reduce the abnormal amount of lipids and lipoproteins in the blood.

Anti-oedematous Reduces or suppresses oedema.

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 fertilisation (antizygotic).

Anti-fibrosis Preventing/retarding the development of fibrosis, i.e. excessive growth and activity of fibroblasts.

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.

Antigastralgic Preventing or alleviating gastric colic.

Antihaematic Agent that stops vomiting.

Antihaemorrhagic An agent which stops or prevents bleeding.

Antihepatotoxic Counteracting injuries to the liver.

Antiherpetic 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.

Antihypercholesterolemia Term to describe lowering of cholesterol level in the blood or blood serum.

Antihypercholesterolemic Agent that lowers chlolesterol 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).

Anti-inflammatory 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 leukaemia.

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.

Antioxytocic 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.

Antiophidian Antivenoms of snake.

Antiosteoporotic Substance that can prevent osteoporosis.

Antiovulatory 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) and 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.

Antiprotozoal 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.

Antispermatogenic Preventing or suppressing the production of semen or spermatozoa.

Antisudorific See Antiperspirant.

Antisyphilitic A drug (or other chemical agents) 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 neutralise 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 animals or insects.

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.

Aplastic anaemia (AA) is a disease in which the bone marrow and the blood stem cells that reside there are damaged and do not make enough new blood cells.

Apnoea Suspension of external breathing.

Apoprotein The protein moiety of a molecule or complex, as of a lipoprotein.

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 intemediate density lipoprotein and chylomicron that binds to a specific receptor on liver and peripheral cells.

Apoplexy Unconsciousness or incapacity of the brain to function resulting from a cerebral haemorrhage or stroke.

Apoptogenic Ability to cause death of cells.

Apoptosis Death of cells.

Appendicitis Is a condition characterised 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.

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 characterised by mouth lesions, seborrhea and vascularisation.

Aromatase An enzyme involved in the production of oestrogen that acts by catalysing the conversion of testosterone (an androgen) to estradiol (an oestrogen). Aromatase is located in oestrogen-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 groundwater 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.

Arthrodynia An affection characterised by pain in or about a joint.

Arthus reaction An allergic reaction of the immediate hypersensitive type that results from the union of antigen and antibody, with complement present in blood vessel walls.

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 Failure or suppression of the respiratory process due to obstruction of airflow to the lungs or due to the lack of oxygen in inspired air.

Asphyxiation The process of undergoing asphyxia.

Asthenia A nonspecific symptom characterised 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.

Asthenozoospermia (asthenospermia) Reduced sperm motility.

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 coordination) results from the degeneration of nerve tissue in the spinal cord and of nerves that control muscle movement in the arms and legs.

Ataxic polyneuropathy Is a syndrome characterised by problems with coordination and balance (sensory ataxia) and disturbances in nerve function (sensory neuropathy), bilateral optic atrophy and bilateral sensorineural deafness.

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

Atelectasis The collapse or closure of the lung resulting in reduced or absent gas exchange.

ATF-2 Activating transcription factor 2.

Athlete's foot A contagious skin disease caused by parasitic fungi affecting the foot and 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 characterised 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 aetiology; often called eczema.

Atresia A congenital medical condition in which a body orifice or passage in the body is abnormally closed or absent.

Atretic follicle Follicular atresia is the breakdown of the ovarian follicles.

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; the most serious consequence of atrial fribillation is ischemic stroke.

Atrioventricular node A node of specialised heart muscle located in the septal wall of the right atrium; receives impulses from the sino-atrial node and directs them to the walls of the ventricles.

Attention-deficit hyperactivity disorder (ADHD, ADD or AD/HD) Is a neurobehavioural developmental disorder, primarily characterised by the coexistence 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 are 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 hydrolyses 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.

Autonomic neuropathy Is a nerve disorder due to damage to the autonomic nerves that affects involuntary body functions, including heart rate, blood pressure, perspiration and digestion.

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 tumour 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 haemolytic disease known as babesiosis.

Babesiosis Malaria-like parasitic disease caused by *Babesia*, a genus of protozoal piroplasms.

Back tonus Normal state of balanced tension in the tissues of the back.

Bactericidal Lethal to bacteria.

BAFF A cytokine that belongs to the tumour necrosis factor (TNF) ligand family.

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.

Barbiturates Are drugs that act as central nervous system depressants and can therefore produce a wide spectrum of effects, from mild sedation to total anaesthesia. They are also effective anxiolytics, hypnotics and anticonvulsants.

Baroreceptor A type of interoceptor that is stimulated by pressure changes, as those in blood vessel wall.

Barrett's oesophagus (Barrett oesophagitis) A disorder in which the lining of the oesophagus 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 leukaemia.

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.

Beriberi Is a disease caused by a deficiency of thiamine (vitamin B_1) 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 signalling 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→3), (1→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 haemoglobin.

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.

BID The only known Bcl-2 family member that can function as an agonist of proapoptotic Bcl-2-related proteins such as Bax and Bak.

Bifidobacterium Is a genus of Gram-positive, nonmotile, 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 haem (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, alterative or appetiser.

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 (haemorrhage) due to a defect in the system of coagulation.

Blennorrhagia Gonorrhoea.

Blennorrhoea Inordinate discharge of mucus, especially a gonorrhoeal discharge from the urethra or vagina.

Blepharitis Inflammation of the eyelids.

Blepharospasm Involuntary twitching, blinking closure or squeezing 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 Da.

Blood stasis syndrome Blood stagnation or slowing of blood, an important underlying pathology of many disease processes according to traditional Chinese medicine.

BMPs (bone morphogenetic proteins) A family of secreted signalling molecules that can induce ectopic bone growth.

BNIP3 A pro-apoptotic BH3-only protein which is associated with mitochondrial dysfunction and cell death.

Boil Localised 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 downwards.

Bowman–Birk inhibitors Type of serine proteinase inhibitor.

Bouillon A broth in French cuisine.

Bradicardia 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 neutrophic factor (BDNF) A protein member of the neutrophin 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 the 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.

Bulbectomy Removal of the olfactory bulb.

Bulimia An emotional disorder characterised by a distorted body image and an obsessive desire to lose weight, in which bouts of extreme overeating are followed by fasting or self-induced vomiting or purging.

Bullae Blisters; circumscribed, fluid-containing, elevated lesions of the skin, usually more than 5 mm in diameter.

Bursa A fluid-filled sac or saclike cavity situated in areas subjected to friction.

Bursitis Condition characterised 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-I (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-alpha) Regulates gene expression in adipocytes in the liver.

Cachexia Physical wasting with loss of weight, muscle atrophy, fatigue and weakness caused by disease.

Caco-2 cell line A continuous line of heterogeneous human epithelial colorectal adenocarcinoma cells.

Cadaver A dead body, corpse.

Ca^{2+} ATPase (PMCA) is a transport protein in the plasma membrane of cells that serves to remove calcium (Ca^{2+}) 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 (Ca2+) 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 towards the urinary bladder.

Calefacient Substance that gives a sensation of warmth.

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 signalling cascade used in cell communication in living organisms.

CAMP factor Diffusible, heat-stable, extracellular protein produced by Group B *Streptococcus t*hat enhances the haemolysis of sheep erythrocytes by *Staphylococcus aureus.* It is named after Christie, Atkins and Munch-Petersen, who described it in 1944.

Campylobacteriosis Is a gastrointestinal disease (gastroenteritis) caused by bacteria called *Campylobacter* which is frequently associated with the consumption of contaminated poultry.

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.

Cannabinoid receptor family Includes CB1 cannabinoid receptors found predominantly in the brain and nervous sytem and CB2 cannabinoid receptors mainly associated with immune tissues and expressed at low levels in the brain.

Cannabinoid receptor type 2 (CB 2 receptor) A G protein-coupled receptor from the cannabinoid receptor family that is mainly expressed on T cells of the immune system, on macrophages and B cells and in haematopoietic cells.

Carboxypeptidase An enzyme that hydrolyses the carboxy-terminal (C-terminal) end of a peptide bond. It is synthesised 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 five-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 characterised 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 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 eight 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 defaecation.

Caustic Having a corrosive or burning effect.

Cauterisation A medical term describing the burning of the body to remove or close a part of it.

Caveolae Tiny (50–100nm) invaginations of the plasma membrane of the cell.

CB-1 receptor Cannabinoid receptor type 1 held to be one of the most widely expressed G protein-coupled receptors in the brain.

CCAAT/enhancer-binding proteins (C/EBP) Family of of transcription factors that interact with CCAAT (cytidine–cytidine–adenosine–adenosine–thymidine) box motif.

CCAAT/enhancer-binding protein (C/EBP)-α A key adipogenic transcription factor.

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.

CD4T cell Helper T cell with CD4 receptor that recognises antigens on the surface of a virus-infected cell and secretes lymphokines that stimulate B cells and killer T cells.

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, haematopoietic progenitor cells, epithelial cells and carcinomas.

CD68 A glycoprotein expressed on monocytes/macrophages which binds to low-density lipoprotein.

Cecal ligation Tying up the cecam.

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 extracellular 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 cata-

bolic 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 serous chorioretinopathy (CSCR) is a disease in which a serous detachment of the neurosensory retina occurs over an area of leakage from the choriocapillaris through the retinal pigment epithelium.

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 travelled to the brain.

Cerebral ischemia Is the localised 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.

Cervical spondylotic myelopathy A common cause of spinal cord dysfunction in older persons.

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.

Chaperones Are proteins that assist the noncovalent folding or unfolding and the assembly or disassembly of other macromolecular structures.

Chemoembolisation 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 pheripheral neurons that are sensitive to chemical stimuli.

Chemosensitiser A drug that makes tumour cells more sensitive to the effects of chemotherapy**.**

Chemosis Oedema of the conjunctiva of the eye.

Chickenpox Is also known as varicella and 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 anaemia characterised by greenish yellow colour.

Cholagogue Is a medicinal agent which promotes the discharge of bile from the system.

Cholecalcifereol A form of vitamin D, also called vitamin D3. See Vitamin D.

Cholecyst Gallbladder.

Cholecystitis Inflammation of the gallbladder.

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 characterised by severe, watery diarrhoea.

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 from the liver to the duodenum.

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 gallbladder.

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 signalling roles for cell membranes, cholinergic neurotransmission (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.

Chonotropic 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).

Choroidal neovascularisation (CNV) is the creation of new blood vessels in the choroid layer of the eye.

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.

Chromoblastomycosis A chronic fungal infection of the skin and the subcutaneous tissue caused by traumatic inoculation of a specific group of dematiaceous fungi (such as *Fonsecaea pedrosoi, Phialophora verrucosa, Fonsecaea compacta*) through the skin.

Chromosome Long pieces of DNA found in the centre (nucleus) of cells.

Chronic Persisting over extended periods.

Chronic anterior uveitis Inflammation of the iris and middle coat of the eyeball.

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.

Chronotropic Affecting the rate of rhythmic movements (e.g. heartbeat).

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 tenderise 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 haematopoietic, gonadal and pigment stem cells.

Cirrhosis Chronic liver disease characterised 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 and breaks in chromosomes that results 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 tissues; comprises the amino acids, hydroxyproline, proline, glycine and hydroxylysine.

Collagenases Enzymes that break the peptide bonds in collagen.

Colibacillosis Infection with *Escherichia coli*.

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 oxidise, 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 wart, venereal wart, anal wart or anogenital wart, a highly contagious sexually transmitted infection caused by epidermotropic human papillomavirus (HPV).

Congestive heart failure Heart failure in which the heart is unable to maintain adequate circulation of blood in the tissues of the body or to pump out the venous blood returned to it by the venous circulation.

Conglutination Becoming stuck together.

Conjunctival hyperemia Enlarged blood vessels in the eyes.

Conjunctivitis Sore, red and sticky eyes caused by eye infection.

Conn's syndrome Extremely rare condition characterised by adenoma, carcinoma or hyperplasia of the zona glomerulosa of the adrenal cortex, resulting in excessive production of aldosterone and leading to sodium retention and hydrogen loss.

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 homoeostasis.

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 centres 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 anaemia-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.

Cor pulmonale Or pulmonary heart disease is enlargement of the right ventricle of the heart as a response to high blood pressure or increased resistance in the lungs.

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.

Corpora lutea A yellow, progesterone-secreting body that forms from an ovarian follicle after the release of a mature egg.

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 and plays an essential role in homeostasis .

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 signalling processes, such as inflammatory response.

CPY1B1, CPY1A1 A member of the cytochrome P450 superfamily of haem-thiolate monooxygenase enzymes.

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.

CRP (C-reactive protein) A substance produced by the liver that increases in the presence of inflammation in the body.

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).

Cryptococcal meningitis A fungal infection of the membranes covering the brain and spinal cord (meninges).

Crytochidism (cryptochism) A developmental defect characterised 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 Ubihydroquinone: Cytochrome c oxidoreductase.

Cytochrome P450 3A CYP3A A very large and diverse superfamily of haem-thiolate proteins found in all domains of life. This group of enzymes catalyses 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 signalling 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 nonliving tissue from pressure ulcers, burns and other wounds.

Debriding agent Substance that cleans and treats certain types of wounds, burns and ulcers.

Deciduogenic Relating to the uterus lining that is shed off at childbirth.

Deciduoma Decidual tissue induced in the uterus (as by trauma) in the absence of pregnancy.

Deciduomata Plural of deciduoma.

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 after depolarisations (DADs) Abnormal depolarisation that

begins during phase 4—after depolarisation 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.

Deoxypyridinoline (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 diminishes 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.

Dermopathy A skin disorder characterised by discoloured patches and small papules that often become pigmented and ulcerated and result in scars, most commonly occurring on the shins of people with diabetes mellitus.

Desmutagen Substances that inactivate mutagens (cancer-causing agents).

Desquamation The shedding of the outer layers of the skin.

Desquamative ginginvitis Red, painful, glazed and friable gingivae which may be a manifestation of some mucocutaneous conditions such as lichen planus or the vesiculobullous disorders.

Detoxifier A substance that promotes the removal of toxins from a system or organ.

Diabetes A metabolic disorder associated with inadequate secretion or utilisation of insulin and characterised by frequent urination and persistent thirst. See Diabetes mellitus.

Diabetes mellitus (DM) (Sometimes called 'sugar diabetes') is a set of chronic, metabolic disease conditions characterised 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 characterised by high blood glucose in the context of insulin resistance and relative insulin deficiency in which insulin is available but cannot be properly utilised.

Diabetic autonomic neuropathy (DAN) is a serious and common complication of diabetes involving damage of the autonomic nerves. Major clinical manifestations of DAN include resting tachycardia, exercise intolerance, orthostatic hypotension, constipation, gastroparesis, erectile dysfunction, sudomotor dysfunction, impaired neurovascular function, 'brittle diabetes' and hypoglycaemic autonomic failure.

Diabetic foot Any pathology that results directly from diabetes mellitus or any long-term or chronic complication of diabetes mellitus.

Diabetic neuropathy A neuropathic disorder that is associated with diabetes mellitus. It affects all peripheral nerves including pain fibres, 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 midsection (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.

Diverticulitis Common, sometimes painful digestive disease which involves the formation of pouches (diverticula) within the bowel wall.

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 Refers 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.

Drug metabolising enzymes Play central roles in the biotransformation, metabolism and/or

detoxification of xenobiotics or foreign compounds that are introduced to the human body.

Drusen Tiny yellow or white deposits of extracellular materials in the retina of the eye or on the optic nerve head.

Dry eye syndrome Also called keratoconjunctivitis sicca, occurs when there are not enough tears on the front of the eyes.

DT diaphorase Also called DTD or NAD(P)H Quinone oxidoreductase, is an obligate two-electron reductase which bioactivates chemotherapeutic quinones.

Dysarthria Is a motor speech disorder.

Dysbiosis Also called dysbacteriosis, refers to a condition with microbial imbalances on or inside the body.

Dysentery (Formerly known as flux or the bloody flux) is a disorder of the digestive system that results in severe diarrhoea containing mucus and blood in the faeces. 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.

Dyshomeostasis An imbalance or other breakdown of a homeostasis system.

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.

Dysmenorrhoea Is a menstrual condition characterised 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 (oesophagus, stomach, small and large intestines).

Dysosmia Qualitative alteration or distortion of the perception of smell.

Dyspareunia Painful sexual intercourse.

Dyspedia Indigestion followed by nausea.

Dyspepsia Refers to a symptom complex of epigastric pain or discomfort. It is often defined as chronic or recurrent discomfort centred in the upper abdomen and can be caused by a variety of conditions. *cf.* functional dyspepsia.

Dysphagia Difficulty in swallowing.

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 childbirth or labour.

Dystonia A neurological movement disorder characterised by prolonged, repetitive muscle contractions that may cause twisting or jerking movements of muscles.

Dysuria Refers to difficult and painful urination.

E-Cadherin Has traditionally been categorised as a tumour suppressor.

E-Selectin Also known as endothelial leucocyte 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 50 % 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 discolouration 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 catalysing the dismutation of superoxide radicals.

Ectopic heartbeats Small changes in an otherwise normal heartbeat that lead to extra or skipped heartbeats.

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 characterised by one or more of these symptoms: redness, skin oedema, itching and dryness, crusting, flaking, blistering, cracking, oozing or bleeding.

Eczematous rash Dry, scaly, itchy rash.

ED 50 Is defined as the dose producing a response that is 50 % of the maximum obtainable.

Edema Formerly known as dropsy or hydropsy, is characterised as 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 signalling molecules made by oxygenation of arachidonic acid, a twenty-carbon essential fatty acid, and include 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 characterised by chronic thickened and oedematous tissue on the genitals and legs due to various causes.

11β-Hydroxysteroid dehydrogenase (HSD-11**β** or 11**β**-HSD) is the name of a family of enzymes that catalyse the conversion of inert 11 keto-products (cortisone) to active cortisol, or vice versa.

Embrocation Lotion or liniment that relieves muscle or joint pains.

Embryonation Formation of embryo in the egg.

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 caused by a virus.

Encephalocele A neural tube defect characterised by saclike protrusions of the brain tissue through a congenital fissure in the skull.

Encephalomalacia Cerebral softening, a localised softening of the brain substance, due to haemorrhage 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 antiangiogenic 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.

Endotoxaemia 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.

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.

eNOS (Endothelial nitric oxide synthase) the enzyme responsible for most of the vascular nitric oxide produced.

Enteral Term used to describe the intestines or other parts of the digestive tract.

Enteralgia Pain in the intestines; intestinal colic.

Enteral administration Involves the oesophagus, 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.

Enterohaemorrhagic Causing bloody diarrhoea 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.

Epidermal growth factor receptor (EGFR) Belongs to the ErbB family of receptor tyrosine kinases (RTK). EGFR are involved in the pathogenesis and progression of different carcinoma types.

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.

Epidural haematoma Accumulation of blood in the potential space between dura and bone and may be intracranial or spinal .

Epigastralgia Pain in the epigastric region.

Epigastric discomfort Bloated abdomen, swelling of abdomen, abdominal ditension.

Epilepsy A common chronic neurological disorder that is characterised 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.

Epithelial–mesenchymal transition or transformation (EMT) A process by which epithelial cells lose their cell polarity and cell–cell adhesion and gain migratory and invasive properties to become mesenchymal cells.

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 haemorrhage from the nostril, nasal cavity or nasopharynx (nosebleed).

Epstein–Barr virus Herpesvirus that is the causative agent of infectious mononucleosis. It is also associated with various types of human cancers.

ERbeta Oestrogen receptor beta, a nuclear receptor which is activated by the sex hormone, oestrogen.

Ergocalciferol A form of vitamin D, also called vitamin D2. See Vitamin D.

Ergogenic Increasing capacity for bodily or mental labour, especially by eliminating fatigue symptoms.

Ergonic Increasing capacity for bodily or mental labour, especially by eliminating fatigue symptoms.

ERK (extracellular signal regulated kinases) Widely expressed protein kinase intracellular signalling molecules which are involved in functions including the regulation of meiosis, mitosis and postmitotic 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.

Eryptosis Suicidal death of erythrocytes, characterised by cell shrinkage, membrane blebbing, activation of proteases and phosphatidylserine exposure at the outer membrane leaflet.

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 Characterised by erythema.

Erythroderma Exfoliative dermatitis.

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.

Erythropoiesis Is the process whereby erythroid precursor cells proliferate and differentiate into red blood cells.

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.

Estrogenic Relating to oestrogen or producing oestrus.

Euglycaemia Normal blood glucose concentration.

Eupeptic Conducive to digestion.

Exanthema Sudden widespread rash.

Exanthematous Characterised 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.

Exencephaly A type of cephalic disorder wherein the brain is located outside of the skull.

Exfoliative cheilitis Is a reactive process, in which upper, lower or both lips become chronically inflamed, crusted and sometimes fissured.

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.

Experimental allergic encephalomyelitis (EAE) Is an animal model of brain inflammation.

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.

Eyelid oedema Swollen eyelid caused by inflammation or excess fluid.

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 in 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 multienzyme that plays a key role in fatty acid synthesis.

Fas molecule A member of the tumour necrosis factor receptors, which 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 characterised 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 characterised 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.

Felon A purulent infection in the bulbous distal end of a finger.

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 synthesises the extracellular matrix and collagen, the structural framework (stroma) for animal tissues, and plays 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 (~440kDa) 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 characterised 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 organs 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, hydrolyses 5′-nucleotides to their corresponding nucleosides.

5-HT1A receptor A serotonin protein that binds to 5-5-hydroxytryptamine (5-HT) with high affinity to exert subtle control over emotion and behaviour.

Flash electroretinogram or flash ERG (fERG) Is a test which measures the electrical response of the eye's light-sensitive cells (rods and cones). It also checks other cell layers in the retina.

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 that 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 recognised: 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 and heavy menstrual bleeding, and are also anti-inflammatory.

Flourine F is an essential chemical element that is required for the maintenance of healthy bones and teeth and to reduce tooth decay. It is found in seaweeds, 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 eval-

uate cardiovascular risk. Also called FMVD (flow-mediated vasodilation).

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 breakdown 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 plays 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.

Fibrillation Is the rapid, irregular and unsynchronised contraction of muscle fibres, especially with regard to the heart.

5-Dihydroaldosterone A hormone secreted by the adrenal cortex that regulates electrolyte and water balance by increasing the renal retention.

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 localised accumulation of pus and dead tissue.

Furunculosis Skin condition characterised by persistent, recurring boils.

G protein-coupled receptor kinases (GRKs, GPCRKs) A family of protein kinases which regulate the activity of G protein-coupled receptors (GPCRs) by phosphorylating their intracellular domains after their associated G proteins have been released and activated.

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 proapoptotic gene.

Galctifuge Or lactifuge, causing the arrest of milk secretion.

Galactogogue A substance that promotes the flow of milk.

Galactophoritis Inflammation of the milk ducts.

Galactopoietic Increasing the flow of milk; milk producing.

Gallbladder 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, cholecystitis.

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.

Gap junction intercellular communication Is considered to be the sole means by which low molecular weight factors inside a cell can pass directly into the interior of neighbouring cells. Gap junctions are considered to play an essential role in the maintenance of homeostasis.

Gastralgia (Heartburn) 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.

Gastrodynia Pain in the stomach.

Gastroparesis Also called **delayed gastric emptying**, a medical condition consisting of a paresis (partial paralysis) of the stomach, resulting in food remaining in the stomach for an abnormally long time.

Gastroprokinetic See Prokinetic.

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 another agent that damages cellular DNA, resulting in mutations or cancer.

Geriatrics Is a subspecialty of internal medicine that focuses on healthcare of elderly people.

Gestational hypertension Development of arterial hypertension in a pregnant woman after 20 weeks of gestation.

Ghrelin A gastrointestinal peptide hormone secreted by epithelial cells in the stomach lining; it stimulates appetite and 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 insulinotropic 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 gonorrhoea) 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 tumour.

Glioblastoma multiforme Most common and most aggressive type of primary brain tumour in humans, involving glial cells.

Glomerulonephritis (GN) A renal disease characterised by inflammation of the glomeruli, or small blood vessels in the kidneys. Also known as glomerular nephritis. *adj.* glomerulonephritic.

Glomerulopathy Any disease of the renal glomeruli.

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-6-phosphate dehydrogenase (G6PD or G6PDH) Is a cytosolic enzyme in the pentose phosphate metabolic pathway.

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.

Glucosyltranferase An enzyme that enables the transfer of glucose.

Glucuronidation A phase II detoxification pathway occurring in the liver in which glucuronic acid is conjugated with toxins.

Glutamic oxaloacetic transaminase (GOT) An enzyme that catalyzes the reversible transfer of an amino group from aspartate to α-ketoglutarate to form glutamate and oxaloacetate.

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 x available carbohydrate divided by 100. Glycaemic 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. goitre.

Goitrogenic *adj.* causing goitre.

Gonadotroph A basophilic cell of the anterior pituitary specialised to secrete follicle-stimulating hormone or luteinising hormone.

Gonatropins 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 prepares for mitosis and where chromatids and daughter cells separate.

Guillain–Barre syndrome Is a serious disorder that occurs when the body's defence (immune) system mistakenly attacks part of the nervous system, leading to nerve inflammation, muscle weakness and other symptoms.

Gynecomastia Enlargement of the gland tissue of the male breast, resulting from an imbalance of hormones.

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 localised 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. Haematuria 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 catalyses degradation of haem.

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.

Haemolyis 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 sulphur-producing bacteria that live within the surface of the tongue and in the throat.

Hallucinogen Drug that produces hallucinogen.

Hallucinogenic Inducing hallucinations.

Hallux abducto valgus Commonly called bunion is an abnormal bending of the big toe towards the other toes of the foot.

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.

HBD-2 (human β-defensin 2) A member of the defensin family of antimicrobial peptides

that plays important roles in the innate and adaptive immune system of both vertebrates and invertebrates.

Heartburn Burning sensation in the stomach and oesophagus 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 responses.

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.

Haemagglutination A specific form of agglutination that involves red blood cells.

Haemagglutination–inhibition test Measures the ability of soluble antigen to inhibit the agglutination of antigen-coated red blood cells by antibodies.

Haemagglutinin Refers to a substance that causes red blood cells to agglutinate.

Haemangioma Blood vessel.

Haematocrit Is a blood test that measures the percentage of the volume of the whole blood that is made up of red blood cells.

Haematopoietic Pertaining to the formation of blood or blood cells.

Haematopoietic stem cell Is a cell isolated from the blood or bone marrow that can renew itself and can differentiate to a variety of specialised cells.

Haem oxygenase-1 (HO-1) An enzyme that catalyses the degradation of haem; an inducible stress protein, confers cytoprotection against oxidative stress in-vitro and in-vivo.

Hemiplegia Paralysis of the arm, leg and trunk on the same side of the body.

Haemoglobinopathies Genetic defects that produce abnormal haemoglobins and anaemia.

Haemolytic anaemia Anaemia due to haemolysis, 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.

Haemorrhagic colitis An acute gastroenteritis characterised by overtly bloody diarrhoea that is caused by *Escherichia coli* infection.

Haemolysin Certain proteins and lipids that cause lysis of red blood cells by damaging their cell membranes.

Haemolytic uremic syndrome Is a disease characterised by haemolytic anaemia, acute renal failure (uraemia) and a low platelet count.

Hepa-1c1c7 A type of hepatoma cells.

Hepatalgia Pain or discomfort in the liver area.

Hepatectomy The surgical removal of part or all of the liver.

Hepatic Relating to the liver.

Hepatic cirrhosis Affecting the liver, characterised by hepatic fibrosis and regenerative nodules.

Hepatic encephalopathy Is the loss of brain function that occurs when the liver is unable to remove toxins from the blood.

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.

Hepatomegaly Condition of enlarged 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 normalise 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 characterised by the development of vesicles on an inflammatory base.

Herpes circinatus Dermatitis herpetiformis (resembling herpes).

Herpes simplex virus 1 and 2 (HSV-1 and HSV-2) Are two species of the herpesvirus family which cause a variety of illnesses/infections in humans such as 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 herpesvirus 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 characterised by a painful skin rash with blisters.

Herpes zoster ophthalmicus (HZO) Is a viral ocular disease characterised 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 reutilisation—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 catalyses 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 grey 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.

Histone acetyltransferases (HAT) Are enzymes that acetylate conserved lysine amino acids on histone proteins by transferring an acetyl group from acetyl CoA to form e-*N*-acetyl lysine. HATs act as transcriptional coactivators.

Histone lysine demethylases (KDMs) Enzymes that play a key role in the amplification of hypoxia-inducible-factor signalling and expression of proangiogenic genes in cancer and neurological disorders.

HIV See Human immunodeficiency virus.

Hives (Urticaria) is a skin rash characterised by circular wheals of reddened and itching skin.

HLA Human leucocyte 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 leucocyte antigen complex on chromosome 6 region 6p21.31.

HMG-CoAr 3-Hydroxy-3-methyl-glutaryl--CoA reductase or HMGCR 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 characterised by enlargement of the lymph glands, spleen and anaemia.

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.

Hormesis a Term used by toxicologists to refer to a biphasic dose response to an environmental agent characterised by a low-dose stimulation or beneficial effect and a high-dose inhibitory or toxic effect.

Hormonal (female) Substance that has a hormone-like effect similar to that of oestrogen and/or a substance used to normalise female hormone levels.

Hormonal (male) Substance that has a hormone-like effect similar to that of testosterone and/or a substance used to normalise male hormone levels.

HRT Hormone replacement therapy, the administration of the female hormones, oestrogen and progesterone and sometimes testosterone.

HSF-1 factor Major regulator of heat shock protein transcription in eukaryotes.

HSP27 Is an ATP-independent, 27kDa heat shock protein chaperone that confers protection against apoptosis.

HSP70 Heat shock protein chaperone that confers protection against heat-induced apoptosis.

HSP90 A 90kDa heat shock protein chaperone that has the ability to regulate a specific subset of cellular signalling proteins that have been implicated in disease processes.

HSPD 1 Heat shock 60kDa protein 1

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 herpesvirus 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 synthesised 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 sulphates.

Hydatidiform A rare mass or growth that forms inside the uterus at the beginning of a pregnancy.

Hydrocele Abnormal accumulation of fluid inside the scrotum.

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.

Hyperdipsia Intense thirst that is relatively temporary.

Hyperemia Is the increased blood flow that occurs when tissue is active.

Hyperemesis Severe and persistent nausea and vomiting (morning sickness) during pregnancy.

Hyperemesis gravidarum Is a pregnancy complication characterised by severe nausea, vomiting, weight loss and electrolyte disturbance.

Hyperfibrinogenemia Excessive fibrinogen in the blood.

Hyperglycaemia hyperglycaemic High blood sugar; is a condition in which an excessive amount of glucose circulates in the blood plasma.

Hyperglycaemic A substance that raises blood sugar levels.

Hyperhomocysteinemia Is a medical condition characterised 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 prediabetes.

Hyperkalemia Is an elevated blood level of the electrolyte potassium.

Hyperkeratosis Abnormal thickening of the outer layer of the skin. *adj.* hyperkeratotic.

Hyperknesis Enhanced itch to pricking.

Hyperleptinemia Increased serum leptin level.

Hyperlipoproteinemia A metabolic disorder characterised by abnormally elevated concentrations of lipid/lipoprotein in the plasma; also known as hyperlipidaemia and hyperlipemia.

Hypermenorrhea Abnormally heavy or prolonged menstruation.

Hypermethylation An increase in the inherited methylation of cytosine and adenosine residues in DNA.

Hypermineralocorticoidism Excessive mineralocorticoid activity.

Hyperoxaluria An excessive urinary excretion of oxalate.

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.

Hyper-pre-beta-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 Characterised 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 hypertriglycaemia A disorder that causes high triglycerides in the blood.

Hypertrophy Enlargement or overgrowth of an organ.

Hyperuricaemia Is a condition characterised 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.

Hypocalcaemic tetany A disease caused by an abnormally low level of calcium in the blood and characterised 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.

Hypoglycaemic An agent that lowers the concentration of glucose (sugar) in the blood.

Hypogonadism syndrome Characterised by defects of the gonads, a diminished functional activity of the gonads—the testes and ovaries in males and females, respectively.

Hypokalemia Medical condition in which the concentration of potassium (K^+) in the blood is low.

Hypoparathyroidism An uncommon condition in which your body secretes abnormally low levels of parathyroid hormone (PTH). PTH plays a key role in modulating the balance of calcium and phosphorus levels in the body.

Hypoperfusion Decreased blood flow through an organ, characterised by an imbalance of oxygen demand and oxygen delivery to tissues.

Hypophagic Undereating.

Hypophysectomy The surgical removal of the hypophysis (pituitary gland).

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.

Hypoxia-inducible factors (HIFs) Transcription factors that respond to changes in available oxygen in the cellular environment, specifically, to deficiency in oxygen.

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.

IC_{50} 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.

Ichthyosis Dry, rectangular, fishlike scales on the skin.

Ichthyotoxic A substance which is poisonous to fish.

Icteric hepatitis An infectious syndrome of hepatitis characterised 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 mesenteric phlebosclerosis (IMP) a rare disease, characterised by thickening of the wall of the right hemicolon with calcification of mesenteric veins.

Idiopathic sudden sensorineural hearing loss (ISSHL) Is a 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 IvarKappaBeta kinase complex and a regulator for kinases involved in pro-inflammatory cytokine signalling.

IKappa B Or IkB-beta, a protein of the NF-Kappa-B inhibitor family.

Ileus A temporary disruption of intestinal peristalsis due to nonmechanical 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 prediabetic state of dysglycaemia associated with insulin resistance, increased risk of cardiovascular pathology and also a risk factor for mortality.

Impetigo A contagious, bacterial skin infection characterised by blisters that may itch, caused by a *Streptococcus* bacterium or *Staphylococcus aureus* and mostly seen in children.

Impotence A sexual dysfunction characterised by the inability to develop or maintain an erection of the penis.

Incontinence (faecal) 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.

Inflammasomes Are large intracellular caspase-1-activating multiprotein complexes that play a central role in innate immunity.

Inflammation A protective response of the body to infection, irritation or other injuries, aimed at destroying or isolating the injuries and characterised 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 vapour 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 characterised 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.

Intercellular adhesion molecule (ICAM) A part of the immunoglobulin superfamily. They are important in inflammation, in immune responses and in intracellular signalling events.

Interferons (IFNs) Are natural cell-signalling 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 behaviour.

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, haemopoetin-1 and mononuclear cell factor, among others that IL-1 is composed of two distinct proteins, now called IL-1α and IL-1β.

Interleukin 1 beta (IL-1β) 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 signalling 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 when 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.

Intimal hyperplasia The thickening of the tunica intima of a blood vessel as a complication of a reconstruction procedure.

Intoxicant Substance that produces drunkenness or intoxication.

Intracavernosal Within the copus cavernsoum, 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 iodised 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.

Janus kinase (JAK)-signal transducer and activator of transcription (STAT) signalling Are essential molecules in cytokine signal transduction pathways involved in cancer development and progression.

Jaundice Refers to the yellow colour 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 leukaemia.

KB cell A cell line derived from a human carcinoma of the nasopharynx, used as an assay for antineoplastic (antitumour) agents.

Kainate receptors Or KARs, are non-NMDA (N-methyl-D-aspartate) ionotropic receptors which respond to the neurotransmitter glutamate.

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 herpesvirus (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.

Keloids Benign dermal tumours characterised by fibroblastic proliferation and excessive accumulation of collagen.

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.

Keratoconjunctivitis sicca Also called keratitis sicca, xerophthalmia or dry eye syndrome (DES), is an eye disease characterised by a deficiency of aqueous tear film over the surface of the eye and in the lining of the lids.

Keratolysis Softening and separation of the horny layer of the epidermis.

Keratolytic Pertaining to keratolysis.

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 α2-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.

Konzo Is an epidemic paralytic disease occurring in outbreaks in remote rural areas of low-income African countries.

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 catalyses the conversion of lactate to pyruvate.

Lactation Secretion and Production of milk.

Lactic acidosis Is a condition caused by the build-up 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.

Lamella In cell biology, it refers to numerous plate or disc-like structures at both a tissue and cellular level.

Laminin A glycoprotein component of connective tissue basement membrane that promotes cell adhesion.

Laparoscopic cholecystectomy Is a procedure in which the gallbladder is removed by laparoscopic techniques.

Laparotomy A surgical procedure involving an incision through the abdominal wall

to gain access into the abdominal cavity. *adj.* laparotomised.

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 LD 50.

LD 50 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, which agglutinate cells and/or precipitate glycoconjugates. They play a role in biological recognition phenomena involving cells and proteins.

Leiomyoma Benign smooth muscle neoplasm that is very rarely (0.1%) premalignant.

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; easing pain or discomfort.

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 (ten-question 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 helps to combat infection.

Leucocytopenia Abnormal decrease in the number of leucocytes (white blood cells) in the blood.

Leucocytosis Increase in white blood cell count above its normal range.

Leucoderma A skin abnormality characterised by white spots, bands and patches on the skin; they can also be caused by fungus and tinea. Also see Vitiligo.

Leucomyelopathy Any diseases involving the white matter of the spinal cord.

Leucopenia A decrease in the number of circulating white blood cells.

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 characterised by an abnormal proliferation (production by multiplication) of blood cells, usually white blood cells (leucocytes).

Leukemogenic Relating to leukaemia, causing leukaemia.

Leukoplakia Condition characterised 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.

Leydig cells Also called interstitial cells of Leydig, are found adjacent to the seminiferous tubules in the testicle. They produce testosterone in response to luteinising hormone.

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.

Linterised starch Starch that has undergone prolonged acid treatment.

Lipodiatic Having lipid and lipoprotein lowering property.

Lipodystrophy A medical condition characterised by abnormal or degenerative conditions of the body's adipose tissue.

Lipofuscin Finely granular yellow-brown pigment granules composed of lipid-containing residues of lysosomal digestion.

Lipogenesis Is the process by which acetyl-CoA is converted to fats; *adj.* lipogenic.

Lipolysis Is the breakdown of fat stored in fat cells in the body.

Liposomes Artificially prepared vesicles made of lipid bilayer.

Lipotoxicity Refers to tissue diseases that may occur when fatty acids spill over 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, the urinary bladder, urethra) can be of any one of several compositions.

Lithogenic Promoting the formation of calculi (stones).

Lithontripic Removes stones from the kidney, gallbladder.

Liver X receptors Nuclear hormones that function as central transcriptional regulators for lipid homeostasis.

Lochia Vaginal discharge containing blood, mucus and uterine tissues, during the postpartum period

Lotion A liquid 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 signalling functions as well as in lipid metabolism.

LTB4 A type of leukotriene, a major metabolite in neutrophil polymorphonuclear leucocytes. It stimulates polymorphonuclear cell function (degranulation, formation of oxygen-centred 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. *adj*. luteolytic.

Luteotorpic Stimulating the formation of the corpus luteum.

Lymphadenitis The inflammation or enlargement of a lymph node casued by microbial infection.

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.

Lymphangitis An inflammation or bacterial infection of the lymphatic channels, mostly commonly caused by the bacterium *Streptoccocus pyogenes* in humans.

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 in the number of lymphocytes in the blood.

Lysosomes Are small, spherical organelles containing digestive enzymes (acid hydrolases) and other proteases (cathepsins).

mTOR, the mammalian (or mechanistic) target of rapamycin Regulates a wide range of cellular and developmental processes by coordinating signalling responses to mitogens, nutrients and various stresses.

Maceration Softening or separation of parts by soaking in a liquid.

Macrophage A type of large leucocyte that travels in the blood but can leave the bloodstream and enter tissue; like other leucocytes 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 colour of skin that are neither raised (elevated) nor depressed.

Maculopapular Describes a rash characterised by raised, spotted lesions.

Magnesium (M g) 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 nacrophage 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 source includes 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, disregulated 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.

Mastalgia Breast pain.

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 disc, muscle, tendon and skin. They respond to a noxius (damaging) mechanical load.

Medial preoptic area Is located at the rostral end of the hypothalamus; it is important for the regulation of male sexual behaviour.

Megaloblastic anaemia An anaemia that results from inhibition of DNA synthesis in red blood cell production, often due to a deficiency of vitamin B12 or folate, and is characterised by many large immature and dysfunctional red blood cells (megaloblasts) in the bone marrow.

Melaene (melena) Refers to the black, 'tarry' faeces that are associated with gastrointestinal haemorrhage.

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 Refers 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 specialised cells around blood vessels in the kidneys, at the mesangium.

Mesencephalon Midbrain**.**

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.

Metabolomics Is the scientific study of chemical processes involving metabolites.

Metalloproteinase Enzymes that break down proteins and require 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.

Methaemoglobinemia Is a disorder characterised by the presence of a higher than normal level of methaemoglobin (ferric [Fe^{3+}] rather than ferrous [Fe^{2+}] haemoglobin) in red blood cells. This results in a decreased availability of oxygen to the tissues.

Metropathy Any disease of the uterus especially of the myometrium.

Metroptosis 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.

Micellisation Formation process of micelles.

Michael acceptors See Michael reaction.

Micahel donors See Michael reaction.

Michael reaction Conjugate addition of a carbon nucleophile to an **α**,**β**-unsaturated acceptor; a thermodynamically controlled reaction between unusually acidic donors (**β**-ketoesters or **β**-diketones) and unhindered **α**,**β**-unsaturated acceptors. Stable enolates, active methylenes such as malonates and nitroalkanes are Michael donors, and activated olefins such as **α**,**β**-unsaturated carbonyl compounds are Michael acceptors.

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.

Microphthalmia-associated transcription factor (MITF) A basic helix-loop-helix leu-

cine zipper transcription factor protein that plays a role in the development, survival and function of melanocytes and osteoclast.

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 characterised by altered bodily perceptions; severe, painful headaches; and nausea.

Mimosine Is an alkaloid, **β**-3-hydroxy-4 pyridone amino acid; it is a toxic nonprotein 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.

Mineralcorticoids A group of steroid hormones that are secreted by the adrenal cortex and regulate the balance of water and electrolytes (sodium, potassium) in the body.

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 Da in molecular weight. MPT is one of the major causes of cell death in a variety of conditions.

Mitogen An agent that triggers mitosis and elicits 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 breastl, stomach, oesophagus and bladder cancers.

Mitosis Cell division in which the nucleus divides into nuclei containing the same number of chromosomes.

Mitral valve prolapse The most common heart valve abnormality. Symptoms could include palpitations, shortness of breath, cough, fatigue, dizziness or anxiety, migraine headaches and chest discomfort.

MMP Matrix metalloproteinases, a group of peptidases involved in the 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 and 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 ingests microbes, other cells and foreign matter.

Monogalactosyl diglyceride Are the major lipid components of chloroplasts.

Monorrhagia Is heavy bleeding and that is 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 641kDa.

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.

Musculotropic Affecting or acting upon muscular tissue.

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 facor, found on chromosome 8 in human.

Mycosis An infection or disease caused by a fungus.

Mydriasis Abnormal, excexsive dilation of the pupil caused by disease or drug.

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, characterised by excessive number of white blood cells.

Myeloma Cancer that arises in the plasma cells, a type of white blood cells.

Myelopathy Refers to pathology of the spinal cord.

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 leucocytes 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.

Myiasis Parasitic infestation of the body of a live mammal by fly larvae.

Myocardial Relating to heart muscle 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 fibres.

Myoclonus Brief, involuntary twitching of a muscle or a group of muscles.

Myogenesis The formation of muscular tissue, especially during embryonic development.

Myoglobin A red, iron- and oxygen-binding protein which carries and stores oxygen in muscle tissues; this haemoprotein resembles a single subunit of haemoglobin.

Myoglobinuria Is the presence of myoglobin in the urine, usually associated with rhabdomyolysis or muscle destruction.

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 characterised 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 fibre 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 characterised by the slow relaxation of the muscles after voluntary contraction or electrical stimulation.

***N*-Nitrosmorpholine** A human carcinogen.

***N*-Nitrosoproline** An indicator for *N*-nitrosation of amines.

Nicotinamide adenine dinucleotide phosphate (NADP) A coenzyme comprising nicotinamide mononucleotide coupled by pyrophosphate linkage to adenosine 2′,5′-bisphosphate; it acts as an electron carrier in numerous reactions, being alternately oxidised (NADP+) and reduced (NADPH).

NADPH The reduced form of nicotinamide adenine dinucleotide phosphate that serves as an electron carrier.

NAFLD Non-alcoholic fatty liver disease.

Narcosis A state of stupor, drowsiness or unconsciousness produced by drugs.

Narcotic An agent that produces narcosis; in moderate doses it dulls the senses, relieves pain and induces sleep; in excessive dose it causes 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 constitutes 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.

Neovascularisation Is the development of tiny, abnormal, leaky blood vessels inside the eye.

Neovasculature 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).

Neurectomy Surgical cutting through or removal of a nerve or a section of a nerve.

Neurite Refers to any projection from the cell body of a neuron.

Neuritis An inflammation of the nerve characterised by pain, sensory disturbances and impairment of reflexes. *adj*. neuritic.

Neuritogenesis The formation of neuritis. a*dj*. neuritogenic.

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.

Neurolathyrism Is a neurodegenerative disease that is caused by heavy consumption of *Lathyrus* legumes, resulting in weakness and paralysis of the legs.

Neuroleptic Refers to the effects on cognition and behaviour of antipsychotic drugs that reduce confusion, delusions, hallucinations and psychomotor agitation in patients with psychoses.

Neuroma Is a growth or tumour of nerve tissue.

Neuropathy A collection of disorders that occurs when the peripheral nervous sytems are damaged causing pain and numbness in the hands and feet.

Neuropharmacological Relating the effects of drugs on the neurosystem**.**

Neuroradiology Is a subspecialty of radiology focusing on the diagnosis and characterisation of abnormalities of the central and peripheral nervous system. *adj.* neuroradiologic.

Neurotrophic Relating to the nutrition and maintenance of nervous tissue (neurons).

Neutropenia a disorder of the blood, characterised by abnormally low levels of neutrophils.

Neutrophil Type of white blood cell, specifically a form of granulocyte.

Neutrophin Protein that induces 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.

Nidation Implantation.

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 constitutes 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 Specialised peripheral sensory neurons that respond 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 shows 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 Nuclear erythroid 2-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 specialised vision cells.

Nystagmus Fast, involuntary movements of the eyes.

Nycturia Excessive urination at night; especially common in older men.

Obsessive–compulsive disorder (OCD) A common psychiatric disorder defined by the presence of obsessive thoughts and repetitive compulsive actions; self-grooming.

Occludin A novel integral membrane protein localising 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 the 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.

Oestrogen Female hormone produced by the ovaries that play an important role in the estrous cycle in women.

Oestrogen 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.

Oestrogen receptor positive (ER+) Means that oestrogen is causing the tumour to grow and that the breast cancer should respond well to hormone suppression treatments.

Oestrogen receptor negative (ER-) Tumour is not driven by oestrogen and needs another test to determine the most effective treatment.

Oestrus Sexual excitement or heat of female; or period of this characterised by changes in the sex organs.

Oligoarthritis An inflammation of two, three or four joints.

Oligoasthenoteratozoospermia A combination of asthenozoospermia (reduced sperm motility) and oligozoospermia (low spermatozoon count).

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% to 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

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 swelling necrosis.

Ophthalmia Severe inflammation of the 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 auntoimmune 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.

Oppilation Obstruction particularly of the lower intestines.

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 characterised 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 the 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.

Osmophobia A fear, aversion or psychological hypersensitivity to odours.

Ostalgia, ostealgia Pain in the bones. Also called osteodynia.

Osteoarthritis Is the deterioration of the joints that becomes more common with age.

Osteoarthrosis 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 refers to as bone gamma-carboxyglutamic acid-containing protein.

Osteoclasts A kind of bone cell that removes bone tissue by removing its mineralised 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 mineralisation.

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.

Osteosacrcoma 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.

Otitis media Inflammation of the middle 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 oxidised, 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 labour 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 and PADGEM, a member of the selectin family. It is expressed by activated platelets and endothelial cells.

P65 transcription factor Is a protein that in humans is encoded by the RELA gene. Its alternative name is nuclear factor NF-kappa-B p65 subunit.

P300/CBP Are transcriptional coactivators that play critical roles in integrating multiple signal-dependent transcription events and may have specific roles in tumour suppression pathways.

p21waf1/cip1 Encodes a cyclin-dependent kinase inhibitor that is transcriptionally activated by the p53 tumour 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.

Palinosmia Olfactory perservation.

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 characterised by high fever and chills.

Pancreatectomised Having undergone a pancreatectomy.

Pancreatectomy Surgical removal of all or part of the pancreas.

Pancreatitis Inflammation of the pancreas.

Pancytopenia A haematological 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 tenderise meat.

Papilloma A benign epithelial tumour growing outwardly like in fingerlike 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.

Parageusia Abnormal sense of taste.

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.

Paraplegia An impairment in motor or sensory function of the lower extremities.

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.

Parenteral administration Administration by intravenous, subcutaneous or intramuscular routes.

Paresis A condition characterised by partial loss of movement, or impaired movement.

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'.

Parotitis Inflammation of salivary glands.

Paroxysm A sudden outburst of emotion or action and 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 midbrain).

Parturition Act of childbirth.

Pathognomonic Distinctively characteristic of a particular disease.

PCAF P300/CBP-associated factor, a histone acetyl transferase (HAT) that plays an important role in the remodelling of chromatin and the regulation of gene expression, transcription, cell cycle progression and differentiation.

PCE/PCN ratio Polychromatic erythrocyte/normochromatic erythrocyte ratio used as a measure of cytotoxic effects.

PCNA Proliferating cell nuclear antigen, an auxiliary protein of DNA polymerase delta

involved 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.

Pectoralagia Pain experienced in the thorax or chest.

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 Describes a group of autoimmune disorders in which there is blistering of the skin and/or mucosal surfaces.

Pemphigus neonatorum Staphylococcal scalded skin syndrome, a bacterial disease of infants, characterised 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 YY 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 localised 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.

Perineum The region between the thighs inferior to the pelvic diaphragm.

Perineal Pertaining to the perineum.

Periodontal ligament (PDL) Is a group of specialised 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.

Perioral paresthesias Are sensations of numbness and tingling around the mouth.

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, parestesia, dysesthesia, spasm, weakness, hypoesthesia or anaesthesia.

Peripheral vascular disease (PVD) See Peripheral artery occlusive disease .

Peristalsis A series of organised, 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 a process the human body uses to destroy dead or foreign cells.

Phantosmia A form of olfactory hallucination.

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, 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.

Pharyngopathy Disease of the pharynx.

Phase II drug metabolising enzymes Play an important role in biotransformation of endogenous compounds and xenobiotics to more easily excretable forms as well as in the metabolic inactivation of pharmacologically active compounds. Phase II drug metabolising enzymes are mainly transferases.

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.

Phonophobia Fear of loud sound.

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 an 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 colour; 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 hydrolyses 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 utilisation 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 provide 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 towards 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.

Pica The persistent eating of substances with no nutrition, such as dirt, chalk, sand, ice, clay or paint.

Piebaldism Rare autosomal dominant disorder of melanocyte development characterised by distinct patches of skin and hair that contain no pigment.

Piles See Haemorrhoids.

PI3K Phosphoinositide 3-kinase.

PI13K/AKT signalling 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.

Pityriasis versicolor Common fungal infection of the skin; the fungus interferes with the normal pigmentation of the skin, resulting in small, discoloured patches.

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.

Plantar verruca Wart occurring on the sole of the foot.

Plasma The yellow-coloured liquid component of blood, in which blood cells are suspended.

Plasma kallikrien A serine protease, synthesised in the liver and circulated 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.

Platelet-derived growth factor (PDGF) Is one of the numerous growth factors or proteins that regulate cell growth and division.

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 characterised by symptoms that range from a mild non-paralytic infection to total paralysis in a matter of hours; also called polio or infantile paralysis.

Pollakiuria Extraordinary daytime urinary frequency.

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, excessive hair growth, acne, obesity, reduced fertility and an increased risk of diabetes. The ovaries are larger and have many cysts or follicles that rarely grow to maturity or produce eggs capable of being fertilised.

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.

Polyposis Describes a condition where there are a lot of polyps.

PolyQ disease Polyglutamine repeat diseases are neurodegenerative ailments elicited by glutamine-encoding CAG nucleotide expansions within endogenous human genes.

Polyuria A condition characterised by the passage of large volumes of urine with an increase in urinary frequency.

Pomade A thick oily dressing.

Porphyria A disorder wherein the body cannot convert naturally occurring compounds (prophyrins) into haem which contains iron.

Porphyrin Any of a class of water-soluble, nitrogenous biological pigments, derivatives of which include the haemoproteins.

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.

Postural hypotension Also called orthostatic hypotension—a condition of low blood pressure that can cause dizziness.

Potassium (K) Is an element that is essential for the body's growth and maintenance. It is 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.

PR interval Is the time (in seconds) from the beginning of the P wave (onset of atrial depolarisation) to the beginning of the QRS complex.

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-eclampsia Toxic condition of pregnancy characterised by high blood pressure, abnormal weight gain, proteinuria and oedema.

Prenidatory phase Preimplantation phase.

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 oestrogens.

Prenidatory Referring to the time period between fertilisation and implantation.

Prenylated flavones Flavones with an isoprenyl group in the 8 position, has been reported to have good anti-inflammatory properties.

Presyncopal sensation State consisting of light-headedness, muscular weakness, blurred vision and feeling faint.

Primiparous Relating to a woman who has given birth once.

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 proathocyanidin, oligomeric proathocyanidin, leukocyanidin and leucoanthocyanin, is a class of flavanols found in many plants. It has antioxidant activity and plays a role in the stabilisation of collagen and maintenance of elastin.

Progestational Of or relating to the phase of the menstrual cycle immediately following ovulation, characterised by secretion of progesterone.

Proglottid One of the segments of a tapeworm.

Prognosis Medical term to describe the likely outcome of an illness.

Prokinetic Or gastroprokinetic, substance that enhances gastrointestinal motility by increasing the frequency of contractions in the small intestine or making them stronger.

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.

Prolapus 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) Is a blinding retinal condition. It involves the formation of pathological membranes, which dislodges the retina and thereby compromises an individual's ability to see.

Prolyl-4-hydroxylase (P4H) Key enzyme in collagen synthesis.

Promastigote The flagellate stage in the development of trypanosomatid protozoa, characterised by a free anterior flagellum.

Promyelocytic leukaemia A subtype of acute myelogenous leukaemia (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.)

Prostanoid EP 4 A prostaglandin receptor that may be involved in the neonatal adaptation of circulatory system, osteoporosis as well as initiation of skin immune responses.

Prostate A gland that surrounds 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.

Pseudoaldosteronism Is a medical condition characterised by hypertension, reduced aldosterone secretion, hypokalemia and metabolic acidosis and associated with low plasma renin activity.

Pseudohyperaldosteronism (also pseudoaldosteronism) Is a medical condition that mimics hyperaldosteronism. Like hyperaldosteronism, it produces hypertension associated with low plasma renin activity and metabolic alkalosis associated with hypokalemia.

Pseudohypoaldosteronism A hereditary disorder of infancy characterised by severe salt and water depletion and other signs of aldosterone deficiency, although aldosterone secretion is normal or increased; causes include aldosterone receptor defects and renal dysfunction.

Psoriasis A common chronic, non-contagious autoimmune dermatosis that affects the skin and joints.

Psychoactive Having effects on the mind or behaviour.

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 behaviour.

PTEN Phosphatase and tensin homolog, a tumour suppressor gene.

Ptosis 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 signalling 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 childbirth.

Puerperium Postpartum 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 discolourations 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.

Pyelitis Acute inflammation of the pelvis of the kidney caused by bacterial infection.

Pyelonephritis An ascending urinary tract infection that has reached the pyelum (pelvis) of the kidney.

Pyoderma Bacterial skin infection.

Pyodermatitis Refers to inflammation of the skin.

Pyorrhea 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.

QSR complex Series of deflections in an electrocardiogram that represent electrical activity generated by ventricular depolarisation prior to contraction of the ventricle.

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.

Radiculitis Inflammation of the radicle of a nerve.

Radiodermatitis A skin disease associated with prolonged exposure to ionising radiation.

Radiolysis The dissociation of molecules by radiation.

Radioprotective Serving to protect or aiding in protecting against the injurious effect of radiations.

RAD23B UV excision repair protein RAD23 homolog B

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.

RANKL Receptor activator of nuclear factor kappa-B ligand, a type II membrane protein and a member of the tumour necrosis factor (TNF) superfamily.

RAS See Renin–angiotensin system or recurrent aphthous stomatitis.

Rash A temporary eruption on the skin; see Uticaria.

Reactive oxygen species Species such as superoxide, hydrogen peroxide and hydroxyl radical. At low levels, these species may function in cell signalling 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-kDa *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.

Recticulocyte Non-nucleated stage in the development of the red blood cell.

Recticulocyte lysate Cell lysate produced from reticulocytes, used as an in-vitro translation system.

Recticuloendothelial 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 defences 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). It regulates the body's mean arterial blood pressure.

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, 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.

Respiratory burst Is the rapid release of reactive oxygen species (superoxide radical and hydrogen peroxide) from different cells.

Resorb To absorb or assimilate a product of the body such as an exudate 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.

Reticuloendothelial system Part of the immune system that consists of the phagocytic cells located in reticular connective tissue. Also called macrophage system or mononuclear phagocyte system.

Retinal ischemia Is a common cause of visual impairment and blindness.

Retinitis pigmentosa (RP) An inherited, degenerative eye disease that causes severe vision impairment and may lead to blindness.

Retinol A form of vitamin A; see Vitamin A.

Retinoblastoma protein A tumour suppressor protein that is dysfunctional in several major cancers.

Retinopathy A general term that refers to some form of noninflammatory damage to the retina of the eye.

Revulsive Counterirritant, used for swellings.

Reye's syndrome A potentially fatal disease that has numerous detrimental effects to many organs, especially the brain and liver, and occurs commonly in children after a viral infection.

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 and tendons. Rheumatic diseases are characterised 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 anaemia.

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, characterised 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 Proteins 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 diarrhoea (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 subcutaneous, 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.

Salve Medical ointment used to soothe the head or body surface.

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 characterised 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, bilharziasis or snail fever.

Schizophrenia A psychotic disorder (or a group of disorders) marked by severely impaired thinking, emotions and behaviours.

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 thickening 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 sales become detached.

Scurvy A state of dietary deficiency of vitamin C (ascorbic acid) which is required for the synthesis of collagen in humans.

Sebotropic Having an affinity for or a stimulating effect on sebaceous glands; promoting the excretion of sebum.

Sebum Oily secretion of the sebaceous glands.

Secretagogue A substance that causes another substance to be secreted.

Sedative Having a soothing, calming or tranquilising effect; reducing or relieving stress, irritability or excitement.

Seizure The physical findings or changes in behaviour 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 and 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 bradyacuasia Hearing impairment of the inner ear resulting from damage to the sensory hair cells or to the nerves that supply the inner ear.

Sepsis Potentially fatal whole-body inflammation caused by severe infection.

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 synthesised in serotonergic neurons in the central nervous system.

Sepsis Is a potentially fatal medical condition characterised 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 and 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.

Sialorrhea Excessive production of saliva.

Sialyation 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 haemoglobin S, an abnormal type of haemoglobin. 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, and is 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.

Sirtuin Also called Sir2 proteins, a class of proteins that possess either histone deacetylase or mono-ribosyltransferase activity.

6-Keto-PGF1 alpha A physiologically active and stable hydrolysis product of epoprostenol, found in nearly all mammalian tissues.

Sjögren's syndrome An autoimmune disease that mainly affects the eyes and salivary glands, but can affect different parts of the body. Symptoms include dry and itchy eyes, a dry mouth, thirst and swallowing difficulties.

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 signalling by members of the TGF-beta (transforming growth factor beta) superfamily.

Smad2/3 A key signalling 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 has resulted in high mortality over the centuries.

Snuff Powder inhaled through the nose.

SOCE (store-operated Ca^{2+} Is a receptor-regulated Ca^{2+} entry pathway.

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.

Spastic paraparesis A disorder that causes gradual weakness with muscle spasms (spastic weakness) in the legs.

Spermatogenic Giving rise to sperms.

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.

Spinocerebellar ataxia (SCA) is a progressive, degenerative, genetic disease with multiple types.

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.

Spongiosis Abnormal accumulation of fluid in the epidermis.

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, a transcription factor, 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 faeces which appear frothy, foul smelling and floats because of the high fat content.

Steatohepatitis Liver disease, characterised 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.

Stereotypy Excessive repetitive or ritualistic movement, posture or utterance.

Sterility Inability to produce offspring, also called asepsis.

Sternutatory Causing or tending to cause sneezing.

Steroidogenic Relating to steroidogenisis.

Steroidogenisis The production of steroids, as by the adrenal glands.

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 localised 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 characterised 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 aluminium sulphate (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 haemostatic pencil. See Antihaemorrhagic.

Subarachnoid haemorrhage 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 and neuromodulator and is associated with the sensation of pain.

Substantia nigra Is a dark coloured brain structure located in the midbrain that plays an important role in reward, addiction and movement.

Sudatory Medicine that causes or increases sweating. Also see Sudorific.

Sudorific A substance that causes sweating.

Sulphur Sulphur is an essential component of all living cells. Sulphur is important for the synthesis of sulphur-containing amino acids, all polypeptides, proteins and enzymes such as glutathione, an important sulphur-containing tripeptide which plays a role in cells as a source of chemical reduction potential. Sulphur is also important for hair formation. Good plant sources are garlic, onion, leeks and other alliaceous vegetables and brassicaceous vegetables like cauliflower, cabbages, Brussels sprout, kale; legumes, beans, green and red gram and soybeans; horse radish; water cress; and 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.

Superoxidae 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.

Sympathomimetic Mimicking the effects of impulses conveyed by adrenergic postganglionic fibres of the sympathetic nervous system.

Synaptic plasticity The ability of neurons to change the number and strength of their synapses.

Synaptogenesis The formation of synapses.

Synaptoneurosomes 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 nourishes the articular cartilage.

Syphilis Is perhaps the best known of all the STDs. Syphilis is transmitted by direct contact with infection sores, called chancres, syphilitic 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 plays a key role in the immune system and attacks virus-infected cells, foreign cells and cancer cells.

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, rapidly acting secretagogues, and cause smooth muscle contraction and vasodilation (hypotension).

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.*

Taeniacide An agent that kills tapeworms.

Tardive dyskinesia A disorder characterised by repetitive, involuntary, purposeless movements in the body such as grimacing, tongue

protrusion, lip smacking, puckering and pursing of the lips and rapid eye blinking. Rapid, involuntary movements of the limbs, torso and fingers may also occur.

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.

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.

Teletherapy A noninvasive procedure using external beam radiotherapy treatments.

Telomerase Enzyme that acts on parts of chromosomes known as telomeres.

Temporomandibular joint disorder (TMJD or TMD syndrome) A disorder characterised 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.

Teras (Medicine) a grossly malformed and usually nonviable fetus. *plural* terata.

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 infections.

Tetraparesis Weakness of muscles of all four limbs.

Tetter Any of a number of skin diseases.

TGF-beta 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.

Th 1 cells Helper cells that play an important role in the immune system.

Th 17 cells A subset of T helper cells producing interleukin 17.

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.

Thermonociceptors Or thermal nociceptors, sensory receptors that are stimulated by noxius heat or cold at various temperatures.

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**.**

Thoracodynia Pain in the chest.

3-β-HSD (Or 3-**β**-hydroxysteroid dehydrogenase/**δ**-5-4 isomerase) is an enzyme that catalyses the synthesis of progesterone from pregnenolone.

3-Nitrotyrosine (3-NT) protein Used as a marker for oxidative damage or nitrosative stress.

Thrombocythaemia A blood condition characterised 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 characterised by white spots on the tongue.

Thymocytes Are T cell precursors which develop in the thymus.

Thyrotoxicosis Or hyperthyroidism—an overactive thyroid gland, producing excessive circulating 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 imbricata (Also called Tokelau) an eruption characterised by concentric rings of overlapping scales forming papulosquamous patches scattered over the body; it occurs in tropical climates especially prevalent in southwest Polynesia and is caused by the fungus *Trichophyton concentricum*.

Tinea pedis Fungal infection of the foot, also called atheletes' foot.

Tinnitus A noise in the ears, as ringing, buzzing, roaring, clicking, etc.

Tisane An 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 labour.

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 generalised 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.

Topoiosmerase inhibitors A new class of anticancer agents with a mechanism of action aimed at interrupting DNA replication in cancer cells.

Torsade de Pointes An uncommon condition of the heart. It is a polymorphic ventricular tachycardia occurring in the context of QT prolongation.

Total parenteral nutrition (TPN) Is a method of feeding that bypasses the gastrointestinal tract.

Toxaemia 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.

Tranquiliser A substance drug used in calming person suffering from nervous tension or anxiety.

Transaminase Also called aminotransferase, is an enzyme that catalyses 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 chemoembolisation (TACE) Is an interventional radiology procedure involving percutaneous access 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 Is a set of all RNA molecules, including mRNA, rRNA, tRNA and other non-coding RNA transcribed in one cell or a population of cells.

Transcriptome profiling To identify genes involved in peroxisome assembly and function.

Transoesophageal echocardiogram Uses sound wave (ultrasound) technology to examine heart function.

Transforming growth factor beta (TGF-β) A protein that controls proliferation, cellular differentiation and other functions in most cells.

Transient receptor potential ankyrin 1 (TRPA1) Is a Ca(2+)-permeant, non-selective cationic channel that may play a role in nociception.

Transient receptor potential vanilloid 1 (TRPV1) Receptor also known as capsaicin receptor and vanilloid receptor, is a Ca 2+-permeable non-selective cation channel localised 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 *Trichophyto*n.

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 neutrophils.

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 hydrolyses proteins into smaller polypeptide units.

Trypsin inhibitor Small protein synthesised 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*, characterised by the formation of lesions (tubercles) and necrosis in the lung tissues and other organs.

Tubulopathy Any disease of the renal tubules of the nephron.

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 two 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 one 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 acid 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.

Uricaemia 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.

Urinary incontinence Sudden and strong need to urinate because of poor bladder control.

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 catalyses 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 characterised by raised red skin welts.

Uterine Relating to the uterus.

Uterine myomas Also called fibroids, tumours that grown from the uterine wall.

Uterine prolapse Occurs when weakened or damaged muscles and ligaments allow the uterus to slip into the vagina.

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.

Vaginal dystrophy A condition in which the outer part of the vagina becomes dry and the skin thickens or thins.

Vaginitis Infectious or non-infectious inflammation of the vaginal mucosa.

Vaginopathy Any disease of the vagina.

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. *pl.* vasa vasori.

Vascular cell adhesion molecule (VCAM) A part of the immunoglobulin superfamily. They are important in inflammation, immune responses and intracellular signalling events.

Vascular endothelial growth factor (VEGF) A polypeptide chemical produced by cells that stimulates the growth of new blood vessels.

Vasculitis Group of disorders that destroy blood vessels by inflammation.

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 S Shiga-like toxin produced by *Escherichia coli*, which disrupts the function of ribosomes, causing acute renal failure.

Verruca A contagious and painful wart on the sole of the foot.

Verruca plana Is a reddish-brown or flesh-coloured, 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 is 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 schwannoma Also called acoustic neuroma is a benign tumour that may develop from an overproduction of Schwann cells that press on the hearing and balance nerves in the inner ear.

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.

Vimentin A type III intermediate filament protein that is expressed in mesenchymal cells.

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.

Visual entopia Visual disturbances

Vitamin Any complex, organic compound, found in various food or sometimes synthesised 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, and help regulate the immune system in preventing or fighting off infections. Vitamin A that is found in colourful 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 coenzyme in redox reactions. Deficiency causes ariboflavinosis.

Vitamin B3 Comprises niacin and niacinamide, water-soluble vitamin that functions 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 functions 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 haemoglobin formation. Deficiency causes anaemia and peripheral neuropathy.

Vitamin B 7 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 prevents anaemia. 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 mineralisation of bone and prevent hypocalcaemic 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 helps prevent or delay the chronic diseases associated with free radicals. Besides its antioxidant activities, vitamin E is involved in immune function, cell signalling, regulation of gene expression and other metabolic processes. Deficiency is very rare but can cause mild haemolytic anaemia in newborn infants.

Vitamin K A group of fat-soluble vitamin and consists of vitamin K_1 which is also known as phylloquinone or phytomenadione (also called phytonadione) and vitamin K_2 (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 haemorrhage.

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.

Vulva-vaginal erythema Abnormal redness and inflammation of the skin in the vagina.

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 one 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 proteins Are a diverse family of secreted lipid-modified signalling glycoproteins that are 350–400 amino acids in length

Wnt signalling 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 (Fe_2S_2) clusters, involved in purine metabolism. In humans, inhibition of xanthine oxidase reduces the production of uric acid and prevents hyperuricaemia 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.

Xerostomia Dryness in the mouth due to lack of saliva production.

Yaws An infectious tropical infection of the skin, bones and joints caused by the spirochete bacterium *Treponema pertenue*, characterised by papules and papilloma 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 transition, 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 haemorrhagic 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.

ZK1 Kruppel-type zinc finger protein—binds DNA and, through this binding, regulates gene transcription.

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.

Abortive Imperfectly formed.

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 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, referring 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.

Adelphous 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 naturalised, 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.

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 11, Modified Stems, Roots, Bulbs,*
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Amplexicaul Clasping the stem as base of certain leaves.

Anatomising 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 ringlike 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 and upward.

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.

Appendiculate Having small appendages

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 fibres.

Arborescent Resembling a tree; applied to nonwoody 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 forms 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 areolae.

Areole (Botany) a small, specialised, cushion-like area on a cactus from which hairs, glochids, spines, branches or flowers may arise; an irregular angular specs marked out on a surface, e.g. fruit surface. *pl.* areolae.

Aril Specialised 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 Bristlelike part or appendage, e.g. awns of grains and grasses.

Aristulate Having a small, stiff, bristlelike 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 bristlelike 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 two 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 leaflike 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 greyish 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).

Caruncle (Bot) fleshy structure attached to the seed of certain plants.

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.* cauliflorus.

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.

Chamaephyte A low-growing perennial plant whose dormant overwintering buds are borne at or just above the surface of the ground.

Chartaceous Papery, of paper-like texture.

Chasmogamous Describing flowers in which pollination takes place while the flower is open.

Chatoyant Having a velvety sheen or lustre.

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 coloured 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 referring 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, montmorrillonite-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 fertilisation 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 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.

Crested Frilled and ruffled edge.

Crispate Weakly undulating edge.

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, having 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 genera *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 and 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 fertilisation 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 removes 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.

Dioecious 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 its alternation of generations, which features 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.

Diplochory Seed dispersal involving two or more modes.

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 four- or five-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; disc shaped. *cf.* disciform, radiate.

Discolorous Having two colours, as of a leaf which has different colours 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.

Elaioplasts A type of leucoplast that is specialised for the storage of lipids in plants.

Elaiosome Fleshy lipid-rich structures that are attached to the seeds of many plant species.

Ellipsoid A three-dimensional shape; elliptic in outline.

Elliptic Having a two-dimensional shape of an ellipse or flattened circle**.**

Elongate 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.

Ensiform Shaped like the blade of a sword, long and narrow with sharp edges and a pointed tip.

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.

Epithet Name.

Equitant In a loose fan pattern.

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 and stamens. *adj.* fasciculate.

Fasciclode 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 Zigzagging, 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 Leaflike.

Foliage Leaves of the plant.

Foliar Pertaining to a leaf.

Foliolate Pertaining to leaflets, used with a number prefix to denote the number of leaflets.

Foliose Leaflike.

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.

Foveolate Surface pitted with shallow depressions.

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.

Frutescent Shrubby.

Fugacious Shedding off early.

Fulvous Yellow, tawny.

Funiculus (Botany) short stalk which attaches the ovule to the ovary wall.

Fuscescent Dusky.

Fusiform A three-dimensional shape; spindle shaped, i.e. broad in the centre, but tapering at both thick ends.

Galea A part of the calyx or corolla having the form of a helmet.

Gall flower Short-styled flower that does not develop into a fruit but is 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 characterised 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 is pushed into the soil by the gynophore and matures.

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 and 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, extrafloral nectary or a gland tipped, hair-like or wartlike 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 colour 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 flower only once and then die. c.f. pleonanthic.

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 outwards 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 nonwoody 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 disc florets may be bisexual. *cf.* homogamous.

Heteromorphous Having two or more distinct forms. *cf.* homomorphous.

Heterophyllous Having leaves of different forms.

Heterosporous Producing spores of two sizes, the larger giving rise to megagametophytes (female) and 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.

Homogeneous endosperm Endosperm with even surface that lacks invaginations or infoldings of the surrounding tissue.

Homomorphous Uniform, with only one form. *cf.* heteromorphous.

Homosporous Producing one kind of spores. Refer to the ferns and fern allies. *cf.* heterosporous.

Hormogonium A part of a filament of a cyanobacterium that detaches and grows by cell division into a new filament. *pl.* hormogonia.

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 fertilised, 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. *adj.* relating to or of the nature of a hypanthium.

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 inwards or downwards, 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.

Infrafoliar Located below the leaves.

Infraspecific Referring to any taxon below the species rank.

Infructescence The fruiting stage of an inflorescence.

Infundibulum Funnel-shaped cavity or structure.

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.

Lacerate Irregularly cleft.

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 Woolly, 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: landrace Plants adapted to the natural environment in which they grow, devel-

oping naturally with minimal assistance or guidance from humans and usually possess more diverse phenotypes and genotypes. They have not been improved by formal breeding programmes.

Laterite Reddish-coloured soils rich in iron oxide, formed by weathering of rocks under oxidising 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, introrse.

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.

Ligneous Woody.

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 two-dimensional shape, narrow with nearly parallel sides.

Linguiform Tongue shaped. *cf.* ligulate.

Lipotubuloids Are cytoplasmic domains containing aggregates of lipid bodies surrounded by a network of microtubules, which join one lipid body with the others.

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 made 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.

Loculus 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.

Lorate Strap shaped with obtuse tip.

Lyrate Pinnately lobed, with a large terminal lobe and smaller lateral 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.

Marcescent 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 and contains ovules within which, when fertilised 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 one-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 three outer floral whorls, e.g. a five-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 and 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 pteridophytes. *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 midrib.

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.

Monostichous Forming one row.

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 defence responses in plants.

Mycorrhiza The mutualistic symbiosis (non-pathogenic association) between soilborne 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 arbuscules. *abbrev.* VAM.

Myrmecochory Seed dispersal by ants.

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.

Nixtamalisation Refers to a process for the preparation of maize (corn), or other grains, 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, 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 one-celled fruit with a hard pericarp.

Nutlet A small, one-seeded, indehiscent lobe of a divided fruit.

Ob- Prefix meaning inversely or opposite to.

Obconic A three-dimensional shape; inversely conic; cone shaped, conic with the vertex pointing downwards.

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.

Oblanceolate Inversely lanceolate, lance shaped but broadest above the middle and tapering towards 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 four-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 three-dimensional shape, e.g. spheroid.

Ochraceous A dull yellow colour.

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 membraneous bracts of a grass floret, usually enclosing the lodicules, stamens and ovary. *pl.* paleae. *adj.* paleal. *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. *adv.* 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 throughout 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, pappous.

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 penninerved Pinnately veined.

Pentamerous In five parts.

Perennial A plant that completes its life cycle or lives for more than two 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.

Petiolar 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 scalelike 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 functions as a leaf. *adj.* phyllodineous. *cf.* cladode.

Phyllopodia Refer to the reduced, scalelike 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 midrib 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 one- to many-seeded dehiscent fruit, as applied to the fruit of Fabaceae, i.e. Caesalpiniaceae, Mimosaceae and Papilionaceae.

Podzol, podsolic soil Any of a group of acidic, zonal soils having a leached, light-coloured, grey 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.

Protandrous 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 swell, 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.

Purpurascent Purple or becoming purple.

Pusticulate Characterised by small pustules.

Pyrene The stone or pit of a drupe, consisting of the hardened endocarp and seed.

Pyriform Pear shaped, a three-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, characterised 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.

Retrorse 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.* homogeneous endosperm.

Rz value Is a numerical reference to the mesh/emulsion equalisation 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 vigour 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**µ**m 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 because of scattered rough hairs.

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.

Scorpoid Refers to a cymose inflorescence in which the main axis appears to coil.

Scutellum (Botany) any of various parts shaped like a shield.

Scutiform 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 originates from the scutellar node located within the seed embryo and is 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 Tooth 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 Bristlelike.

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 with many branches 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.

Sinuous 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 and 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 spikelike 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 spiklets. *adj.* spicate, spiciform.

Spikelet A small or secondary spike characteristics of the grasses and sedges and, generally, composed of two glumes and one or more florets. Also applied to the small spikelike 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 Podzol.

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 specialised 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 scalelike 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 lacked 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 supports some other structures 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 leaflike, scalelike or bristlelike 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-like.

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.

Strophile An appendage at the hilum of certain plant seeds.

Strophiolate Furnished with a strophile or caruncle.

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.

Subfamily 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 of 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.

Suffrutescent stem Stem woody at the base.

Sulcate Grooved longitudinally with deep furrows.

Sulcus A groove or depression running along the internodes of culms or branches.

Superior Refers to the ovary that 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 fertilisation 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 specialised lateral growth pattern in 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, thread-like 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 three 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 woolly 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, three angled and three 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.

Trigonous 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 three angled.

Trullate With the widest axis below the middle and with straight margins; ovate but margins straight and angled below middle, trowel, angular, ovate shaped.

Truncate With an abruptly transverse end as if cut off.

Tuber A stem, usually underground, enlarged as a storage organ and with minute scalelike leaves and buds. *adj.* tuberous.

Tubercle A wartlike protuberance. *adj.* tuberculate.

Tuberculate Bearing tubercles; covered with warty lumps.

Tuberisation 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 downwards, 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, having 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 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 bladdery pericarp.

Vaginate Forming or enclosed in a sheath.

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.

Veinlets Small veins.

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 5mm 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, scaliness or other covering commonly found on the external parts of plants. *cf.* indumentums.

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 colour 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 ringlike 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 oxidised 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 fist cell formed by the union of two gametes in sexual reproduction. *adj.* zygotic.

Common Name Index

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Scientific Name Index

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