Plant Resources of South-East Asia

No 16

Stimulants

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Foreword

With this volume on stimulants a very important and diverse group of plants has been covered, including species that have acquired worldwide economic importance. Three of these – coffee, tea and cocoa – from respectively Africa, Asia and America are the source of the world's major non-alcoholic beverages. Philippe Dufour depicted this allegorically in his 'Traités nouveaux et curieux du café, du thé et du chocolat' [New and curious essays on coffee, tea and cocoa], published in 1671, by showing an African, an Asian and an Amerindian at table, each drinking their own beverage. The history and development of these three beverage plants was intimately linked with European colonization from the 17th Century onwards, and they have developed into important cash crops, particularly in the 19th and 20th Centuries.

Many stimulants that are deeply rooted in the local and regional cultures of South-East Asia do not enter the international market. Their social and cultural role in the region is great; for example, the combination of betel leaves with the areca nut for chewing, which has spread around the margins of the Indian Ocean. Other plants, such as kava, show a distinct pattern of distribution, being used in different contexts and embedded in rituals that vary from island to island. The reader will also be struck by how many species are only used locally, and on which information has been scarce until now.

This volume includes 54 species. It gives sound and up-to-date information on the major species and on many minor species. Most species have also other uses, such as medicinal and culinary. The information is presented in the same format as in the companion volumes and includes not only the species' botany, origin and uses, but also basic information on ecology and agricultural practices. Such a synthesis has been achieved by combining a comprehensive literature search in major libraries and databanks with the input of specialists from universities and research centres in South-East Asia and from Western countries.

More than any other commodity group of plants, stimulants show how crucial cultural preferences and social choices are. Stimulants are not staples of life, but they give us pleasure, which makes life enjoyable, and they sometimes alleviate pain and anxiety. Some are luxury products, others are cherished by the poorest. Some species may be highly valued culturally in some countries, but are considered to be intoxicants or are even banned in others. It is up to decision-makers and civil societies to decide whether a particular species should be promoted or not, but any decision should be based on sound scientific information. It is the great merit of this book to provide such information.

The Prosea programme is nearing completion. Its achievements are impressive. The handbook is already helping researchers and stakeholders to evaluate the feasibility of crops. Promoting minor crops, developing sustainable agriculture, conserving biological diversity and respecting cultural diversity are now on the agenda of most international, regional and national organizations. The Prosea handbook is a powerful tool for achieving these objectives. The Prosea programme is in line with our international commitments, particularly the Convention on Biological Diversity and the FAO Global Plan of Action on Plant Genetic Resources for Food and Agriculture.

Montpellier, December 1999.

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1 Introduction

1.1 Definition and species diversity

1.1.1 Choice of species

Most of the plant resources brought together in this volume have in common that they are cultivated or collected for the stimulating properties of certain alkaloids (e.g. caffeine) and other psycho-active compounds that are present in non-toxic concentrations in the seeds, leaves or other harvested plant parts. Based on general use, three types of stimulant plants may be distinguished: (1) plants used to make beverages: hot or cold infusions are prepared, mainly from dried and processed seeds or leaves; (2) masticatory plants: the stimulating effect is obtained by chewing plant parts, often fresh or dried seed, sometimes in combination with other plant products; (3) plants whose dried and processed leaves are smoked.

Full descriptions of 15 major stimulants (20 species) are given in Chapter 2. An overview of the origin, geographic distribution and other basic data for each of these 15 stimulants is presented in Table 1. Tea (*Camellia sinensis* (L.) Kuntze), coffee (*Coffea arabica* L., *C. canephora* Pierre ex Froehn. and *C. liberica* Bull ex Hiern), cocoa (*Theobroma cacao* L.) and tobacco (*Nicotiana tabacum* L. and *N. rustica* L.) are the four dominant and globally most significant stimulants. The major stimulants of regional importance are maté (*Ilex paraguariensis* A. St.-Hil.) and guaraná (*Paullinia cupana* Kunth) both in South America, areca nut (*Areca catechu* L.) in combination with betel pepper (*Piper betle* L.) in South and South-East Asia, kola (*Cola nitida* (Vent.) Schott & Endl. and *C. acuminata* (P. Beauv.) Schott & Endl.) in West Africa and kava (*Piper methysticum* G. Forster) in Melanesia and Polynesia. Another 5 stimulants (6 species) have also been included because of their local importance in South-East Asia as beverage plants. In certain cases a given plant resource is used as much for its medicinal or refreshing as for its stimulating properties, and its allocation to the group of stimulants is somewhat arbitrary.

Brief descriptions of 33 minor 'stimulants' (34 species) are presented in Chapter 3, which also includes some species used in association with stimulants, such as plants used to wrap tobacco (*Licuala pumila* Blume, *L. rumphii* Blume and *Microcos paniculata* L.). Several species that are difficult to assign to Prosea commodity groups have also been included: two species that are used to obtain potable water (*Desmos dumosus* (Roxb.) Safford and *Piper bantamense* Blume) and two species that are used to improve the taste of palm wine (*Garcinia amboinensis* Spreng. and *Garcinia picrorhiza* Miquel). Other plant species whose use as a stimulant or in association with stimulants is a secondary use are listed in Chapter 4.

Table 1. Origin, geographic distribution and other basic data of major stimulant plants.

Scientific name	Common name	Region of origin	First cultivation
Plants for beverages			
Camellia sinensis			1000 BC
var. *assamica*	Assam tea	north-eastern India	
var. *sinensis*	China tea	southern China	
Chloranthus erectus	keras tulang	Asia	weed, home gardens
Coffea spp.			AD 1200
C. arabica	arabica coffee	Ethiopia	
C. canephora	robusta coffee	Central and West Africa	
C. liberica	liberica coffee	Central and West Africa	
Ilex paraguariensis	maté	South America	AD 1670
Matricaria recutita	German chamomile	Europe and West Asia	500 BC
Mesona palustris	black cincau	Asia	wild plant
Paullinia cupana	guaraná	Amazon Basin	AD 1850
Piper methysticum	kava	Vanuatu	AD 1000
Poikilospermum spp.		Asia, Pacific	wild plants
P. amboinense	tali ayer		
P. suaveolens	mentawan		
Senna occidentalis	negro coffee	unknown	wild plant, weed
Theobroma cacao	cocoa	Amazon Basin	100 BC
Masticatory plants			
Areca catechu	areca palm	Asia	500 BC
Cola spp.		West Africa	AD 1600
C. acuminata	Abata kola		
C. nitida	Gbanja kola		
Piper betle	betel pepper	South-East Asia	500 BC
Plants for smoking			
Nicotiana spp.		South America	100 BC
N. rustica	nicotine tobacco		
N. tabacum	tobacco		

1.1.2 Origin and domestication

The majority of stimulants are of tropical origin, though a few originate from the subtropics. Asia, Africa and South and Central America have been equally important in terms of the origin and first domestication of the great beverages (tea, coffee and cocoa), tobacco and another 5 major stimulants (Figure 1).
Tea is probably the oldest domesticated stimulant. According to Chinese legend, an infusion from tea leaves was used for medicinal purposes as early as 3000 BC, but written evidence of widespread tea (*Camellia sinensis* (L.) Kuntze var. *sinensis*) cultivation in China dates back to AD 350. The local people of

Table 1. Continued.

Scientific name	Region of distribution	Main active compound	Health risk
Plants for beverages			
Camellia sinensis var. *assamica* var. *sinensis*	Asia, Africa, South America	caffeine	low
Chloranthus erectus	tropical Asia	β-coumaric acid	unknown
Coffea spp. *C. arabica* *C. canephora* *C. liberica*	South and Central America, Africa, Asia, Pacific	caffeine	low
Ilex paraguariensis	South America	caffeine	low
Matricaria recutita	world-wide (cool climates)	flavonoids	low
Mesona palustris	Asia	flavonoids	unknown
Paullinia cupana	Amazon Basin	caffeine	low
Piper methysticum	Pacific, New Guinea	kavalactones	unknown
Poikilospermum spp. *P. amboinense* *P. suaveolens*	Asia, Pacific	unknown	low
Senna occidentalis	tropics, subtropics	alkaloids	considerable
Theobroma cacao	Africa, South and Central America, South-East Asia	theobromine + caffeine	low
Masticatory plants			
Areca catechu	tropics	arecoline	some
Cola spp. *C. acuminata* *C. nitida*	West Africa	caffeine	some
Piper betle	South and South-East Asia, East Africa, West Indies	phenols	unknown
Plants for smoking			
Nicotiana spp. *N. rustica* *N. tabacum*	world-wide	nicotine	considerable

north-eastern India, Burma (Myanmar) and adjacent countries have long been familiar with wild tea, using the leaves for chewing or preparing infusions, but domestication of Assam tea (*Camellia sinensis* (L.) Kuntze var. *assamica* (Mast.) Kitamura) probably started after 1840 with the first British tea plantations in northern India. The cultivation of arabica coffee (*Coffea arabica* L.) and the preparation of a beverage from roasted and ground seeds developed in Yemen, probably in the 12th or 13th Century, and before long coffee was known as the 'wine of Arabia'. There may have been some form of domestication before that time in the region of origin of arabica coffee in south-western Ethiopia; early Arab travellers must have learned the stimulating properties of

America	Africa	Asia
Ilex paraguariensis	***Coffea* spp.**	*Areca catechu*
***Nicotiana* spp.**	*Cola* spp.	***Camellia sinensis***
Paullinia cupana		*Piper betle*
Theobroma cacao		

Figure 1. Origin and domestication of important stimulants.

infusions from arabica coffee leaves, fruits or seeds from the local people. Uganda has a centuries-old tradition of deliberate planting of coffee (*Coffea canephora* Pierre ex Froehn.) near homesteads, and since time immemorial the inhabitants of central Africa have chewed dried seeds collected from wild or planted coffee for their stimulating effect. Cocoa and tobacco are both of South American origin, but it was Central American people like the Maya who started cultivating these crops on a large scale more than 2000 years ago. Cocoa became of major socio-economic significance to pre-Columbian civilizations of Central and South America as a nutritious and stimulating beverage and also as general currency. Tobacco found widespread use, even among indigenous North American peoples for ritualistic, medicinal and hedonistic purposes. The South American beverages maté and guaraná were domesticated only a few centuries ago close to their area of origin, as was kola in West Africa. On the other hand, the first cultivation in Asia of the areca palm and betel pepper, two of the essential ingredients of the 'pan' (South Asia) or 'sirih' (South-East Asia) quid, could have been 2500–3000 years ago. Kava, from which the Polynesians prepare their national beverage, was domesticated around AD 1000. German chamomile (*Matricaria recutita* L.) originates from the Mediterranean region, while the remaining 4 stimulants listed in Table 1 originate from Asia or South America. Domestication of the latter stimulants was generally restricted to backyard gardens. Certain stimulant plants (e.g. *Senna occidentalis* (L.) Link) are sometimes considered to be weeds. The minor stimulants are all endemic to South-East Asia, except for two species of African origin *Coffea congensis* Froehner and *C. stenophylla* G. Don. Many of these are not or only partly domesticated.

1.1.3 Geographic distribution

Tea, coffee, cocoa and tobacco were domesticated by Chinese, Arab and Central American civilizations respectively, long before these civilizations came into contact with the first European explorers at the beginning of the 16th Century. However, the expanding and competing colonial empires – first the Spanish and Portuguese but soon followed by the Dutch, British and French – were quick to appreciate the social and economic potential of the novel stimulants. The de-

mand for these commodities rapidly exceeded the amount obtainable by trade with the original sources of supply, so cultivation of major stimulants was subsequently introduced into the newly colonized areas. Cocoa and tobacco were already being cultivated outside the traditional regions by the end of the 16th Century. Coffee produced in Indonesia and South America started to arrive in Europe in large quantities by the middle of the 18th century. On the other hand, China maintained a monopoly on the international tea trade until the end of the 19th Century, at which time tea produced on plantations in India, Sri Lanka and Indonesia finally started to overtake the tea from China in volume.
At present, these four stimulants have a wide distribution: cocoa and coffee are mainly confined to the tropics, tea cultivation extends into subtropical regions, but the annual tobacco is also grown during summer in temperate zones. Many other stimulants – e.g. kola, maté, guaraná and kava – have remained close to their origin and region of first domestication. An overview of present main geographic distribution of all major stimulants is given in Table 1.

1.2 Role of stimulants

1.2.1 Social and cultural aspects

The human interest in tea and coffee may initially have had a religious motive, e.g. tea to keep Buddhist monks awake during long hours of meditation in China and coffee as an acceptable substitute for alcoholic drinks in Islamic Arabia. However, these stimulating beverages would soon gain general popularity at all levels of societies in and around the countries of first cultivation and eventually also in Europe and the Americas. The numerous tea and coffee houses of 17th and 18th Century Europe, as places for people to meet and debate important issues, have been of great influence on major cultural, commercial and even political developments of the last 200 years. Without exaggeration it can be stated that most people in the present world drink tea, coffee or both on a daily basis to banish fatigue and refresh the mind. The two beverages continue to have considerable social functions, starting with the simple gesture of offering a guest a cup of tea or coffee to convey hospitality.
Tea is the predominant beverage in Asia. The elaborate rituals of tea ceremonies bear witness to its significance in Chinese and Japanese cultural traditions, but in most other Asian countries too, tea drinking has a role in social life. After early proliferation of coffee houses in 17th Century London, Great Britain and also Ireland became nations of tea drinkers in the 18th Century, initially for political and economic reasons. Exactly the opposite happened in the United States, after the famous Boston tea party of 1773. The Russian preference for tea as non-alcoholic beverage, dates back to 17th Century supplies of tea obtained overland from China. Tea drinking has overtaken coffee in some of the Arab and Middle-East countries, even in Yemen – the country where arabica coffee was first domesticated. Tea is generally more popular than coffee in most African countries too, except in Ethiopia, where more than half of the total coffee crop is consumed locally. Coffee drinking is a typical aspect of the societies of continental Europe, the United States and several Latin American countries, contributing as much to the quality of work as well as that of social life. Coffee consumption is increasing in the United Kingdom and, with the

globalization of the Western lifestyle, coffee is becoming more popular in traditional tea countries such as Japan, South Korea and even China.
Cocoa was known in 18th Century Europe, where it continues to be consumed by the more affluent. Chocolate consumption is increasing in countries such as Japan and Singapore, but about 85% of world cocoa production is still exported to Europe and North America.
The smoking of tobacco in cigarettes, cigars or pipes, reached global proportions more than a century ago and the habit has made an impact on almost all societies of the world. The dependence on this stimulant met with little religious or cultural resistance, and smoking was universally appreciated for its socializing aspects. Tobacco consumption is still on the increase in Asia and the developing world in general. On the other hand, there is growing opposition to tobacco in view of the potential harm to public health, and the smoking of cigarettes in particular is now often considered to be an anti-social activity in Europe and North America.
Regionally important stimulants, such as maté, guaraná, kola, areca nut (with betel pepper) and kava, all have considerable cultural and social functions. The remaining species treated as major stimulants are mostly of very restricted or traditional use, sometimes with occasional additional medicinal applications.

1.2.2 Nutritional and health aspects

With the exception of cocoa (> 50% fat), the nutritional value of the products from major stimulants is negligible. On the other hand, the various alkaloids and phenolic substances present in these products often have considerable physiological effects on the human body. The effects on health have been extensively investigated for the universally important stimulants tea, coffee, cocoa and tobacco and some of the recent conclusions will be reviewed below. The health risk associated with maté and guaraná is considered to be low, although supporting experimental or epidemiological evidence is scarce. For the remaining stimulants the risk is unknown, or assumed to be low to considerable, depending on concentration and frequency of consumption. An overview of the main active compounds and estimated health risk for the major stimulant plants is given in Table 1.

Caffeine

The occurrence of the purine alkaloid caffeine (1,3,7-trimethyl-xanthine) appears to be restricted to six higher plant genera: *Camellia* L., *Coffea* L., *Theobroma* L., *Ilex* L., *Paullinia* L. and *Cola* Schott & Endl. (Crozier et al., 1998). Caffeine originates in the young leaves and fruits by biosynthesis from purine nucleotides. The chemical structure of caffeine is shown in Figure 2. Theobromine (3,7-dimethylxanthine) is similar, except for the absence of one methyl group. Due to the universal consumption of tea and coffee, especially the latter, caffeine is certainly the most widely used psycho-active substance in the world. The caffeine content of the cured product and the quantity of caffeine intake per cup of tea, coffee and cocoa, are presented in Table 2 (Baumann, 1996; Chow & Kramer, 1990). A 100 ml cup of tea contains half to one-third as much

Table 2. Caffeine content of the three main stimulant beverages.

Beverage	Caffeine in cured product (%)	Content per cup of 100 ml	
		Cured product (g)	Caffeine (mg)
Tea	3.0–4.0	2– 3	20– 80[2]
Coffee	1.0–2.5	10–12	50–150
Cocoa[1]	0.2–0.6	7– 8	5– 20

[1] Also containing theobromine 2–3%; theobromine only has one-tenth of the stimulating effect of caffeine.
[2] As actually present in the beverage.
Sources: Baumann (1996), Chow & Kramer (1990).

caffeine as a cup of coffee. The cocoa drink has less caffeine than a cup of tea, but also contains 100–120 mg theobromine, which, however, has only one-tenth of the stimulating activity of caffeine.

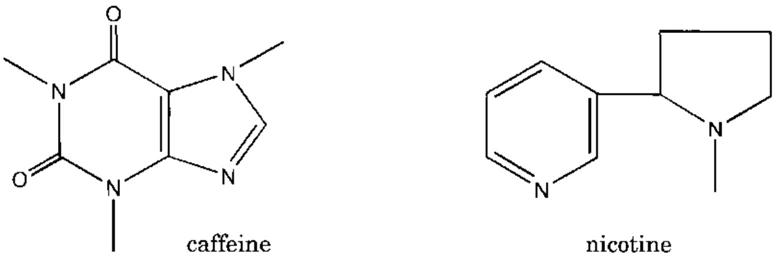
Caffeine is odourless and has a bitter taste, although this contributes only partly to the perceived bitterness of the consumed stimulants. After ingestion, caffeine is rapidly absorbed from the gastro-intestinal tract, reaching maximum blood plasma levels within 30–45 minutes. About 50% of the caffeine is metabolized and excreted as methylxanthine derivatives in the urine 5–6 hours later. Low to moderate caffeine doses, not exceeding a daily total of 200–600 mg, usually result in increased alertness, energy and ability to concentrate. Higher doses may induce negative effects such as anxiety, nervousness, insomnia and rapid heart action, but individual variation of tolerance levels is considerable. In contrast to the drugs of abuse, addiction to caffeine occurs only at very high doses that are rarely reached through the regular consumption of tea, coffee or other caffeine-containing beverages. In general, caffeine is not a threat to the health of most people (Clarke & Macrae, 1988a; Nehlig, 1998; Smith, 1985).

Phenolic substances

The flavanols in tea (30–35%) and chlorogenic acids in coffee (6–15%) contribute to the characteristic colour and taste of the respective beverages (Clifford, 1985; Robertson, 1992). There is no evidence of negative biological effects; indeed, due to their anti-oxidant properties these polyphenols or their metabolites may provide some protection against carcinogenic substances (Clifford, 1998; Marks, 1992; Viani, 1993).

Nicotine

The perceived strength of tobacco is primarily determined by the nicotine content. The chemical structure of this alkaloid is presented in Figure 2. Nicotine has a considerable addictive effect, even at low doses, and because of the hazardous carcinogenic constituents present in tobacco and its smoke this poses potential health risks to regular consumers (Shopland et al., 1991).



caffeine nicotine

Figure 2. The chemical structures of caffeine and nicotine.

1.2.3 Economic aspects

Table 3 presents a summary of data on production and international trade for the globally most important stimulant crops, as derived from statistics (1995-98) provided by the Food and Agriculture Organization of the United Nations (FAO) and various commodity trade associations, such as the International Coffee Organization (ICO), International Cocoa Organization (ICCO), International Tea Committee (ITC) and Tobacco Merchants Association (TMA).

Compared with a single cereal crop like rice, the area cultivated with tea, coffee, cocoa and tobacco together (23.7 million ha) is less than 17% and total production (17.3 million t) only about 3%, but combined trade value of the cured products is estimated at US$ 35–44 billion. Coffee alone accounts for almost half of this value, followed by tobacco, then tea and lastly cocoa. The value of the manufactured products at retail prices is likely to be 4–10 times higher. The contribution of these four stimulants to the economies of several producer and consumer countries and to world trade is therefore considerable.

A large number of countries, the majority within the tropics, produce one or more of these stimulants. India and China are prominent producers of tea and tobacco, Brazil of coffee, cocoa and tobacco, Indonesia of coffee, tea and cocoa, Ivory Coast, Ghana and Nigeria of cocoa, Sri Lanka and Kenya of tea. Continent-wise (Table 4) Asia is predominant in tea (75%) and tobacco (59%), Africa in cocoa (66%) and South and Central America in coffee (61%). Tea and tobacco are produced outside the tropics to a considerable extent.

Table 3 also indicates the variation in export and consumption patterns. Cocoa is almost exclusively an export product for all countries except Brazil. Coffee production is also export-oriented in most countries, but in Brazil, Indonesia and Ethiopia there is also considerable local consumption. On the other hand, some of the most important producers of tea (China, India) and tobacco (China, India and the United States) have larger internal than export markets.

Data on area and production per country in the South-East Asian region for the four major stimulants are given in Table 5. The region accounts for 5–17% of world production of the four major stimulants. Indonesia is predominant in all four, Vietnam has once more become an important coffee producer and Malaysia is still a significant cocoa producer.

Maté is produced in Argentina, southern Brazil and Paraguay on 0.5 million ha. Most of the product (0.5 million t/year) is consumed in Latin America, with minor exports to the United States, Japan and the European Union. Kola is an

Table 3. World production, value and exports for tea, coffee, cocoa and tobacco (mean 1995–1998).

	Tea	Coffee	Cocoa	Tobacco
Number of producing countries	30	60	40	110
Cultivated area (10^6 ha)	2.5	10.6	6.1	4.5
Annual production (10^6 t)	2.6	5.8	2.7	6.6
Value (10^9 US$)	5–7	17–20	3–5	10–12
Exports (% of production)	40	75	85	30
Main producing countries	India China Sri Lanka Kenya Indonesia	Brazil Colombia Indonesia Mexico Ethiopia	Ivory Coast Ghana Indonesia Brazil Nigeria	China United States India Brazil Turkey
Main consuming countries	India China United Kingdom Russian Federation United States Pakistan	European Union United States Brazil Japan Ethiopia Indonesia	European Union United States and Canada Brazil Eastern Europe Singapore Japan	China United States India Japan Indonesia

Various sources.

important product (200 000 t) with considerable commercial value in West Africa (Nigeria, Ghana, Benin, Sierra Leone). The Caribbean and South America are significant export markets for kola nuts. Guaraná is produced exclusive-

Table 4. Present production of major stimulants per continent (mean 1995–1998).

Stimulant	% of world production		
	America	Africa	Asia
Tea	2	23[1]	**75**
Coffee	**61**	19	20
Cocoa	17	**66**	17
Tobacco	21[2]	20[3]	**59**

[1] Including 9% tea in south-eastern Europe and Turkey.
[2] Including 9% tobacco in North America.
[3] Including 13% tobacco in Europe and Turkey.
Various sources.

Table 5. Areas and production of tea, coffee, cocoa and tobacco in South-East Asia (mean 1995–1998).

Country	Tea		Coffee		Cocoa		Tobacco	
	Area (10^3 ha)	Prod. (10^3 t)	Area (10^3 ha)	Prod. (10^3 t)	Area (10^3 ha)	Prod. (10^3 t)	Area (10^3 ha)	Prod. (10^3 t)
Burma (Myanmar)	–	–	4	1	–	–	36	38
Cambodia	–	–	–	–	–	–	9	5
Indonesia	138	142	840	450	675	286	215	155
Laos	1	1	20	10	–	–	4	3
Malaysia	4	6	15	8	200	115	12	12
Papua New Guinea	5	7	45	65	90	35	–	–
the Philippines	–	–	140	55	9	5	37	50
Thailand	10	5	75	75	–	–	47	60
Vietnam	71	40	160	210[1]	–	–	36	29
South-East Asia	229	201	1299	874	974	441	396	352
% of world	9.2	7.7	12.3	15.1	16.0	16.3	8.8	5.3

[1] 420 000 t in 1999.
Various sources.

ly in the Amazon region of Brazil (4000 ha) and only a small amount of the total production of 1200 t is exported to Japan and the United States. For the remaining major stimulants listed in Table 1 statistical data on production are incomplete or unavailable.

1.3 Botany

1.3.1 Taxonomy and morphology

An overview of the 20 major and 34 minor species with stimulant properties is presented in Table 6. These belong to 21 different families, all of them being dicotyledons except one family of monocotyledons, the *Palmae*, which alone contains as many as 10 stimulant species (including *Areca catechu*). The *Rubiaceae* is the next most important family with 9 species (including *Coffea* species), followed by the *Piperaceae* with 6 species, the *Sterculiaceae* with 4 species (including *Cola* species and *Theobroma cacao*), the *Solanaceae* with 3 species (including *Nicotiana* species) and the *Chloranthaceae* with 3 species. The remaining families include only one or two stimulant species, such as the *Aquifoliaceae* (*Ilex paraguariensis*), *Camelliaceae* (*Camellia sinensis*) and *Sapindaceae* (*Paullinia cupana*).

Details of type of plant, plant parts harvested and main use for each stimulant are also indicated in Table 6. The vast majority of the stimulants are perennials: woody shrubs and trees (30), palms (10) and woody or epiphytic vines (8). Only 6 stimulants are annual, biennial or perennial herbs, belonging to the *Compositae, Labiatae, Leguminosae* and *Solanaceae*.

The plant parts harvested are roots (6 species), bark (7 species), sap from the stem (4 species), leaves (23 species), flowers (2 species), infructescences (1 species) and seeds (18 species). In half of the stimulant species these plant

Table 6. Taxonomic and morphologic data on 54 stimulant plant species.

Family	Species	Type of plant	Plant parts harvested	Main use
Annonaceae	*Desmos dumosus*	shrub	sap from stem	beverage
Aquifoliaceae	*Ilex paraguariensis*	shrub – tree	leaves	beverage
Camelliaceae	*Camellia sinensis*	shrub – tree	leaves	beverage
Cecropiaceae	*Poikilospermum amboinensee*	epiphytic vine	aerial roots, sap from stem	smoking, beverage
	Poikilospermum suaveolens	epiphytic vine	sap from stem	beverage
Chloranthaceae	*Chloranthus erectus*	shrub	leaves, roots	beverage
	Chloranthus spicatus	shrub	leaves, flowers	beverage
	Sarcandra glabra	shrub	leaves, roots	beverage
Compositae	*Matricaria recutita*	annual herb	flowers	beverage
Euphorbiaceae	*Acalypha siamensis*	shrub	leaves	beverage
	Actephila excelsa	shrub – tree	leaves	beverage
Guttiferae	*Garcinia amboinensis*	tree	roots	beverage
	Garcinia picrorhiza	tree	roots	beverage
Labiatae	*Mesona palustris*	annual herb	leaves	beverage
Leguminosae	*Bauhinia winitii*	climbing vine	bark	masticatory
	Senna occidentalis	annual or perennial herb	seeds	beverage
Moraceae	*Ficus ribes*	tree	leaves, bark	masticatory
Oleaceae	*Fraxinus griffithii*	tree	leaves	smoking
Palmae	*Areca caliso*	palm	seeds	masticatory
	Areca catechu	palm	seeds	masticatory
	Areca latiloba	palm	seeds	masticatory
	Areca macrocalyx	palm	seeds	masticatory
	Areca triandra	palm	seeds	masticatory
	Areca whitfordii	palm	seeds	masticatory
	Calyptrocalyx spicatus	palm	seeds	masticatory
	Iguanura geonomiformis	palm	seeds	masticatory
	Licuala pumila	palm	leaves	smoking
	Licuala rumphii	palm	leaves	smoking
Piperaceae	*Piper argyrites*	woody vine	bark	masticatory
	Piper bantamense	woody vine	sap from stem	beverage
	Piper betle	woody vine	leaves	masticatory
	Piper caducibracteum	shrub	leaves, bark	masticatory
	Piper methysticum	shrub	stem, roots	beverage
	Piper siriboa	climbing vine	fruiting spike, leaves	masticatory
Rubiaceae	*Coffea arabica*	shrub – tree	seeds	beverage
	Coffea canephora	shrub – tree	seeds	beverage
	Coffea congensis	shrub	seeds	beverage
	Coffea liberica	shrub – tree	seeds	beverage
	Coffea stenophylla	shrub – tree	seeds	beverage
	Diplospora kunstleri	shrub – tree	leaves	beverage
	Diplospora malaccensis	tree	leaves	beverage
	Discospermum singulare	tree	leaves	beverage
	Uncaria homomalla	woody vine	bark	masticatory
Sapindaceae	*Paullinia cupana*	shrub	seeds	beverage
Saxifragaceae	*Astilbe philippensis*	perennial herb	leaves	smoking
Solanaceae	*Nicotiana rustica*	annual herb	leaves	smoking
	Nicotiana tabacum	annual herb	leaves	smoking
	Solanum inaequilaterale	shrub	leaves	smoking
Sterculiaceae	*Cola acuminata*	tree	seeds	masticatory
	Cola nitida	tree	seeds	masticatory
	Pterospermum semi-sagittatum	tree	bark	masticatory
	Theobroma cacao	tree	seeds	beverage, food
Tiliaceae	*Microcos paniculata*	shrub – tree	leaves	smoking
Verbenaceae	*Clerodendrum villosum*	shrub	bark	masticatory

parts are processed to prepare a beverage, in about one third they are processed into a masticatory and in about one sixth they are processed for smoking. Only in the case of *Theobroma cacao* can the harvested plant parts be considered to be nutritious as well as stimulant.
The remaining sections of this introductory chapter focus on three major stimulants: tea, coffee and cocoa. The wealth of published information available for these crops and the analogies in ecological requirements and crop production practices favour a comparative approach. Though tobacco is also of major economic significance it has little in common with the other three major stimulants because it is an annual crop.

1.3.2 Growth and development

Structures and processes

Tea, coffee and cocoa belong to the group of branched perennials (shrubs/trees) with an episodic growth rhythm. This means that the extension of the shoots is not constant but fluctuates. It is an important mechanism regulating the activity and growth of the numerous meristems of the branched species and balancing the growth of aerial and subterranean plant parts. Periods of quiescence in shoot growth also permit the initiation and development of flowers and so ease the apparent antagonism between vegetative and reproductive growth. Both coffee and cocoa show a further adaptation to cope with this problem. In coffee, shoot dimorphism spatially separates the vegetative growth of the orthotropic stem and flower development on the plagiotropic branches, while in cocoa cauliflory (i.e. flowering on the stem and older branches) fulfils the same function. Absence of such an adaptation in tea has no implications for its cultivation, because the crop is a vegetative product and periodic removal of young shoots prevents flowering.
Whereas rhythmic growth of shoots is controlled by endogenous factors of individual plants, environmental factors can synchronize this growth habit at plant and population levels. In seasonal climates this leads to distinct phenological cycles of flushing, flowering, fruiting and leaf fall. Another specific feature of the branched perennials is that the mature generative phase of development is usually preceded by a juvenile phase. In cocoa, for example, young seedlings elongate their stem at about 6-week intervals with a shoot section carrying 5–7 leaves in a spiral arrangement. When the plants reach a height of 1–2 m, vertical growth ceases and up to 5 buds at the end of the stem may grow out simultaneously into side branches with distichously alternate leaves. This is the starting point of the mature phase; the rhythmic growth of branches and flowering begins. The juvenile phase is characterized by orthotropic shoot growth and the mature phase by plagiotropic branching. In coffee seedlings the juvenile phase ends when the orthotropic stem starts to produce plagiotropic branches. As the vertical growth of the orthotropic stem continues and only the plagiotropic branches flower, it is probably better to say that in coffee the juvenile phase is followed by a stage in which juvenility of the stem and maturity of the branches co-exist.

Scope for interventions

Cultivation practices cannot change rhythmic growth, but in some cases they can influence synchronization. An example is the use of irrigation after a dry period to stimulate and synchronize flowering in coffee. Periods of immaturity, however, can be shortened by cultivation practices and also by selection for early branching and bearing. Vegetative propagation using plagiotropic, physiologically mature plant material is an obvious technique to eliminate the unproductive juvenile phase. Although proper training techniques enable plagiotropic material of cocoa to be successfully used to produce early bearing plants, this practice cannot be applied to coffee. Cuttings from the plagiotropic branches of coffee produce a horizontally growing shrub that cannot be developed into an erect plant. In tea growing it is not relevant to shorten the juvenile period, so the common application of vegetative propagation is for the large-scale multiplication of superior plants.

A complex issue for agronomic interventions in the generative phase is the already mentioned antagonism between vegetative and reproductive growth. Coffee and cocoa give two contrasting models for the processes involved. In coffee, fruits are very strong sinks for assimilates. With heavy cropping these are withdrawn from leaves and branches and sometimes the reserves in stems and roots are also utilized. This may lead to a biennial cropping pattern and in extreme cases to dieback of leaves and branches. In a crop like coffee, which lacks an efficient physiological mechanism of fruit thinning, measures are needed to stimulate vegetative growth or regulate fruiting and so match the requirements for assimilates with actual supply. The reverse situation is found in cocoa, in which shoot development out-competes young fruits for assimilates. This results in the wilting of young fruits, a process which is commonly called cherelle wilt. In cocoa, measures to stimulate vegetative growth may suppress yields.

In a crop yielding a vegetative product, such as tea, cultivation measures are straightforward and should simply be directed towards maintaining a well-developed layer of photosynthetically efficient leaves that supply the reserves for continuous production of young shoots and leaves that are regularly harvested.

1.4 Ecology

1.4.1 Climatic factors

In the natural environment and the major production areas of tea, coffee and cocoa, light is one of the most important ecological factors affecting growth and development. Wild coffee and cocoa are both components of the understorey of tropical forests. Adaptation to conditions of low light intensity is still reflected in the current cultivars. Coffee and cocoa leaves have a low light saturation point associated with a low photosynthetic rate, which declines when leaves are exposed at above-optimal light levels. The ecology of the tea plant in its natural habitat is not known for certain. Tea leaves do not easily reach light saturation in full sunlight but still have a low photosynthetic rate. Exposure to full sunlight is associated with a rise in leaf temperature. When this exceeds

35°C, the net assimilation rate of tea leaves starts to decline.
The temperature and rainfall requirements for commercial cultivation of tea, coffee and cocoa are given in Table 7. Whereas both tea and cocoa produce best in humid, non-seasonal climates, coffee needs a distinct dry period for synchronized flowering and successful pollination. During the dry season water stress gradually decreases the dormancy of the flower buds and a sudden relief by rainfall or a drop in temperature triggers flowering. This is why in seasonal climates well defined cropping periods are found, with implications for labour demands and processing capacity. Seasonal flushing and cropping may play an important role in crop protection because they interrupt the life cycles of pathogens and pests.
The temperature and moisture requirements of the three crops can be met by carefully selecting the growing site, while to a certain extent cultivation practices can tune the environment to the crop requirements. Matching the prevailing light conditions with the specific requirements, however, can only be achieved by agronomic interventions such as shading and plant density and to a limited extent by breeding and selection.

1.4.2 Soils

Generally speaking, tree crops require deep, well-drained, clayey soils with a high nutrient content and a topsoil rich in organic matter. The soil should be rootable to at least 150 cm deep. The high organic matter content is important for retaining nutrients, especially in soils with a low cation exchange capacity and also as a source of mineralizable nitrogen and phosphorus. Cocoa is among the most demanding tree crops in terms of soil conditions. A special feature of tea is its requirement of acid soils with a pH of between 4 and 6.
As chemical conditions of soils can be improved by fertilizer use but physical defects can often not be amended, the soil suitability criteria for tree crops are mainly based on the presence or absence of certain physical characteristics. In sub-optimal climates, soil conditions are more critical than under optimum climatic conditions. In areas with frequent and long dry spells, for example, tree crops can only be grown on soils with much moisture storage capacity, a property mainly depending on the texture and the potential rooting depth of the soil.

Table 7. Temperature and rainfall requirements of tea, coffee and cocoa.

Crop	**Temperature** (°C)		**Annual rainfall** (mm)		**Dry months**[2]	
	Minimum[1]	**Optimum range**	**Minimum**	**Optimum range**	**Maximum**	**Optimum**
Tea	0	18–30	1200	1500–3500	1	0
Arabica coffee	5	18–24	1100	1500–2000	4	2
Robusta coffee	10	24–30	1200	1500–2000	4	2
Cocoa	10	20–32	1200	1500–2000	3	0

[1] Minimum temperature: temperature below which the crop is severely damaged.
[2] Dry month: month with less than 100 mm rainfall.
Sources: Carr & Stephens (1992), Willson (1985), Wood (1985a).

1.5 Agronomy

A special feature of the cultivation of tea, coffee and cocoa is their long economic lifetime. With adequate management and periodic 'rejuvenation', tea and coffee plantations can remain highly productive for more than 50 years, whereas the economic lifetime of cocoa may vary between 20–40 years. This gives scope for long-term investments, crop monitoring for mineral nutrition and biological control of diseases and pests. Another feature in common is the large variation in production systems and cropping intensity.

1.5.1 Production systems

The three stimulant crops are grown in systems varying from extensively managed mixed cropping systems to intensively managed home gardens and sole crop plantations. Smallholder fields are often less than 0.5 ha, while plantation areas may be well over 2000 ha.

Smallholder production systems

Smallholders play a very important role in the production of coffee and cocoa. Apart from historical events, four reasons in particular may explain the success of the smallholder sector. These are: (1) the shade tolerance of the plants which allows mixed cropping with annual and other perennial crops; (2) the simple, non-capital-intensive establishment methods and the processing techniques giving a product which can be temporarily stored on-farm; (3) an abundance of virgin forest land and labour; and (4) the rapidly expanding demand on the world market.

The development of the entirely smallholder-based cocoa production sector in West Africa highlights these points. In the last decades of the 19th century returning plantation workers brought cocoa seeds from Fernando Po to the forest belt of the West African mainland, where cocoa growing fitted well into the existing food crop shifting cultivation system. Farmers planted cocoa seeds at close spacing among their food crops. As food crop cultivation was abandoned, cocoa seedlings were left to compete with the regenerating forest which was gradually cut back, leaving a few trees as shade. Under favourable conditions, this resulted in a dense irregular stand of cocoa as a separate new component of the farming system. Encouraged by good crop growth and economic prospects, farmers started to grow cocoa in selectively thinned forests. Processing consisted of fermentation of beans in baskets or in heaps covered by banana leaves to remove the mucilage, followed by sun-drying.

Abundance of virgin forest land, availability of labour (migrant labourers), and access through nearby ports to the expanding world market further contributed to the exponential trend of the West African cocoa production in the first half of the 20th century. Government support for the farmers' cocoa cultivation was originally export-oriented: development of infrastructure to facilitate access to cocoa-producing areas, improvement of bean quality and marketing. Only after major diseases had started to threaten the existence and continuity of cocoa growing, were major investments made in research and extension (Anonymous, 1946).

The spectacular development of smallholders' cocoa in Sulawesi, Indonesia, in the late 1970s and 1980s has features in common with cocoa development in West Africa. On this island cocoa had become an almost forgotten crop. However, when the news of the cocoa boom in Sabah (East Malaysia) reached farmers in Sulawesi, the interest in cocoa revived. The presence of forest land, surplus labour migrating from densely populated areas to the forest zone and a well-developed private trade sector provided the basic conditions for the massive farmers' response to the high cocoa prices on the world market. With additional government support cocoa production rose within less than a decade from a few tonnes to about 120 000 t dry beans in 1991 (Ruf, 1994).

Smallholder coffee in Indonesia has a long history. Shortly after coffee was introduced in Java in 1696, plants were distributed to farmers. In the 19th Century there was a period in which coffee growing was compulsory. At present, smallholder coffee is mainly found on Sumatra. Growing conditions and cultivation methods vary widely: where land is scarce it is grown in home gardens as a horticultural crop and where land is abundant it is extensively grown on 'ladang' fields and partly cleared forest land. In the first years after planting it is normal practice to practice mixed cropping of coffee and food crops (Paerels, 1949).

In Indonesia, smallholder tea cultivation is a spin-off from the plantation industry. Plantation labourers and farmers in West Java were encouraged to establish tea gardens and sell their product to the estates. This outgrowers concept is currently widespread in other estate crops such as rubber and oil palm. In Kenya the smallholders' tea production is based on cooperatives that provide the farmer with planting material, inputs and management advice. The cooperatives collect the tea leaves on the farms and are responsible for the processing and marketing. This system gives a high-quality export product and a regular income to the farmers.

Generally speaking the three stimulants are 'engines of development' of smallholder farming systems. They provide households with cash income for livelihood and education and for the purchase of inputs for food crops. The revenues from the stimulants are usually not invested in the crops concerned, hence the yields remain low. As long as land is not limiting, low yields can be compensated for by cultivating relatively large areas. Population growth and increasing demands for food, however, will certainly reduce the area for cash crops and bring the need to intensify production systems.

Plantations

In sharp contrast to the smallholder sector, large-scale plantation agriculture is capital-intensive and highly dependent on external inputs. Whereas farmers direct their attention and resources to the various components of their farming system and for obvious reasons give priority to food crop growing, estates have as their major objective the growing and processing of a single crop and the maximizing of profits. A striking feature of the plantation approach is the investments in high quality planting material, land preparation and processing facilities. The latter allow production of quality products: black instead of green tea and fermented and washed instead of dry-processed coffee.

By selecting suitable environments, hiring of labour and management, and attracting capital for investment, estates have created conditions in which research has contributed to a large increase in yield per unit of land and time but to a lesser extent per unit of labour.

1.5.2 Propagation

Given the long lifetime of perennial stimulants, it is best to use high-quality plant material. This involves the production of seeds of known parentage in seed gardens, or the use of cuttings and budwood from selected 'mother' trees, as well as raising uniform plants under optimum nursery conditions. In coffee and cocoa, seedlings are mainly used. They are relatively cheap to produce, do not require early pruning, while the presence of a taproot gives them an establishment advantage over cuttings, especially in seasonal climates. In modern tea growing, cuttings have become the preferred method of propagation.

The nursery periods for cocoa and coffee are of the order of 4–6 and 6–18 months, respectively. For tea, the length of the nursery period depends on the transplanting method. Plants with adhering soil can be planted at an age of 12–24 months. Under unfavourable soil and climatic conditions, nursery seedlings are allowed to grow much longer to accumulate sufficient food reserves in the taproot and stem (stump planting method).

1.5.3 Land preparation and field planting

In extensive systems of smallholder production, land preparation for tree crops is no different from that for food crops. The fallow vegetation is slashed and burnt before plants are sown or planted directly without tillage. Mixed cropping of food crops and coffee or cocoa is common practice. In coffee this may last about one year, whereas in cocoa perennial food crops such as banana, plantain and cassava are kept longer as temporary shade. This is usually succeeded by permanent shade from regenerating forest trees and palms or planted fruit trees. When forest land is abundant, cocoa is also planted in selectively thinned forest.

The land preparation for plantations is more elaborate. After clearing the existing vegetation, cover crops are often sown to protect the soil and to maintain or restore soil fertility. In view of the high plant density used for the three crops, the cover crops will disappear after the early years of establishment. In future cocoa fields, shade trees are planted one or two years ahead of the cocoa, often with additional legume hedges for temporary shade and lateral protection. On sloping terrain, land preparation also involves terracing and/or contour planting of hedges and grass bunds.

In seasonal climates transplanting from the nursery into the field should take place early in the wet season to ensure proper establishment before the dry season starts. Plants are planted at final densities of 1000–1300 plants per ha for cocoa and coffee, and 11 000–14 000 plants per ha for tea. Following the development of dwarf cultivars high-density planting of coffee has been introduced (3300–5000 plants per ha). Some experimental high-density plantings of cocoa clones have been successful in Sabah (Yapp & Hadley, 1994). These systems require intensive management: a horticultural instead of an agricultural approach.

1.5.4 Shading

Shade requirements and effects

Tea, coffee and cocoa differ considerably in their requirements for shading (Willson, 1999). Saturating irradiances for leaf photosynthesis are much higher for tea than for coffee or cocoa, allowing most tea to be grown successfully without shade trees, except where temperatures become very high during the peak growing season (e.g. low-altitude areas in north-eastern India and Bangladesh). Arabica and robusta coffee are grown with and without shade trees, depending on the environmental conditions and crop management practices. Coffee leaves have the photosynthetic characteristics typical of shade-adapted plant species (Cannell, 1985), but cultivation without shade is often possible due to the high degree of self-shading in the deep and well structured canopies of intensively managed coffee bushes. Cocoa requires more shade than coffee. Shade is essential in the nursery and during the first years in the field to produce trees of the right shape and geometry, but it can be reduced in mature cocoa because of the self-shading effects of the closing canopies. Yield responses to fertilizers increase as shade intensity is reduced (Wessel, 1985). Nevertheless, the high yield levels of unshaded cocoa can only be sustained by high-input farming practices and under very favourable conditions of climate and soil.
Basically, shade reduces plant stress by improving climatic and soil conditions, but shade trees may also compete with the main crop for soil moisture and nutrients. Important beneficial effects to be attributed to shade in coffee and cocoa include: (1) prevention of over-bearing in coffee and excessive vegetative growth in cocoa due to partial interception of incoming light, (2) lowering of moisture stress by moderation of temperature extremes, reduction of air movement, increase of air humidity and improved availability of soil moisture and (3) amelioration of soil fertility and reduced soil erosion (Beer et al., 1998). The effects of shade on disease and pest incidence vary. For instance, diseases such as blister blight (*Exobasidium vexans*) in tea and black pod (*Phytophthora* spp.) in cocoa are favoured by shade and so is the coffee berry borer (*Stephanoderes hampei*). On the other hand, the white stem borer (e.g. *Xylotrechus quadripes*) in coffee and mirids (e.g. *Helopeltis* spp.) of cocoa always cause much more damage where the shade canopy has disappeared.

From mono-shade to agroforestry systems

When environmental conditions dictate the use of permanent shade trees in tea, coffee or cocoa, large estates generally prefer to interplant with a single species. Such trees should be tall, produce a large and even canopy, be easy to prune, have feathery leaves to give a dappled shade and compete as little as possible with the main crop for soil water and nutrients. Species used as shade trees in South-East Asia are presented in Table 8. Most belong to the *Leguminosae*, including the very widely used lamtoro tree (*Leucaena leucocephala* (Lamk) de Wit), but there are also the non-leguminous *Grevillea robusta* A. Cunn. ex R. Br. and *Cordia alliodora* (Ruiz & Pavon) Oken (which also produces high quality timber). Cocoa and robusta coffee have been successfully planted under mature coconut palms in various parts of South-East Asia, as

Table 8. Shade trees used in tea, coffee and cocoa in South-East Asia.

Scientific name	**Origin**	**Used in**		
		tea	**coffee**	**cocoa**
Albizia chinensis (Osbeck) Merrill	Asia	x	x	
Cordia alliodora (Ruiz & Pavon) Oken	Central and South America		x	x
Derris microphylla (Miquel) B.D. Jackson	South-East Asia	x	x	x
Erythrina fusca Loureiro	tropics		x	x
Erythrina poeppigiana (Walp.) O.F. Cook	South America		x	x
Erythrina subumbrans (Hassk.) Merrill (syn.: *E. lithosperma* Miquel)	South and South-East Asia	x	x	x
Erythrina variegata L. (syn. *E. indica* Lamk)	South Asia		x	x
Gliricidia sepium (Jacq.) Kunth ex Walp.	Central America	x	x	x
Grevillea robusta A. Cunn. ex R. Br.	Australia	x	x	
Leucaena diversifolia (Schlecht.) Benth.	Central America		x	x
Leucaena leucocephala (Lamk) de Wit (syn.: *L. glauca* (Willd.) Benth.)	Central America	x	x	x
Paraserianthes falcataria (L.) Nielsen (syn.: *Albizia falcata* sensu Backer)	South-East Asia	x	x	x
Parkia spp. (e.g. *P. singularis* Miquel)	tropics		x	
Senna siamea (Lamk) Irwin & Barneby (syn.: *Cassia siamea* Lamk)	South and South-East Asia	x	x	

Sources: Faridah Hanum & van der Maesen (1997), Willson (1999).

the gradually diminishing crowns of the tall palms provide just the right degree of shade (e.g. Ramadasan et al., 1978).

Coffee and cocoa can also form part of agroforestry systems. Much of the arabica and robusta coffee in South India is effectively grown in a multicropping system with pepper (*Piper nigrum* L.), and often also with some clove (*Syzygium aromaticum* (L.) Merrill & Perry) and mandarin (*Citrus reticulata* Blanco) trees, under a double shade canopy of *Erythrina variegata* L. and thinned natural forest or planted *Grevillea robusta* trees (Kurikanthimath et al., 1994). The combination of robusta coffee and pepper under shade is also found on Sumatra, Indonesia. Various studies have described the socio-economic and ecological advantages of smallholder coffee and cocoa production in agroforestry systems in Central America (Beer et al., 1998) and West Africa (Herzog, 1994). With few external inputs yields of coffee or cocoa will be modest but regular, while the added revenue from timber, firewood, fruits and other products will help to make farmers less financially vulnerable to fluctuations in world market prices.

1.5.5 Fertilizer use and mulching

The nutrient requirements and fertilizer recommendations are well established for tea, coffee and cocoa (de Geus, 1973).

For a leaf crop such as tea, the most important fertilizer nutrient is nitrogen. In unshaded tea there is a linear response to nitrogen up to a rate of 120 kg N per ha or more. Provided that other nutrients, especially P and K, and environmental conditions are not yield-limiting factors, responses are of the order of 4–8 kg processed tea per kg applied N. With regard to coffee, nitrogen and potassium are particularly required by the ripening crop. Adequate nitrogen is essential for optimum photosynthesis that has to provide the carbohydrates to the developing crop directly or through accumulated reserves. Under conditions of serious carbohydrate shortage, twigs may die back; applications of nitrogen and also of potassium have been found effective to control this physiological disorder. The low-yielding and shaded smallholders' cocoa has low nutrient requirements. When yield levels of 700 kg dry beans per ha or more have been reached with good management, a response to added P can be expected (Wessel, 1972, 1985). This is not the result of high P requirements but of the generally low availability of P in the soil. With little or no shade, cocoa will generally respond to N application, while with high yields additional K may also be needed.
The nutrient requirements of the three crops depend on light conditions and their production capacity, as determined by environmental and genetic factors.
Foliar analysis plays an important role in the assessment of fertilizer needs of perennial crops. Once critical nutrient concentrations and ratios in leaves have been established in fertilizer trials, these can be used to assess the fertilizer requirements in field plantings. By periodically sampling leaves and analyzing trends in nutrient concentrations, the effects of fertilizer use can be assessed and application rates be amended if needed. Apart from the external supply, nutrient levels are also influenced by the age and position of the leaf, light and other environmental conditions, and by cultivar. Therefore strict sampling procedures have to be followed. Although foliar analysis is widely used in tea and coffee, it is of little practical value for cocoa because large variations in light conditions occur within plantings and, as not all branches flush simultaneously, leaf age cannot be determined by leaf position. A practical problem is that the leaves to be sampled are mainly found in the upper canopy of 2–4 m tall trees.
Mulching generally helps perennial crops to establish. This is especially true in drier areas with light textured soils and a long cropping history. Mulch improves the root environment by reducing moisture losses and soil erosion, by lowering soil temperature and by improving the physical and chemical condition of the soil. The response to mulching of young, particularly unshaded coffee is often considerable (Mitchell, 1988). Mulching of young coffee is a widespread practice in Kenya, where cut elephant grass (*Pennisetum purpureum* Schumach.) is usually used at rates as high as 25 t dry matter per ha per year. Bottlenecks in this system are the need to set aside land for mulch production, the transport of large amounts of organic material and the labour involved. Applying a heavy mulch with a high C/N ratio tends to depress the availability of soil nitrogen, making additional nitrogen necessary. Application of mulch during the dry season increases the risk of fire.

1.5.6 Pruning

As the general principles of pruning of woody perennials have been dealt with in Prosea volume 2 'Edible fruits and nuts' (Verheij & Coronel, 1991), this sec-

tion will highlight only the differences in pruning requirements of the three major stimulants.
It is essential to prune coffee. Over time, fruiting shifts from the inside to the edges of the shrubs, so they become too tall and the branches become too long for optimum production and management. Although checking the growth of plagiotropic branches by pruning can temporarily remedy this situation, periodic stumping is needed to rejuvenate the entire bush. This drastic replacement pruning leaves only the basal part of the main stem, encouraging dormant buds to grow out into new orthotropic shoots that later bear the plagiotropic branches. The prolific fruiting of coffee and the strong sink function of the fruits account for the positive yield response to pruning, while the strict dimorphism allows coffee to be repeatedly rejuvenated by periodic stumping.
In tea, repeated pruning of shoots and branches starts at an early stage, in order to achieve a bush of a spreading habit and of a convenient height for plucking. The harvesting of leaves is itself a form of pruning, in which a careful balance is sought between the leaves removed and the retained maintenance foliage. The removal of apical shoots by plucking encourages active growth of secondary shoots which are harvested later on. To keep the plant permanently in a productive vegetative stage and to keep the height of the plucking table within workable limits, periodic pruning is needed in which most of the foliage and some of the branches are cut. The severest form of pruning is collar pruning, in which the bush is cut near ground level. Tea's potential to recover fully from pruning explains why century-old plantings are still productive.
Cocoa seedling trees need little pruning. Once the jorquette (3–5 plagiotropic fan branches) is formed, only low and inward growing branches are cut and orthotropic shoots removed. For ease of harvesting some secondary plagiotropic branches in the centre of the tree are removed as well. More intensive pruning often reduces yield. Stimulating vegetative growth it shifts the balance between vegetative and generative development in favour of the former. Studies of the shaping and training of young plants budded with plagiotropic material have shown, however, that there are genetic differences in the responses to pruning. Some clones respond mainly with strong vegetative growth whereas others combine moderate vegetative growth with prolific early fruiting (Pang et al., 1994). This is in line with the view that favourable effects of pruning can only be expected in trees with a high fruiting capacity (Verheij & Coronel, 1991).

1.5.7 Crop protection

Large-scale planting of sole crops favours the development of diseases and pests. This applies also to tea, coffee and cocoa.

Disease control

The three crops suffer from diseases affecting roots, trunks and branches, foliage and fruits. Control techniques include cultural and chemical methods as well as the use of host resistance. At national and regional level, introduction and spread of diseases can be prevented by quarantine and health inspection. At field level, disease prevention starts with removal of sources of infection, e.g. the removal of roots and stumps infected by fungal root diseases and the sanitary harvest of infected fruits. Ensuring optimal growing conditions is an effective tool in limiting disease incidence, while deliberate pruning and shade management enables a microclimate to be maintained that is not conducive to the development of fungal diseases.

Chemical control is widely used in the three stimulants, but similar to current practice with insecticides, routine preventive spraying has given way to treatments applied in response to observed disease incidence. In certain cases, frequent spraying is essential, e.g. for the control of black pod disease (*Phytophthora* spp.) in cocoa under very humid conditions, where pods need a permanent protective coating of fungicide.

The use of resistant plant material is by far the best method of disease control. When after 1870 coffee leaf rust destroyed the arabica coffee in Asia, the only solution was to plant the resistant *Coffea canephora*. Since then, resistance breeding has progressed and has resulted in arabica cultivars that combine resistance to major coffee diseases with desired agronomic and quality traits (van der Vossen, 1985). Searching for disease resistance has been the major incentive for the collection of genetic material in the centres of diversity and for the establishment of germplasm collections.

Whereas on estates most diseases and pests can be effectively controlled, crop protection in extensive production systems often faces severe problems. Various factors play a role. Abandoned fields and isolated trees are sources of infection and breeding spots for pests. Furthermore, control treatments in usually small individual fields are only effective if neighbouring fields are treated as well. Another smallholder problem is that revenues of cash crops are used for direct household needs and not to purchase inputs.

Pest control

Although chemical control of certain pests has been effective, negative effects have also been observed, especially where broad spectrum insecticides have been applied and pests have proved to be less susceptible to treatments than their natural enemies.

A contrasting approach makes use of the stable environment of perennial crop fields with its diverse populations of pests and predators. Integrated Pest Management (IPM) is based on simultaneously applied methods of chemical, cultural and biological control to keep pest populations below the threshold of economic damage. IPM techniques, based on studying population dynamics of the insect pests with their natural enemies and establishing threshold values for insecticide treatments, were developed successfully for arabica coffee in East Africa (Bardner, 1985). In a leaf crop such as tea, cultural and biological control techniques are especially important to avoid insecticide residues in processed tea and negative effects on flavour, but IPM in tea is not yet well advanced.

An interesting example of a biological control system is the control of mirids (*Helopeltis theivora*) in cocoa in Indonesia and Malaysia, which dates back to the first decades of the 20th century (Giesberger, 1983). It involves the presence on twigs and pods of the black cocoa ant (*Dolichorus thoracicus*) which uses honeydew produced by the white cocoa mealybug (*Cateanococcus hispidus*) as its food source. The black cocoa ant disturbs *Helopeltis* adults to such an extent that feeding and reproduction are impeded. Black ants and mealybugs only thrive well in shaded conditions provided by shade trees or a well developed closed cocoa canopy. Ants can be introduced into fields by transferring nests and using tree branches and palm fronds as bridges between already colonized and not yet colonized cocoa trees.

Examples of recent developments in biological control in coffee include the use of an entomopathogenic fungus (*Beauveria bassiana*) and exotic parasitoids (e.g. *Cephalomonia stephanoderis*) against the coffee berry borer (Bheemaiah et al., 1996; Bustillo et al., 1995) and the use of pheromone-baited traps against the white stem borer (Hall et al., 1998).

1.5.8 Trends in crop production

High-density planting of dwarf trees is an important common trend for temperate fruit orchards and tropical tree crop plantations. Small trees are easier to maintain and to harvest, while smaller supporting frames have lower assimilate use for maintenance respiration, reduced competition from vegetative growth and require less pruning. Increased plant densities give higher yields per unit area. At high densities, individual trees have only limited crown space. To ensure adequate interception of light energy under these conditions there must be optimum penetration of light to leaves in the lower part of the canopy. With the successful development of compact-growing and disease-resistant cultivars, high density planting has become general practice in arabica coffee (Charrier & Eskes, 1997). Compact cultivars are not yet available in robusta coffee, but the first reports from India of really compact plant types selected in progeny of a cross between *Coffea congensis* and *C. canephora* are encouraging (Srinivasan, 1996).

Research in high-density clonal cocoa fields in Sabah, Malaysia, indicates that once the canopy has closed it is not light interception but light distribution within the canopy that becomes a yield-limiting factor (Yapp & Hadley, 1994). Vigorous clones at high density tended to produce strong, upward-growing fan branches, causing congestion of mutually shaded leaves in the top of the canopy and thus reducing incident light on the lower leaves to levels below the light compensation point. Less vigorous, semi-dwarf clones on the other hand had a crown architecture allowing light penetration in the canopy. They had lower light extinction coefficients and far out-yielded the vigorous clones. Despite these favourable results, the commercial advantage of planting these semi-dwarf clones is still doubtful (Pang et al., 1994). Contrary to the needs of plantations, the low-input smallholder field sector requires vigorous cultivars. During establishment they have to compete with weeds, and initially and often also later on with associated other crops.

The future of the smallholder cocoa in West Africa has been an important issue since the 1980s. Because the cocoa trees are getting old, very large areas are due for replanting. Although many farmers are technically capable of turning replanted areas into modern high-input cocoa holdings, they lack the resources to do this. An alternative approach is to diversify the replanted cocoa fields systematically in low-input agroforestry systems with timber and fruit trees in addition to cocoa. The fluctuating cocoa prices, the demand for timber and the

shade tolerance of cocoa make the development of improved traditional multistrata systems a feasible option.
In tea, high-density planting is now common practice, and here too the importance of light distribution within the shrub has been recognized. China teas with semi-erect leaves have the potential of producing higher yields than Assam types (Hadfield, 1968). However, it is not only photosynthetic efficiency that plays a role, but also the fact that the semi-erect types produce a much higher number of shoots per unit area than the horizontal leaf types (Tanton, 1992).

1.6 Harvesting and processing

1.6.1 Harvesting

The plant parts harvested vary from young leaves to seeds, according to species (see Table 6), but manual harvesting is the predominant practice for all stimulant crops. Selective harvesting at the right stage of maturity is often essential for obtaining a product with the optimum composition of stimulant and other quality-determining components.
Manual harvesting is very labour-intensive for crops requiring regular harvesting rounds during several months of the year. In tea (Willson, 1992), coffee (Mitchell, 1988; Snoeck, 1988) and cocoa (Lass & Wood, 1985) the cost of harvesting alone may account for 30–50 % of total field production costs. Saving on harvesting costs by mechanization can have a direct bearing on profitability of larger estates, but not so much in the case of smallholders where the family provides most of the labour. Cocoa does not lend itself to mechanization of harvesting operations, except possibly the opening of pods after removal from the trees. However, in tea and coffee mechanical harvesting with hand-operated, tractor-mounted or self-propelled machines has found application in a few countries, where labour is in short supply or increasingly expensive and where demands for a quality product are less stringent. Examples are coffee in Brazil and tea in Japan (green tea) and Argentina. On the other hand, more than 80% of all coffee in the world is produced by smallholders, and most of the plantation tea is grown in countries where labour is abundant and still relatively inexpensive. The production of tea, coffee and cocoa will therefore continue to depend mostly on manual harvesting, just as in the case of all other stimulant crops.

1.6.2 Post-harvest handling and processing

For many stimulants, post-harvest handling involves little more than cleaning and drying to a lower moisture content to improve storability. A few stimulant crops are subjected to a more extensive post-harvest treatment. For instance, guaraná seeds are roasted and ground to a paste, maté leaves are heated in a furnace before further drying and grinding and areca nuts, when not consumed fresh, are sliced and boiled before drying for the purpose of preservation.
Tobacco leaves are subjected to various curing processes, from quick drying over hot air or open fire to slower sun- and air-drying, depending on whether they will be used as cigarette, pipe or cigar tobaccos. These curing processes demand technical skill and expertise, but otherwise require relatively modest and

inexpensive facilities. However, the manufacture of cigarettes in particular involves a large industrial set-up with sophisticated machinery.

Curing, processing and manufacturing of tea, coffee and cocoa

The three major stimulants have to undergo several stages of curing and processing before the final products can be offered to the consumers (Hampton, 1992; Wood, 1985b, 1985c; Wrigley, 1988). Most of these are very specific to the particular commodity, but a comparative analysis as presented in Figure 3 indicates considerable analogy in a number of curing and processing stages. Green tea and unwashed coffee have been left out for reasons of simplicity, but will be referred to in the text below.

The harvested products of tea and coffee should undergo the first step of the curing process, withering for tea and pulping in the case of coffee, on the same day to avoid loss of quality. However, for cocoa an interval of 2–3 days between harvesting and opening of the pods to remove the beans may even have a beneficial effect on the fermentation process.

Fermentation in coffee and cocoa involves degradation of the mucilage surrounding the beans by the activity of naturally occurring micro-organisms, which takes about one day for coffee and 4–6 days for cocoa. Proper fermentation in cocoa and fermentation of coffee in combination with subsequent washing and soaking in water is essential to obtain a high quality product. Fermentation in tea is actually a process of enzymatic oxidation of the polyphenols, which results in the formation of several constituents giving black tea its specific flavour and brown colour. The whole curing process for tea lasts less than two days, including forced drying to about 3% moisture content (this drying process is called firing) and packing as graded tea. The same process lasts about 10–14 days for coffee and cocoa, partly because of the need for gradual drying in the sun or by artificial dryers to a moisture content of about 10% for coffee and 6% for cocoa beans. In the case of coffee there is a second stage of curing, lasting a couple of days and usually carried out in large coffee mills, to convert the parchment coffee into cleaned and graded 'green' coffee.

In the curing process of green tea the leaves are fired or steamed, which destroys the enzymes and so prevents oxidation of the polyphenols. Green teas are therefore more astringent and have a different flavour. Dry-processed coffee, dried as whole fruits without prior pulping and fermentation, is called unwashed or cherry coffee. The quality is almost always inferior to washed coffees.

The curing of tea, coffee and cocoa is always carried out in the producer countries within short distance from the production fields. Further processing and manufacturing into the final products generally occurs close to main centres of consumption.

In the case of tea, the conversion from cured to final products is a relatively simple process, involving mainly blending and retail packing, which does not contribute to large increases in added value of the final product.

In contrast to tea, coffee and cocoa are largely export products (Table 3). The processing into final products requires substantial industrial investments and takes place mostly in the industrialized consumer countries. The added value of final products of coffee and cocoa is generally several times that of the imported cured product. Brazil and a few other coffee-producing countries have

Stage	Tea (black)	Coffee (washed)	Cocoa
Harvested products	fresh leaves/shoots	ripe berries	ripe pods / wet beans + pulp
Curing	**Tea factory** withering cutting, rolling fermentation drying, firing sorting packing *duration: 1-2 days*	**Coffee factory** pulping fermentation washing drying bagging *duration: 10-14 days* **Coffee mill** hulling grading sorting bagging *duration: 1-2 days*	**Cocoa factory** fermentation drying sorting bagging *duration 10-14 days*
Cured products	graded black tea (in 40 kg chests or laminated bags)	green coffee beans (in 60 kg bags or aerated containers)	cured cocoa beans (in 65 kg bags or aerated containers)
Further processing and manufacturing	**Tea packers** blending retail packing	**Roasters** blending roasting grinding and packing production of soluble coffee	**Grinders & manufacturers** cleaning roasting and shelling grinding pressing milling, mixing manufacturing
Final products	loose tea tea bags	roast whole coffee beans ground roast coffee instant coffee	cocoa butter fat high fat cocoa powder low fat cocoa powder chocolate bars chocolate confectionery

Figure 3. Processing stages in tea, coffee and cocoa.

developed a sizable capacity for the production and export of instant coffee, but limited shelf-life prevents the development of an export-oriented local industry for roast coffee. In cocoa the situation has changed considerably during the last decade with the development of a cocoa grinding industry producing intermediate products such as cocoa liquor, butter fat and powder. At present about 30% of all cocoa produced is processed in that manner by local cocoa grinders before export to consumer countries.

1.7 Genetic resources and breeding

1.7.1 Genetic resources

Access to substantial genetic variability is essential to successful crop improvement. Germplasm collection, conservation and characterization is actively pursued in the four economically most important stimulants: tea, coffee, cocoa and tobacco. Other stimulants whose genetic resources are receiving some attention from national research centres are maté, guaraná, kava, areca palm, betel pepper and kola.

Tea

The germplasm collections present in the main tea research centres in Asia and Africa have generally provided sufficient genetic variation for considerable selection progress in yield and other agronomic characters, except host resistance to important diseases and pests. Recent collections of 'wild' plants of *Camellia sinensis* var. *sinensis* in the Yunnan province in China have yielded very interesting genotypes. Systematic collection in major centres of genetic diversity (Assam – Burma (Myanmar) area and southern China) should receive high priority to preserve tea genetic resources for future use (Banerjee, 1992a).

Coffee

The first systematic efforts to collect *Coffea arabica* germplasm by a Food and Agriculture Organization of the United Nations (FAO) mission to Ethiopia in 1964 had the real intention of international collaboration and the resulting accessions were distributed worldwide to all coffee research centres (Meyer et al., 1968). The 'Institut de recherche pour le développement' (IRD, formerly ORSTOM) made several collecting expeditions in the period between 1966 and 1985 to all important centres of genetic diversity for several *Coffea* species in Africa and most of those accessions are maintained as field collections in Ivory Coast, Cameroon and Madagascar (Berthaud & Charrier, 1988). There are also large collections of *C. arabica* germplasm in Ethiopia (Bellachew, 1998). Nevertheless, the free exchange of coffee germplasm is hampered by the fact that none of the collections have an international status and the International Plant Genetic Resources Institute (IPGRI) has not yet been given the opportunity to develop an effective network of collaboration on coffee genetic resources (van der Vossen, 1997).

Cocoa

There is a long and intensive history of germplasm collection from the centres of genetic diversity in the Amazon basin, commencing in 1937 with the expeditions led by F.J. Pound of Trinidad. At present, there are two large international cocoa germplasm collections in Trinidad (CRU) and in Costa Rica (CATIE) and several national collections in cocoa research centres elsewhere (End et al., 1992). The IPGRI plays an important role in promoting an international network for the optimal utilization and conservation of cocoa genetic resources (Eskes et al., 1998).

Ex situ germplasm conservation for tea, coffee and cocoa

Conservation in seed banks has not (yet) been possible for these tree crops, so instead there is reliance on expensive field collections. Cryo-preservation of seeds, embryos or meristems may eventually become a practical method of germplasm conservation, and progress in that direction has been reported recently for coffee (Dussert et al., 1998). Attempts to conserve genetic resources in situ, such as once proposed for *C. arabica* in Ethiopia, usually have to be abandoned under pressure from advancing deforestation and food crop production.

Tobacco

The United States Department of Agriculture (USDA) in particular, but also research centres elsewhere in the world, have made extensive collections of wild and domesticated tobacco germplasm. The exploitation of genetic diversity present in diploid *Nicotiana* species is also facilitated by the relative ease of introgression of useful genes into *N. tabacum* by interspecific hybridization (Wernsman & Rufty, 1988). The extreme longevity and small size of the seeds also allows relatively inexpensive and long-term conservation of tobacco germplasm in seed banks.

1.7.2 Breeding

The general objective of plant breeding is to develop crop cultivars with the potential of providing maximum economic benefits to the growers. This usually requires simultaneous selection for plant type and vigour, yield, quality and other characters. If diseases and pests have become a threat to the profitability or even survival of the crop, resistance to these may assume the highest priority in breeding. Selection progress depends on the breeding plan applied, which in turn is largely influenced by the species' life cycle (annual or perennial) and mating system (self- or cross-pollinating). Cross-pollinating species or outbreeders have in common that they are highly heterozygous and often intolerant of strong inbreeding (Simmonds, 1981, 1992).

Practically all woody perennials are outbreeders, including tea, all diploid (e.g. robusta and liberica) coffees, cocoa, kola, areca palm, maté and guaraná. The only exception is the allotetraploid arabica coffee, which is a self-pollinating species just as the annual tobacco.

There are reports on efforts of mass selection for higher yield in kola, maté, guaraná, areca palm and betel pepper, but systematic breeding programmes have been implemented only in the four main stimulants (tea, coffee, cocoa and tobacco). In the three tree crop stimulants there are interesting analogies in the opportunities and limitations of crop improvement that justify further elaboration below.

Early breeding in tea, coffee and cocoa

The long productive life-span of these tree crops and high costs of replanting have been main obstacles to quick genetic improvement. Consequently, most of the production of tea, coffee and cocoa is still based on cultivars released five to eight decades ago from relatively simple breeding and selection programmes.

The majority of the cultivars of the outbreeding tea, robusta coffee and cocoa are produced as open-pollinated seeds from phenotypically selected seedlings (open-pollinated varieties) and from poly- or biclonal gardens (composite or synthetic varieties). Clones offer the opportunity of instant fixation of superior genotypes and high degree of plant uniformity, but the logistics of mass propagation and distribution are often too complex for smallholder production systems, which dominate in coffee and cocoa. Clonal cultivars are also more widely used in tea than in robusta coffee and cocoa, largely because the propagation of tea cuttings is relatively simple and inexpensive. Cultivars of the inbreeding arabica coffee are almost always propagated from seed, as they are true-breeding lines developed from single plant selections from growers' fields or from progenies of simple crosses and backcrosses.

Yield, quality and plant vigour have always been dominant selection criteria in tea (Visser, 1969) and robusta coffee (Charrier & Berthaud, 1988), but in some early breeding programmes disease resistance was already given high priority in cocoa (witches' broom in Trinidad, swollen shoot in West Africa) and arabica coffee (leaf rust in India) to ensure long-term survival of the crop (Srinivasan, 1996; Toxopeus, 1969).

Recent advances in tea, coffee and cocoa breeding

Breeding programmes with systematic crossing designs and statistically laid out field trials of the last 30 years, in coffee and cocoa in particular, have provided opportunities for biometrical genetic analyses of yield and other agronomic characters. There is considerable evidence that the genetic variance for almost all components of yield, quality and other quantitative traits is predominantly due to additive gene effects. This should facilitate the estimation of parental breeding values and speed up selection. Hybrid vigour for yield noticed in crosses between parents of different origin appears to be the result of the accumulation of additive effects of polygenes dispersed over sub-populations. Some breeding programmes in robusta coffee (Charrier & Eskes, 1997) and cocoa (Eskes & Lanaud, 1997; Lockwood & Pang, 1994) have already adopted methods of reciprocal recurrent selection with distinct sub-populations to increase chances of producing genotypes superior in yield, quality and other important traits. However, resistance to important diseases has become a breeding objective of the highest priority in many cocoa-producing countries.

There appears to be considerable scope for achieving satisfactory levels of resistance to one or more diseases according to regional priorities, notably in witches' broom, black pod, vascular-streak dieback and swollen shoot diseases. A prerequisite is the availability of efficient pre-selection tests for host resistance, and sometimes pre-breeding (recombination crosses) may be necessary to improve the resistance levels of breeding parents before these are integrated into the main breeding programme (van der Vossen, 1996).

In tea there is a general lack of biometrical data on the inheritance of yield and quality components, but hybrid vigour for yield in inter-population (e.g. China and Assam teas) crosses has been well documented. So far, no progress has been made in breeding for resistance to blister blight disease in the absence of suitable sources of host resistance (Banerjee, 1992b).

In arabica coffee, disease resistance continues to be a breeding objective of the highest priority. Efforts to obtain durable resistance to coffee leaf rust have had a long history of initial successes followed by disappointments because of repeated appearance of new virulent races of the rust fungus, but some lines of the cultivar Catimor have shown complete resistance so far (Bettencourt & Rodrigues, 1988). These results were obtained by breeding plans normally applied to self-pollinating crops, including recombination crosses followed by back crossing, inbreeding and line selection. A similar plan was initially also applied in a breeding programme in Kenya to obtain resistance to coffee berry disease. The resistance turned out to be controlled by a few major genes but was nevertheless also persistent. The switch to breeding strategies to produce F_1 hybrid (seed) cultivars instead of clones or true breeding lines was partly inspired by the confirmation of transgressive hybrid vigour in genetically divergent crosses in arabica coffee (Walyaro, 1983). Other advantages were the chances of earlier introduction of cultivars with resistance to both coffee berry disease and leaf rust, as well as several other desirable agronomic characters (van der Vossen, 1985). Interspecific hybridization has played a significant role only in coffee. Examples are crosses between *C. arabica* and *C. canephora*, with the objective of introgressing disease resistance into arabica coffees, e.g the cultivar Icatu in Brazil (Carvalho, 1988), or improved liquor quality into robusta coffees, e.g. the cultivar Arabusta in Ivory Coast (Cambrony, 1988). Examples of interspecific hybridization leading to successful cultivars in arabica and in robusta coffee can also be found in India (Srinivasan, 1996).

Opportunities of molecular breeding in tea, coffee and cocoa

In the past decade in particular, plant biotechnology has evolved into an applied science providing powerful additional tools for plant breeders, enabling them to increase efficiency and take new approaches to hitherto unattainable objectives.

There are basically two main applications of plant biotechnology in crop improvement programmes: molecular markers and transgenic plants.

Molecular marker technology in plants has found applications in all phases of plant breeding programmes, including: (1) germplasm management, (2) measuring genetic divergence of sub-populations (e.g. to predict heterosis), (3) gene introgression (possible reduction of number of backcross generations), (4) marker assisted selection (MAS) and (5) cultivar identification and purity testing.

MAS enables early selection of a trait by selecting for a molecular marker closely linked to the gene(s) controlling the trait. For characters inherited through one or few major genes (e.g. disease resistance) closely linked markers have been identified. MAS can be particularly effective in the accumulation of resistance genes in one genotype to raise the level of resistance and increase chances of durability (gene pyramiding) and the simultaneous selection for different disease resistances. Where the trait is controlled by polygenes and the heritability is rather low, a more complex quantitative trait loci (QTL) analysis is required to determine the location on the chromosomes of markers linked to the polygenes controlling the trait. A prerequisite for such a QTL analysis is the availability of a saturated genetic linkage map (Mohan et al., 1997; Stam, 1994).

Molecular markers have been applied to germplasm characterization and identification of genetic diversity between sub-populations in tea (Paul et al., 1997), coffee (Lashermes et al., 1996) and cocoa (Lerceteau et al., 1997). The first genetic linkage maps have already been constructed for coffee (Paillard et al., 1996) and cocoa (Lanaud et al., 1995). Reports on the potential application of MAS have appeared for cocoa (Crouzillat et al., 1996), notably a QTL analysis for black pod resistance, and for arabica coffee (Agwanda et al., 1997) on molecular markers linked to one of the major genes determining resistance to coffee berry disease.

Generally, successful genetic transformation is still limited to characteristics controlled by single major genes for which gene isolation and transfer is relatively easy (e.g. herbicide, pest and disease resistances). Lack of adequate legislation for proprietary rights and biosafety in many countries is still an obstacle to the introduction and unrestricted cultivation of transgenic crop varieties. Some governments are reluctant to act, under pressure from a rather negative public perception of biotechnology in general.

Techniques of in vitro regeneration of plants (somatic embryogenesis) and genetic transformation are still in the initial stages of development in cocoa (Eskes & Lanaud, 1997), but by now these are well-established in coffee (Charrier & Eskes, 1997). Transgenic coffee plants have been produced already, e.g. with insect resistance (based on Bt genes) and with caffeine-free beans (inhibition of caffeine accumulation by anti-sense gene expression). Nevertheless, for the aforementioned reasons it is uncertain whether transgenic coffee cultivars will be widely grown within the next one or two decades.

1.8 Prospects

1.8.1 Supply and demand

The total demand for the universally popular stimulants tea, coffee and cocoa will continue to grow steadily, if only because of an ever increasing world population. However, due to accelerated expansion of traditional and new production areas over the last 15 years, especially for coffee (e.g. robusta coffee in Brazil and Vietnam) and cocoa (e.g. Indonesia and Ivory Coast), supplies are often in excess of demand, causing declining world market prices and consequent loss of revenues for growers and producing countries. The situation appears more stable in the case of tea due to the buffering effect of huge and still grow-

ing internal markets for this stimulant in the most important producing countries (India, China and Indonesia).
Past international coffee and cocoa agreements between producing and consuming countries, aimed at regulating supplies and stabilizing prices, have not usually endured for long periods of time, more often than not because of economic or political conflicts of interest. Recurring abiotic (frost or drought) and biotic (diseases and pests) disasters in major coffee and cocoa producing countries have been important factors contributing to a temporary restoration of the balance of supply and demand and accompanying recovery in prices. There are no indications that these large fluctuations in supplies and market prices for coffee and cocoa will diminish in the short to medium term.
The tobacco market is generally less volatile, partly because the annual nature of the crop allows quicker response to changes in demand and supply. Public awareness of health risks of tobacco smoking is still small outside Europe and North America and it has certainly not had any impact so far on the steadily increasing tobacco markets in Asia.
The areca nut in combination with betel pepper will continue to be an economically important stimulant in South and South-East Asia, but the demand may gradually decrease as its popularity with the younger generations is waning. The exotic kola, maté and guaraná are unlikely to become significant stimulants in Asia.

1.8.2 Research

The scope for further enhancing economic returns of tea, coffee and cocoa production, through genetic, crop physiological and agronomic research, is still considerable. Annual yields of 3 t per ha in tea and 4–5 t per ha in coffee and cocoa have already been realized experimentally and even higher yields are envisaged in the longer term by applying molecular marker techniques to exploit available genetic resources still more efficiently. Molecular biology appears to becoming a powerful tool too for achieving host resistance to crop-threatening diseases and pests that have so far eluded all efforts of plant breeders. Such resistance, sometimes in combination with biological means of control, would contribute much to reducing production costs and environmental hazards of pesticide use. Blister blight and mites in tea, leaf rust and berry borer in coffee, black pod and pod borer in cocoa are just a few examples of major crop-limiting biotic factors.
Nevertheless, the impact of innovative genetic and agronomic advances is almost always much greater in commercial plantations. Tea is mostly an estate crop, whereas more than 80% of the world coffee and cocoa is produced by small farmers, who do not usually have easy access to improved agricultural inputs to sustain economic yields. After the first few years of production – when the new planting may benefit from the high organic matter content and mineral reserves of recent forest clearings, as well as from relative absence of diseases and pests – yields decline generally to less than one quarter of that of high-input coffee or cocoa plantings. In actual fact, the tremendous growth in the world supply of coffee and more particular of cocoa has been much less the result of increased productivity than of area expansion, often at the expense of tropical forests. Research priorities in coffee and cocoa should, therefore, also

include the development of more productive and sustainable smallholder production systems, which resemble forest ecosystems and help to arrest further destruction of natural resources. Of course, successful farmers' adoption of such socio-economically viable and environment-friendly production systems will very much depend on the political determination to provide effective extension services, good infrastructure and easy access to essential inputs.

2 Alphabetical treatment of genera and species

Areca catechu L.

Sp. pl.: 1189 (1753) ('cathecu').
PALMAE
$2n = 32$

Vernacular names Areca palm, areca nut palm, betel palm, betel nut palm (En). Aréquier (plant), noix d'arec (fruit) (Fr). Indonesia: pinang (Indonesian), jambe (Javanese, Sundanese), pua (Lesser Sunda Islands, the Moluccas). Malaysia: pinang. Papua New Guinea: buai. Philippines: bunga (Tagalog, Bisayas), takotob (Bikol), boa (Iloko). Cambodia: sla, daëm sla. Laos: kôk hma:k. Thailand: mak (general). Vietnam: cau, binh lang, t[aa]n lang.

Origin and geographic distribution The exact origin of *A. catechu* is not known, but most probably it originated from central Malesia where it is known to be of very ancient cultivation and where variability of the genus *Areca* L. is greatest. *A. catechu* is only known from cultivation. Seemingly wild plants have always turned out to have been planted or distributed by humans. The cultivation of areca palm had spread from Malesia to the Indian subcontinent in pre-historic times and this spread was to continue later, although slower. At present areca palm is cultivated pantropically but is of greatest importance in South and South-East Asia, where it is grown in almost every village garden.

Uses Throughout Asia and the Central Pacific the fresh or dried endosperm of ripe and unripe seeds ('nuts') of areca palm is chewed as a stimulant, alone or in combination with a leaf of betel pepper (*Piper betle* L.) and some slaked lime. In South-East Asia, the usual practice is to wrap pieces or slices of the nut in fresh betel pepper leaves that are sprinkled or smeared with lime. Other ingredients may be added to the betel quid, including gambier (*Uncaria gambir* (Hunter) Roxb.), tobacco, palm sugar and various spices, such as cardamom (*Elettaria cardamomum* (L.) Maton) and clove (*Syzygium aromaticum* (L.) Merrill & Perry). Very important is that the quid is spat out, not swallowed. The mixture is also taken after meals to sweeten the breath. Chewing the quid is said to increase the production of saliva (which is blood-red in colour) and gastric juices and thus to aid digestion. It is also an appetizer. However, excessive chewing may result in loss of appetite, continuous salivation and general deterioration of health. After years of chewing, teeth may become nearly black. In parts of India, Thailand and Malaysia, the offering and chewing of areca nuts fulfils an important religious and social function. Some 200 million people throughout the western Pacific basin and southern Asia chew betel regularly.

The nut of areca palm is widely used in Asian medicine, e.g. as a vermifuge for humans and animals, as an emmenagogue, as a cure for diarrhoea, urinary disorders, edema and lumbago. It is credited with, among others, astringent, tonic, digestive and bechic properties. The nut is applied externally to ulcers, sores, wounds, swellings and skin diseases. The husks, young shoots, buds, leaves, and roots also have medicinal uses. Tender shoots (the upper part or 'cabbage' of the young stem) are edible and are cooked in a syrup. The central bud or palm cabbage is sometimes eaten, though it may be rather bitter. In Java, the cabbage is eaten as 'lalab' or made into pickles as a vegetable. In the Philippines, it is eaten raw as a salad or cooked, whereas the flowers are also added to salads. Tannins are obtained as a by-product from the process of preparing masticatories from immature nuts. The nuts have also been used to obtain dyes, and their fat is used as an extender of cocoa butter. Husks are used as domestic fuel. In the Philippines, they have been used to make toothbrushes. Industrial uses of husk components and leaves as raw material for fibres, hardboard and plastics have been reported from India. Areca palm stems provide useful building material. The leaf sheaths and spathes are used as wrapping material. The spathes have also been used to make containers and hats.

In South-East Asia the fragrant flowers are used in ceremonies, such as weddings and funerals. In Florida and many parts of the tropics areca palm is grown as an ornamental.

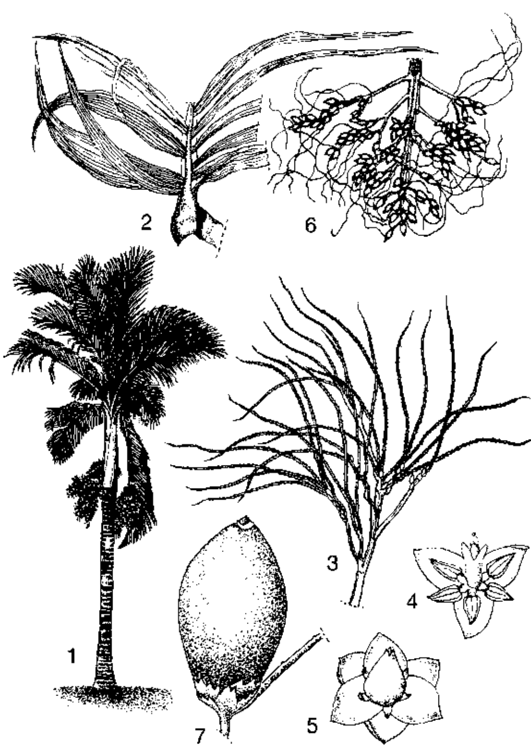
Production and international trade In India, the most important areca palm growing country, the production of areca nuts rose from 75 000 t around 1955 to 250 000 t around 1990. The increase in production was a combination of increase in area under cultivation and in yield per ha. In Indonesia, the total production was 21 800 t in 1993, of which most was exported. Thailand exported about 5 200 t in 1991, with a value of 4.5 million US$. Neither production figures for other areas nor more recent information on domestic and international trade are available.

Properties The main chemical constituents of ripe areca nuts per 100 g fresh weight are approximately: water 21–30 g, protein 5–8 g, carbohydrates 35–40 g, fat 5–10 g, fibre 11–15 g, polyphenols 11–18 g. Alkaloids are present as a minor but

significant constituent. Eight related alkaloids have been identified, the most important one being arecoline; they generally range from 0.1–0.2%, but higher values of the order of 0.7% are also given. The largest amounts of alkaloids are found in the unripe nuts. Arecoline is known to act on the central and peripheral nervous systems. It promotes heart rate and blood pressure, increases the glucose utilization of the brain, and improves the cognitive function in people affected with Alzheimer's disease.
Betel quid use is associated with diseases such as oral leucoplakia, submucous fibrosis and oral squamous cell carcinoma. The possible carcinogenic effects may be due to cytotoxic and teratogenic N-nitrosamines formed from the alkaloids in areca nuts. The formation of N-nitrosamines may be enhanced by the phenolic compounds of the nuts. It has also been suggested that oral squamous cell cancer is caused by lime-induced cell proliferation and by reactive oxygen compounds generated in response to the combination of polyphenols and lime.
The 1000-seed weight is 10–20 kg.

Adulterations and substitutes The seeds of many other palms are used as inferior substitutes for the true areca nut, e.g. *Areca caliso* Becc. (the Philippines), *A. glandiformis* Lamk (Indonesia, New Guinea), *A. ipot* Becc. (the Philippines), *A. laosensis* Becc. (Indochina), *A. latiloba* Ridley (Indonesia), *A. macrocalyx* Zipp. ex Blume (Indonesia, New Guinea), *A. triandra* Roxb. (Indonesia, Indochina), *A. whitfordii* Becc. (the Philippines), *Calyptrocalyx spicatus* (Lamk) Blume (Indonesia) and *Pinanga* spp. (Indonesia).

Description An erect, slender, unarmed, unbranched, solitary, pleonanthic, monoecious palm, up to 30 m tall with a terminal crown of 8–12 leaves. Root system dense but superficial, most roots within a 1 m radius from the trunk in the top 60 cm of soil. Trunk cylindrical, 15–30 m tall, 10–15(–40) cm in diameter, grey-brown, densely and regularly ringed with leaf scars. Leaves arranged spirally (phyllotaxy 2/5), crowded at the trunk top, 1–1.5 m long, paripinnate, sheathing; sheath completely encircling the stem like a tube, 0.5–1 m long; pinnae 30–50, subopposite, linear to lanceolate, 30–75 cm × 3–7 cm, longest in the centre of the blade, longitudinally plaited, apex dentate or irregularly incised, dark green, upper ones often partly cohering. Inflorescence erect, appearing on the trunk below the crown leaves (infrafoliar), 30–60 cm long, branched broomlike to 3 orders basally, tertiary branches filiform, spicate,



Areca catechu L. – 1, habit fruiting palm; 2, base of leaf; 3, inflorescence; 4, male flower; 5, female flower; 6, infructescence; 7, fruit.

15–25 cm long, very fragrant; before opening, inflorescence enclosed by a double boat-shaped bract which opens longitudinally along the upper surface; male flowers numerous, borne above the female flowers, arranged in pairs in 2 rows, sessile, about 6 mm × 3 mm, creamy, deciduous, sepals 3, small, petals 3, lanceolate, larger, stamens 6 in 2 whorls; female flowers borne on the thickened bases of secondary and tertiary branches, 1–3 per branch, 1–2 cm × 1 cm, sessile, with persistent perianth of 3 sepals and 3 longer, creamy-white petals, ovary trilocular (2 carpels usually aborting), ovoid, stigmas 3, triangular, fleshy. Fruit an ovoid drupe, 3–6(–10) cm × 2–5 cm, orange to reddish, usually 1-seeded; pericarp fibrous, about 6 mm thick. Seed (so-called nut) ovoid, globose or ellipsoidal, 3–4 cm × 2–4 cm; endosperm ruminate with hard reddish tissue from inner integument running horizontally for some distance into pale brown endosperm.

Growth and development Mature seeds of areca palm are sown as whole fruits, directly after harvesting or after a few days of drying in semishade. Germination is completed about 90 days after sowing when the first bifid leaf and five roots have developed. An adult palm bears 8–12 leaves and produces 6 new leaves per year. Flowering starts at the age of 4–6 years. In Malesia flowering is year-round, in India from November–February. Male flowers begin to open as the spadix frees itself from the spathe. Each flower lasts only a few hours. It takes 2–4 weeks for all the male flowers to open. After all the male flowers have been shed, the petals of the female flowers turn yellowish white, open slightly and the stigma becomes receptive for 3–4 days, with maximum receptivity between the first and third day. The duration of the female phase ranges from 5–8 days. As a rule there is no overlap between the male and female phase but exceptions (overlap of two days) have been observed. The palm is thus cross-pollinated and most of the pollination takes place by wind. The percentage of fruits set varies widely, not all female flowers set fruit. Fruits produced per spadix range from 50–400. Development from pollination to ripe fruit takes about 8 months. Yields are variable but gradually increasing until the palms reach full maturity at 12–15 years. Production continues until the palms are 40 years old and stop producing fruits. The life span of an areca palm is 60–100 years.

Other botanical information Although Linnaeus originally wrote '*cathecu*' as specific epithet, most authors consider this an orthographic error for *catechu*. As *A. catechu* is cross-fertilized its variability is great. Several varieties have been distinguished, mainly on the basis of fruit morphology. In South-East Asia and India the different forms, sizes, colours and tastes of the nuts have been given different vernacular names, but there is no formal classification of cultivars.

Ecology Areca palm grows well in humid tropical lowland. At altitudes above 900 m fruit quality and germination are adversely affected. It requires a high, well-distributed annual rainfall of 1500–5000 mm. In areas with dry spells irrigation is needed. Areca palm can be grown on a wide range of soils. It thrives on fertile, well-drained and deep clay loams.

Propagation and planting Areca palm is exclusively propagated by seed. Criteria for mother-tree selection are early and regular bearing, a large number of leaves on the crown, short internodes and high fruit set. As to fruit selection, fully mature heavy fruits, floating vertically in water with the calyx end upward, give a high germination percentage and vigorous seedlings. As sprouts of the seedlings are damaged by direct exposure to the sun, nurseries should be shaded. At the age of 12–24 months, plants with five or more leaves are selected and, with a ball of earth adhering to the roots, planted in the field. In well-drained soils, deep planting – at a depth of about 90 cm – allows for gradual earthing up the fresh nodes above the bole. The covered nodes throw out fresh roots, resulting in firm anchorage and a larger rooting volume. In Indonesia, villagers often collect seedlings from fruits dropped by bats and squirrels and raise them into mature palms near their homes.

Selection criteria for areca palm gardens include protection against wind and sun-scorch, adequate drainage and preferably a clay-loam texture. Spacing depends on soil depth and fertility. In a trial in Kerala, India, a spacing of 2.7 m × 2.7 m was found to give the highest cumulative yield. After planting out in the field, seedlings may be protected against direct sun exposure by shading them with coconut palm leaves or planting a banana intercrop. Permanent intercropping takes place, using, among other, banana, cocoa, fruit trees, cardamom, and guinea grass as a fodder. In India pepper and betel pepper may be grown with the palm as support. If interplanted with banana the distance between plants may be 4–5 m × 2–2.5 m. Areca palm is often temporarily intercropped with annuals and biennials. The practice increases the per unit area yield through better use of land and light and provides revenue while the palms are still immature, without reducing their future yields. In many areas young seedlings are planted among 20-year old palms to replace older ones that have ceased bearing. This may be repeated and, unless thinned, an old garden may contain as many as 2500 palms per ha.

Husbandry In young areca palm plantings regular weeding, mulching and sometimes intercultivation by hoe-digging are practised for weed control and water conservation. In India annual fertilizer applications of 100 g N, 40 g P_2O_5 and 140 g K_2O per palm are recommended, together with 12 kg each of green leaf and compost or cattle manure. Irrigation is used in some of the drier areas.

In Indonesia areca palms are usually cultivated around homesteads and along the borders of upland fields. Larger plantations of areca palm are mostly found in India only.

Diseases and pests The most important diseases of areca palm in India are yellow leaf disease, fruit rot, foot rot and inflorescence dieback and button shedding. Yellow leaf disease causes yellowing of leaves and shedding of both mature and immature fruits. It does not kill the palm outright but debilitates it. The nature of the disease and remedial measures are unknown. Fruit rot, i.e. rotting and shedding of immature fruits caused by *Phytophthora arecae* is a serious disease in areas of high rainfall. The fruit stalk and the rachis of the inflorescence are affected, but the fungus may also cause rotting of the growing bud, eventually killing the palm. Protective spraying with Bordeaux mixture and other copper fungicides is effective, and fallen plant material must be removed. Foot rot is a soilborne fungal disease caused by *Ganoderma* spp. destroying the xylem and thereby impeding the water supply and killing the palm. Removal of dead tree stumps and digging of trenches around affected palms limits the spread of the disease. Inflorescence dieback and button shedding is a serious problem in some states of India. Nutritional and physiological factors are probably involved and several fungi have been found to be associated with infected inflorescences.

The following pests, though not highly host specific, cause substantial damage in India: mites, spindle bugs, inflorescence caterpillars, and root or white grubs. The mites recorded on the crop are *Oligonychus biharensis*, *O. indicus*, *Raoiella indica* and *Tetranychus fijiensis*. They suck sap from the leaves, causing yellowish speckles which later coalesce; severely infested leaves wither away. Control measures are cutting and burning of infested leaves and spraying with insecticides. Spindle bugs (*Carvalhoia arecae*) suck on the tender spindle and leaves, causing necrotic lesions. Severely infested spindles fail to open and leaves are shredded, resulting in stunted growth. Various systemic insecticides have been found to give control. The moth of the inflorescence caterpillar (*Tirathaba mundella*) deposits eggs into the spadix. The emerging caterpillars bore into the interior of the spathe and feed on the tender rachillae and female flowers and may also bore into the young buttons. To control this pest, infected inflorescences are removed and burnt. The root grubs affecting the areca palm are larvae of *Leucopholis burmeisteri* and *L. lepidophora*. They feed on the roots and may cause the palms to topple over. Visual symptoms are the drooping and the drying of leaves. Soil insecticides give effective control.

Harvesting The stage of harvesting of areca palm depends on the product wanted. Immature fruits to supply 'kalipak' (an important form of processed areca nut in India) can best be harvested when 6–7 months old. For the mature nut product, fruits should be harvested fully ripe. In Indonesia, unripe fruits are harvested for home consumption, whereas fruits intended for trade are usually harvested ripe, because ripe fruits keep better. In closely and regularly spaced plantings harvesters climb the palms, cut the bunches, lower them down on a rope and move from one crown to the other. Another method is to harvest bunches with a knife mounted on a bamboo pole.

Yield In India mean annual yields of areca palm were of the order of 800 kg dry nuts per ha around 1955 and 1200 kg per ha around 1990. Calculated mean yield of ripe nuts is about 2.5 kg per palm per year, but some farmers obtain yields of 8 kg per palm. The highest yield ever recorded is 30 kg per palm per year.

Handling after harvest The fruits are husked, either fresh or after drying, the embryos are removed, and the whole or sliced nuts are dried in the sun or with artificial heat; sometimes they are smoked. Ripe or almost ripe nuts, whole or sliced, may be boiled in water to which some of the concentrated liquid from previous boilings may be added; they are then dried. Boiling reduces the tannin content of the nuts. The product is graded on the basis of the ripeness at harvesting and on the colour, shape and size of the nuts. The most popular trade type is the dried, ripe, whole nut ('chali'). In Malaysia the nuts are not boiled. Here, the unripe or ripe fruits are usually split in two and dried in the sun or over an oven. Sometimes the fruits are dried without splitting, a slow process which gives an inferior product. In Taiwan the unripe fresh areca nut is directly used as an ingredient of the betel quid.

Genetic resources The Regional Station of the Central Plantation Crops Institute, Vittal, India, maintains a germplasm collection of *A. catechu* and related species from within the country as well as from Sri Lanka, southern China, Thailand, Malaysia, Singapore, Indonesia, the Philippines, Fiji, Solomon Islands and Mauritius. Sixteen exotic accessions have been evaluated for yield in a long-term comparative trial, from which three accessions with high yield potential were released. None of the available cultivars has shown tolerance to yellow leaf disease, which makes identification of disease-tolerant genotypes a priority.

Breeding Procedures for mother-tree and seedling selection in areca palm are well established. It has been found that early-bearing palms were constantly better yielders and that selection of seedlings at the appropriate time for number of leaves, girth at collar and number of nodes totally eliminated the late-bearing palms and so increased the yield of the population. However, it did not prove effective to implement these criteria in a mass pedigree selection programme. Hybridization programmes involving selected exotic and local types were started in the early 70's, but so far no hybrids for commercial use have resulted. Interspecific hybrids between *A. catechu* and *A. triandra* showed hybrid vigour for a number of characteristics. However, these hybrids are sterile and efforts to develop progenies combining the desired traits of both species have failed.

Prospects Yields of areca per palm and per ha can be greatly increased by mother-tree and seedling selection and adequate crop husbandry. However, there is unlikely to be a substantial increase in total consumption, although consumption is increasing in Burma (Myanmar), Borneo, some Polynesian Islands and the highlands of Papua New Guinea. In the rest of Asia chewing of betel quid is not popular with the younger generation. Because of the link between betel quid use and oral cancer, betel quid consumption should not be encouraged.

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S. Brotonegoro, M. Wessel & M. Brink

Camellia sinensis (L.) Kuntze

Um die Erde ('chinensis'): 500 (1881) et in Acta hort. petrop. 10: 195 (1887).

CAMELLIACEAE (Theaceae s.l.)

$2n = 30$

Synonyms *Thea sinensis* L. (1753), *Camellia thea* Link (1822), *C. theifera* Griff. (1854).

Vernacular names Tea (En). Théier (plant), thé (product) (Fr). Indonesia and Malaysia: teh. Philippines: tsa (Tagalog). Burma (Myanmar): leppet. Cambodia: taè. Laos: s'a:, hmièngx. Thailand: cha (central), miang (northern). Vietnam: ch[ef], tr[af].

Origin and geographic distribution The natural habitat of *C. sinensis* is the lower montane forest on mainland Asia from south-western China (Sichuan) to north-eastern India (Assam). The primary centre of origin is presumed to be near the source of the Irrawadi (Ayeyawadi) river in northern Burma (Myanmar), but early human interest in the stimulating properties of tea may have been instrumental in its wider dispersal in Asia. The tea plant was already known to the Chinese peoples more than 4000 years ago. Written records dating from the 5th Century AD confirm its widespread cultivation and general use as a refreshing beverage in several Chinese provinces. Tea cultivation in Japan was started in the 9th Century with seed introduced from China. Tea became an important export commodity for China, first through the Mongols by old overland trading routes in central Asia to Turkey and Russia (mainly as brick tea), and then from the early years of the 17th Century also to Europe by sea, through the Dutch and English East India Companies (green, and later black tea). For more than 300 years all the tea drunk in the Western world came from China (100 000 t in 1850), but this monopoly on the international tea market gradually came to an end with the development of tea plantations in India (1840), Sri Lanka (1870) and Indonesia (1880). By 1925 very little of the 300 000 t of tea imported into Europe came from China. Tea exports from China were resumed in quantity in the 1960s.

The tea grown in China and Japan is all *C. sinen-*

sis var. *sinensis* ('China tea'), which has smaller leaves and more cold tolerance but grows less vigorously than *C. sinensis* var. *assamica* (Mast.) Kitamura ('Assam tea') discovered in the forests of north-eastern India in 1823. Assam tea and subsequently hybrids between the two varieties ('Indian hybrid tea') became the basis for the tea industries of South, South-East and West Asia, as well as for those established in Africa and South America. In South-East Asia, tea cultivation is most important in Indonesia, Vietnam, Papua New Guinea, Malaysia and Thailand.

Uses Tea, the beverage obtained by infusing the leaves in hot water, is used worldwide. Called 'tay' or 'cha' by the Chinese, the beverage derives its stimulating and refreshing properties from the high concentration of the alkaloid caffeine, specific polyphenolic compounds, and the aroma complex present in the leaves of young shoots. In China, Japan, Vietnam and to some extent in other South-East Asian countries people drink green (unfermented) tea, which is prepared from pan-fired or steamed and dried young leaves plucked from China tea plants. This produces a pale and mildly flavoured liquor. More than 78% of the present world tea production is consumed as black tea, which involves withering, rolling or crushing, fermenting and drying the young leaf shoots. Black tea prepared from China tea produces a light brown and delicately flavoured liquor. Black teas made from Assam or Indian hybrid tea shrubs generally give a darker, stronger tasting liquor, hence these are often drunk with milk. 'Oolong' or 'Bohea' is a semi-fermented China tea originally from the Fujian province and Taiwan. In Burma (Myanmar) tea is also consumed as pickled food called 'leppet'.

In addition to regular black tea, several specialty teas are offered to the consumers in the industrialized world based on origin (e.g. Darjeeling), blend (e.g. English Breakfast) or added flavour (e.g. bergamot, orange, jasmine). Herbal teas have nothing to do with real tea. The conventional method of retailing loose tea in small packets (50–250 g) has been largely replaced by tea bags (250–400 bags to 1 kg fine grade tea), which many Western consumers find more convenient. Real instant teas are inferior in liquor quality, but have a significant market share in the United States as bottled or canned cold drinks. Bottled and cartoned tea compete with soft drinks on the Indonesian market. There is also a small market in the United Kingdom and the United States for decaffeinated tea.

Production and international trade World production of tea during 1995–1998 averaged 2.6 million t/year (22% green tea) from a total area of 2.5 million ha in 30 countries. China has the largest area under tea (1.1 million ha), but with 580 000 t (71% green tea) is the second largest producer after India, which produces 755 000 t from 425 000 ha. The third largest tea producer is Sri Lanka (250 000 t) followed by Kenya (240 000 t), Indonesia (140 000 t) and Turkey (120 000 t). South Asia (India, Sri Lanka, Bangladesh) produces about 40% of the world tea, East Asia (China, Japan, Taiwan) 27%, Africa (10 countries) 14%, West Asia (Turkey, Iran, Georgia, Azerbaijan) 10%, South-East Asia 7% and South America (Argentina, Brazil) 2%.

About 50% of all black and 78% of green teas are consumed domestically, leaving about 1.1 million t (93% black tea) for the international tea market. Sri Lanka and most African countries export more than 90% of their tea, Indonesia 60%, China 27% (black and green tea) and India 20%. The largest tea importers are the United Kingdom plus Ireland (155 000 t/year), the Russian Federation (150 000 t), Pakistan (110 000 t), the United States (85 000 t) and Egypt (70 000 t). Annual tea consumption per head varies from 0.1–3.1 kg: e.g. Italy 0.1, United States and Indonesia 0.3, China and Russian Federation 0.5, India 0.6, Japan and Egypt 1.1, Turkey 1.9, United Kingdom 2.5, Ireland 3.1.

The international tea trade is based on regular public auctions in producing countries (e.g. Calcutta, Colombo, Jakarta, Mombasa), but partly also on direct sales from large plantations or national tea selling organisations (e.g. China) to overseas buyers. Tea prices have fluctuated considerably over the years, but there has been a general decline over the last decade. There are also price differentials of 50–200% between plain and very high quality teas. At mean auction prices of US$ 1.20–1.90/kg, the total value of the international tea trade for 1996 (1.1 million t) can be estimated at US$ 1.3–2.1 billion.

In South-East Asia, Indonesia is the most important tea producer with 80 000 ha plantations (110 000 t black tea) and 50 000 ha smallholdings (30 000 t green tea). Vietnam produces some 40 000 t green tea on 70 000 ha (mostly smallholdings) all for domestic consumption. Malaysia produces 6000 t annually from 4000 ha (plantations), but also imports another 7000 t black tea; Papua New Guinea produces 7000 t black tea from 5000 ha (plantations); Thailand 5000 t from 10 000 ha; Laos 1500 t from 2000 ha.

Properties Young green tea shoots (bud and two leaves) of Assam tea have the following approximate chemical composition per 100 g dry weight: polyphenolic compounds (mostly six catechin flavanols) 30–35 g, polysaccharides and carbohydrates 22 g, protein 15 g, caffeine 3–4 g, amino acids (including theanine) 4 g, inorganics 5 g, organic (mainly ascorbic) acids 0.5 g and volatile substances 0.01 g. In addition to these (hot) water soluble components, there are also non-soluble cellulose 7 g, lignin 6 g and lipids 3 g. Compared with Assam teas, the flavonol content of China teas is half and Indian hybrid teas about three-quarters. The polyphenol content decreases with leaf age, being highest in the bud and first leaf and low beyond the third leaf.

In the unfermented green teas most of the components remain unchanged and these determine the colour, taste and aroma of the liquor. During the manufacturing process of black tea, complex biochemical reactions take place, as a result of cell disruption and the mixing of cytoplasmic polyphenol oxidase with the contents of the cell vacuoles. Part of the polyphenols are oxidized and polymerized to theaflavins and thearubigins that give the orange-brown colour, strength and taste typical of black tea liquors. At the same time several hundreds of secondary volatile compounds are formed, mainly derived from carotenes, amino acids, lipids and terpene glycosides. Together with the primary volatile substances already present in fresh tea leaves they form the aroma complex of the black tea liquor. So far, some 650 of such aroma compounds have been detected in the liquor of black tea, compared with 250 in green tea brews. Tea quality is determined not only by the briskness, strength and colour of its liquor but even more so by the composition and concentration of the aroma complex. Research has made considerable progress in distinguishing highly desirable aroma (group I) compounds from those deleterious (group II) to tea quality, but using the ratio between the two as a quantitative method for determining tea quality has limited value. Tea quality is still largely assessed organoleptically by experienced tasters.

The genetic background of the cultivar planted, the climatic conditions (e.g. altitude), the age of the bush, the period since pruning and the agronomic practices, all affect the quality. However, potentially high quality tea can easily be destroyed by poor methods of plucking, handling and processing.

The 1000-seed weight is 450–500 g.

Description Evergreen, multi-stemmed shrub up to 3 m tall (var. *sinensis*), or tree up to 10–15 m tall with one main stem (var. *assamica*); in cultivation pruned to 1–1.5 m and trained as a low profusely branching and spreading bush. Strong taproot and many lateral roots giving rise to a dense mat of feeding roots in the top 50–75 cm of the soil; some lateral roots grow 3–4 m deep; feeding roots in association with endotrophic mycorrhiza, lacking root hairs. Branchlets finely pubescent at apex. Leaves alternate, with short petiole; blade obovate-lanceolate, 4–30 cm × 1.5–10 cm, serrate, obtuse with broad cusp to acuminate, slightly pubescent on lower surface when young, stomata on lower surface only, characteristic sclereids (stone cells) in mesophyll and calcium oxalate crystals in phloem of petiole; in var. *sinensis* leathery and usually stiff-erect, narrow and usually less than 10 cm long, dark green with dull, flat surface and indistinct marginal veins; in var. *assamica* thinly leathery and horizontal or pendant, wider and longer (15–20 cm long), lighter green with glossy, bullate upper surface and distinct marginal veins. Flowers axillary, single or in clusters of 2–4, 2.5–4

Camellia sinensis (L.) Kuntze – 1, flowering branch; 2, fruiting branch; 3, pluckable shoot.

cm in diameter, very fragrant; pedicel short; sepals 5–7, persistent; petals 5–7, obovate, concave, white or light pink, slightly coherent at base; stamens 100–300, with 2-celled yellow anthers, outer filaments fused at base and coherent with petals, inner ones free; pistil with superior 3–5-loculed ovary, 4–6 ovules per carpel, and 3–5 free (var. *sinensis*) or partly fused (var. *assamica*) styles with stigmatic lobes. Fruit a subglobose capsule, 1.5–2 cm in diameter, thick-walled and woody, brownish-green, usually 3-lobed and 3-loculed, 1–2 seeds per locule. Seed globose or flattened on one side, 1–1.5 cm in diameter, testa (shell) light brown and hard, integument thin papery; endosperm absent; cotyledons thick and rich in oil, embryo straight. Seedling with epigeal germination.

Growth and development There is no seed dormancy. Viability of freshly harvested seed diminishes quickly at ambient temperatures, but can be maintained at more than 60% for 6–10 months by storage at 0–4°C at 100% relative humidity. Seeds germinate readily upon removal of the shell. Seedlings have one vertical stem with lateral branches from buds in the leaf axils; cotyledons are shed after 5–6 months. Flowering starts when tea plants are about 4 years old. Root development, whether the initial taproot of seed-grown tea or the adventitious roots of cuttings, is important in tea cultivation. Generally, when roots reach a diameter of 1–2 mm starch reserves already begin to be laid down. This stored carbohydrate plays an important role in the regrowth of shoots following pruning.

Endogenously determined growth cycles in unpruned tea cause a series of flushes of shoot growth alternating with periods of inactivity. These so-called 'banjhi' cycles last 10–14 weeks each; shoots with dormant apical buds are called banjhi shoots. However, the yield cycles observed in cropped tea are mainly the result of synchronization of shoot development.

Pruning and harvesting cause a large number of branched twigs with leaves to develop in the top 20–40 cm of the closely planted bushes. The leaf area index in a mature tea planting is 4–10, and is usually larger in China than in Assam types. Favourable weather conditions induce a synchronized growth flush of apical shoots, which produces the first peak in crop production. When a bud comes out of dormancy 2 scale leaves are formed, one of which usually drops off soon after, followed by a small, non-serrated 'fish' leaf and a flush of normal leaves. Removal of these apically dominant shoots by harvesting encourages a second generation of shoots to grow, but some of these shoots stop growing after only 2 or 3 leaves and end in a dormant (banjhi) bud. A dip in yield occurs until this second flush of shoots has grown to harvestable size and produces the next peak in crop production. The number and length of the shoot replacement cycles (SRC) – defined as the duration between the start of bud expansion and the moment that the new shoot is harvestable – is determined by climatic conditions. Fast-growing flushes (SRC of 30–40 days) in warm and wet weather will reach harvestable shoot size almost simultaneously and so lead to distinct peaks in crop production. Under uniformly cool and humid conditions (SRC of 100 days or more) each shoot flush will reach harvestable size spread out over a longer period, resulting in a more even distribution of the crop over the season.

In the tropics flowering in non-plucked tea occurs year-round. Flowers are pollinated mainly by insects (e.g. bees). Only cross-pollination gives good fruit set and seed, especially in var. *assamica*, which appears to have a system of self-incompatibility. Fruits take 10–12 months to mature; ripe fruits dehisce the seeds by splitting open from the apex into 3 valves.

Other botanical information In the classification of true teas (no hybrids) a third taxon has often been distinguished called 'Cambod' or southern tea, *C. sinensis* (L.) Kuntze var. *lasiocalyx* (Watt) W. Wight, with characteristics intermediate between China and Assam teas. The outbreeding nature of *C. sinensis* and the extensive intercrossing between the taxa has resulted in a wide spectrum from pure China to Assam plant types and all intergrades in presently existing tea populations. There have been suggestions that *C. irrawadiensis* P.K. Barua and *C. taliensis* (W.W. Smith) Melchior have also contributed to the gene pool of tea, although these species as such do not produce a tea of acceptable quality.

The term 'jat' is often used to indicate seedlings from a certain district, but also to distinguish a group of plants that appear to belong to a distinct type on the basis of leaf and floral characteristics.

To classify cultivars it is more appropriate to distinguish cultivar groups, e.g. the cv. groups China Tea, Assam Tea, Cambod Tea and Indian Hybrid Tea, each with their respective cultivars.

Ecology Tea originated from an area of monsoon climates (warm, wet summers and cool, dry winters) but is presently grown in a range varying from Mediterranean to tropical climates, between

42°N (Georgia) and 27°S (Argentina) latitudes, as well as from sea-level to 2300 m altitude.
Mean annual rainfall varies from 1500 mm (Uganda) to 3500 mm (West Java). About 1700 mm annual rainfall is the minimum requirement for economic tea production. Additional irrigation is only effective under sufficiently high air humidity. On the other hand, rainfall of 5000 mm has no adverse effect on tea growth. Rainfall should not fall below 50 mm per month for any prolonged period. Hail can be a serious hazard to tea, causing yield losses of 10–30% in some areas (e.g. in Kenya above 2000 m altitude).
Generally, optimum temperatures for shoot growth are between 18–30°C. The base temperature (Tb), below which shoot growth stops, is about 12.5°C, but this can vary between genotypes from 8–15°C. The thermal time – i.e. the product of number of days and effective temperatures (T – Tb) – for the SRC in tea is on average 475 day°C, in the absence of water stress. It has been shown to be a very useful parameter to estimate seasonal and geographical effects of temperature on the length of the SRC and consequent yield patterns. At average daily temperatures of 22.5°C the SRC would thus be 48 days against 79 days at 18.5°C. The thermal time parameter is not applicable at temperatures above 30°C, as the co-occurring high vapour pressure deficits of the air (> 23 mbar) depress shoot growth. Tea is not killed by the night frost that occurs in important tea-growing areas at higher latitudes. China-type teas are more tolerant of colder climates. Daylength does not have a large influence on seasonal variation in growth (yield) or flowering.
At high altitudes in tropical areas the photosynthesis of whole canopies of the tea crop becomes saturated at 75% of full sunlight. Tea is generally more productive without shade, but shade trees may be necessary to reduce air temperatures during hot periods, e.g. in Assam and Bangladesh. Shelter belts of trees planted between fields are beneficial in protecting tea against prevailing strong winds.
Tea is grown successfully in a wide range of soil types developed from diverse parent rock material under high rainfall conditions. Soils suitable for tea cultivation should be free-draining, have a depth of 2 m, a pH between 4.5 and 5.6, a texture of sandy loam to clay and good water-holding capacity.
Climatic conditions have a great influence on the quality of the tea, especially on the flavour. Fast shoot growth – for instance at low altitudes, during the best part of the growing season or shortly after the bushes have been pruned back – is detrimental to the quality of tea, particularly the flavour, but induces high production. Hence, both in respect of plucking method and inputs to encourage growth (e.g. heavy manuring) the grower has to choose between high yield and good quality. Nevertheless, high yields and excellent quality tea can be obtained in tropical countries on fertile soils, especially at elevations of 1200–1800 m above sea-level. At still higher elevations, the tea will have a well-developed flavour but it will lack strength and yields will be lower. Likewise, the retarded shoot growth during a dry period and the proliferation of growing points with an attendant reduction in shoot vigour shortly before the next pruning round result in better flavour but low yields.

Propagation and planting Both seedlings and cuttings are used as planting material for tea. Seeds are produced in a special orchard, or 'bari', with free-growing, widely spaced (5 m × 5 m) trees from a selected jat, or a restricted number of selected clones (biclonal and polyclonal seed). Seeds with a diameter of 12.5 mm or more are considered to have sufficient food reserves. They are immersed in water for up to half an hour to select the sinkers which show better germination and subsequent vigour. To germinate, seeds are usually placed between wet gunny or hessian cloth and inspected twice weekly. Those that have an emerging radicle are transferred to nursery beds. After 1.5–2.5 years, the stems are cut back to a height of 15 cm, the plants dug up and transplanted to the field.
The techniques of vegetative propagation were mastered commercially during the 1960s in India, Sri Lanka and Kenya, in the 1970s in Indonesia. Since then, rooted cuttings have been used almost everywhere. Multiplication plots of selected clones are being established; the shoots are left to grow up to 15 nodes before being cut. Green, semi-hardwood cuttings with a full leaf, taken from primary shoots, are the best. At the nursery, up to 8 single-node leaf cuttings are made with a sharp knife from the middle part of each shoot. Each cutting is then placed in a small polythene sleeve (10 cm wide, 30 cm long) with the leaf and bud just above soil level. The rooting medium should be acid and low in organic matter. The bags are then watered and placed in small airtight polythene tunnels under shade. The tunnels are periodically opened for watering, while the shade is gradually removed to harden the plants off before planting out at an age of 6–9 months.

A recently developed technique of propagation is the composite tea plant, which is produced by chip-budding on unrooted cuttings. It offers the opportunity of increasing yield without loss of quality, by combining improved vigour of selected rootstocks with scions yielding high-quality tea. Micropropagation by tissue culture appears possible, but the tea industry is currently showing little interest in this. Tea is planted at densities of 11 000 to 14 000 bushes per ha, depending on climatic and edaphic conditions, as well as on varietal vigour. On slopes, tea is planted in contour rows. Although trials in various regions have shown that there is no particular optimum spacing, the need for soil conservation has led to closer planting (60 cm) in the rows, with sufficient space (120 cm) between the rows to allow pluckers to walk and work. To further check erosion and provide some shade for the young plants, *Tephrosia candida* (Roxb.) DC., *Crotalaria micans* Link or *C. trichotoma* Bojer are often sown between the rows of tea. Laying cut or mown matter from these leguminous plants or from Guatemala grass (*Tripsacum andersonii* J.R. Gray) alongside the tea plants provides a mulch to conserve moisture and to control erosion and weed growth. The use of permanent shade trees (most important are *Paraserianthes falcataria* (L.) Nielsen, *Leucaena leucocephala* (Lamk) de Wit and *Erythrina subumbrans* (Hassk.) Merrill) is restricted to low elevations.

Husbandry Regular weeding of tea is needed only during the first few years after planting, until shade from the continuous plucking table and the mulch provided by prunings prevents the further growth of most weeds. Surviving weeds can be controlled by spot application of herbicides. Pruning in tea has the following main objectives:

- Frame formation of young plants: this involves pruning at various levels to induce lateral growth leading to a permanent and wide frame for a continuous gap-free plucking table. Bending and pegging down of branches avoids some of the pruning and accelerates the formation of a good and lower frame. Pegged plants come into bearing earlier, producing a first small crop in the second year after planting.
- Final shaping of the plucking table: 3–5 rounds of 'tipping' (breaking back) of upright growing shoots is carried out to level the plucking surface at a height of 50–60 cm for the first crop. This produces the required 20–25 cm of maintenance foliage and a high density of points from which the flush will grow.
- Maintenance pruning: at 2–5 year intervals (depending on regional differences in climate) all the stems and leaves above the basic frame are removed to lower and rejuvenate the plucking table, which may have reached a height of 120–150 cm and become less productive. Maintenance prunings may vary from very heavy to light (skiffings), the best time being usually at the onset of a cool or dry period, when the starch reserves in the roots are high and regrowth will therefore be fast. Maintenance pruning is followed by rounds of tipping to prepare the plucking table for the new crop.
- Collar or down pruning: cutting below the lowest level of normal pruning, close to ground level, to rejuvenate very old tea bushes; it may take 5–6 years to regain full production after collar pruning.

Tea requires regular fertilizer application to sustain satisfactory yield levels, but types and rates will vary with local conditions of soils, climate, agronomic practices, absence or presence of shade, age of the bushes and type of variety planted. Fertilizer recommendations are based on field experiments, soil and leaf analyses. Foliar analysis (the third leaf below the bud is sampled) provides useful information on the nutrient status of the tea plant. Nutrients removed by one t of processed tea are: 45 kg N, 5 kg P_2O_5, 20 kg K_2O, 8 kg CaO and 3 kg MgO. A considerable part of the nutrient uptake is returned to the soil by the prunings, which are left between the bushes and also improve the organic matter content of the soil. Nitrogen is the most important nutrient in tea; clear yield responses have been recorded to rates of up to 500 kg N/ha in mature tea, but 150–200 kg N/ha is the most economic level. Excessive N application can adversely affect the tea quality. The rates of application of P and K often depend on the type of compound fertilizers used, e.g. NPK 25-5-5 (Kenya), 6-1-2 (Indonesia). Other major (Ca, Mg, S) and minor elements (Mn, Cu, Zn) are applied separately when required, minor elements also as foliar applications.

Diseases and pests Blister blight (*Exobasidium vexans*), which attacks young leaves and shoots, is of major economic importance in all tea-growing areas of Asia, but has not yet occurred in Africa or South America. It spread from Assam (first reported in 1868) to all tea areas in India, to Japan and Taiwan (1920), Sri Lanka (1946) and reached Indonesia in 1950. It can be controlled by regular sprays of copper and also by systemic fungicides. Some clones are less susceptible to blister blight than others, but so far no true host resistance has been found. Anthracnose (*Colletotrichum theae-sinensis*) and net blister blight (*Exobasidium reticulum*) are of importance mainly in Japan and Taiwan. Grey blight (*Pestalotia theae*) and brown blight (*Colletotrichum camilliae*) are weak parasites of mature leaves. They can become a problem in mechanically harvested tea. There are several stem cankers in tea (e.g. *Macrophoma theicola* and *Phomopsis theae*), but these can be controlled by careful pruning, protecting pruning cuts by fungicidal paints and by removing affected branches. A number of important root diseases are extremely difficult to control in tea. They include charcoal root disease (*Ustulina deusta*), red root disease (*Poria hypolateritia*), brown root disease (*Fomes noxius*), root splitting disease (*Armillaria mellea*) and *Ganoderma pseudoferreum*. Initial infection is often from mycelial strands that spread from old stumps and roots of previously cleared forest or shade trees. Control measures include uprooting affected bushes and some apparently healthy ones surrounding them, applying soil fumigants like methyl bromide and observing a 2-year fallow period with grass (e.g. Guatemala grass) before replanting.

More than 300 species of insects and other pests are known to infest tea. The most important tea pests occurring in Asia and accounting for 6–14% of annual crop losses include:

- foliage feeders: mites (*Oligonychus coffeae*, *Tetranychus* spp., *Brevipalpus* spp.), thrips (e.g. *Scirtothrips dorsalis*), mosquito bugs (e.g. *Helopeltis theivora*), scale insects and aphids (*Aphis* spp., *Toxoptera aurantii*), leaf-feeding (e.g. *Homona* spp.) and leaf-rolling caterpillars (e.g. *Caloptilia theivora*) and flushworm (*Cydia leucostoma*). Apart from direct crop loss, these foliage feeders also cause loss of quality in the processed tea.
- pests damaging stems: red coffee borer (*Zeuzera coffeae*), scolytid shot-hole borer (*Euwallacea fornicatus*) and termites.
- pests of the root system: in particular root knot (*Meloidogyne* spp.), root lesion (*Pratylenchus* spp.) and root burrowing (*Radopholus similis*) nematodes.

Pest management by chemical control in tea has to be limited to narrow spectrum pesticides with a half life shorter than 8 days to avoid pesticide residues in processed tea exceeding internationally accepted FAO/WHO limits. With few exceptions, methods of biological control and IPM (Integrated Pest Management) are not yet very advanced in tea.

Harvesting Most tea is still harvested manually by plucking the fresh shoot tips as they appear above the plucking table. The best quality of processed tea (flavour and strength) is achieved by light or 'fine' plucking, which includes only active shoots with 2 young leaves and the bud or pecco. Hard or 'coarse' plucking of 3 young leaves and the pecco increases yield at the expense of quality. Banjhi shoots (with dormant buds) appearing above the plucking table are harvested only when the top leaf is still young (one leaf and the bud), otherwise they are broken off and discarded. The harvested shoots are transferred to a bag or basket on the plucker's back, taking care not to compress or damage the leaves. Full baskets are taken to shaded collecting points for weighing and checking of quality. Plucked tea must subsequently reach the factory as soon as possible and undamaged to prevent early deterioration of quality. The interval between plucking rounds may vary from 4–7 days during peak flushes to 14 days or longer in adverse seasons.

There should be a balance between light and hard plucking in order to prevent the plucking table from rising too fast and at the same time to retain an adequate layer of maintenance foliage on the bushes for continued vigour and yield.

The best teas are produced by skilled manual harvesting, but it is very labour-intensive and accounts for about 60% of total production costs. Mechanical harvesters – from hand-operated devices to tractor-mounted and self-propelled machines – are increasingly being used in countries where labour costs are relatively high, or where the quality aspects are less stringent (e.g. bulk green tea production in Japan).

Yield As a rule, Assam tea and Indian hybrids have a higher yield potential than Chinese teas. Estates, which generally have better management, yield more than smallholdings, whilst coarse plucking produces more than fine plucking. Climatic factors (such as drought, night frost and hail), volcanic activity and outbreaks of diseases and pests influence yields. Constraints in the supply of agricultural inputs (e.g. fertilizers and pesticides) and insufficient labour can affect the yield in a particular period. Price declines since the 1950s have accelerated the uprooting of old plantings and their replacement by higher producing jats or clones.

World average yield for China-type teas is estimated at about 900 kg of processed tea per ha per year, ranging from less than 500 kg in China to 1600 kg in Japan. Mixed plantings of China and

Assam hybrid teas in Sri Lanka yield about 900 kg/ha annually. The predominant Assam and Indian hybrid teas produce per year 2100 kg/ha in Kenya, 1800 kg/ha in Malawi and 1700 kg/ha in India. In South-East Asia national average yields range from 600 kg/ha in Vietnam, 1100 kg/ha in Indonesia, and 2000 kg/ha in Malaysia, to 2100 kg/ha in Papua New Guinea (the latter two wholly from estates). In Indonesia annual yields are on average 550 kg/ha for smallholders, about 900 kg/ha for private estates and 2050 kg/ha for state plantations.

Handling after harvest Black tea is manufactured in tea factories in a process lasting a little over 24 hours and consisting of the following stages:

- withering: by partial removal of the moisture from the leaves over a period of 12–16 hours (down to 70% moisture content) in open or enclosed withering troughs;
- leaf disintegration: by orthodox roller, rotorvane or CTC (crush,tear and curl) machines (about 30 minutes); the CTC machine produces smaller leaf particles, which is of advantage to the modern tea-bag market;
- fermentation (oxidation): in thin-layer floor, or deep-layer and fan-assisted fermentation systems with temperature control (1–3 hours);
- drying: by multi-band or fluid-bed dryers with heated air to reduce the moisture content to a final 2.5–3.5%;
- sorting and fibre removal: to remove stalks and fibre and subsequent sorting into different sizes of tea particles; grades applied in the tea industry include whole-leaf grades, brokens, fannings and dusts;
- packing: in India, Sri Lanka and Indonesia the traditional plywood chest to hold 40–45 kg processed tea is still being used; the United States and United Kingdom encourage alternative packaging in laminated paper sacks (e.g. in Kenya and Malawi), which can protect the tea quality equally well, are cheaper (US$ 1.50 against US$ 4.50 for a tea chest) and lessen demands on dwindling timber reserves.

Green teas are always prepared from *C. sinensis* var. *sinensis*. Chinese tea (Kamaira cha) is produced by firing fresh leaves in a pan for 10–15 minutes with frequent agitation to avoid burning of the leaves, followed by rolling and drying. In the case of Japanese Sen-cha, freshly plucked leaves are steamed for one minute, then subjected to rolling and drying with heating in three different stages until a moisture content of 6% is achieved and a needle-like tea. The pan-firing or steaming destroys the enzymes and thus prevents any fermentation (oxidation) as occurs during the process of black tea manufacturing.

Genetic resources Most tea research institutes in Asia and Africa have living collections of tea germplasm of various origin. The seedling populations in cultivated tea of var. *sinensis*, var. *assamica* and the hybrids between these taxa also provide a rich pool of genetic variation whose potential has not yet been fully exploited. On the other hand, useful host resistance to important diseases and pests is hardly available in tea. For these and other reasons there is ample justification for collecting 'wild' germplasm of tea and related species in the main areas of origin, for preservation and future use. Recent surveys in the Yunnan province of China have identified several interesting genotypes of var. *sinensis* and new tea species.

Breeding Much of the tea in the world is established from open-pollinated seed collected in seed orchards, which at first consisted of unselected families or clones but which nowadays contain mass-selected and even progeny-tested families or clones. Tea is a highly heterogeneous outbreeder and large between-plant variation continues to exist in the most advanced seed cultivars. The development of efficient methods of vegetative propagation by single-node cuttings in India, Sri Lanka and Kenya in the 1960s set the stage for large-scale introduction of clonal cultivars in several tea-producing countries. Clonal selection offers an opportunity for uniform tea plantations and instant fixation of superior genotypes. However, the probability of finding these by simple mass selection within existing tea populations has been shown to be extremely small; better results are obtained when clonal selection is preceded by recombination crosses between selected tea genotypes (mother bushes or existing clones). In tea, as in many other crops, crosses between plants from genetically diverse subpopulations often show considerable hybrid vigour for yield. Molecular marker techniques can assist in measuring genetic diversity of initially selected parents and so increase breeding efficiency.

Improvement of tea cultivars has so far focused on plant type, yield and quality. Satisfactory levels of host resistance to diseases and pests have not been found within existing *C. sinensis* populations. Introgression of resistance from related species has been unsuccessful, not because of crossing barriers but due to inability to recover the quality of the recurrent parent. The product may look like tea, but the taste is commercially unacceptable.

Another handicap in tea breeding is the lack of information (from proper genetic studies) on the inheritance of yield and quality, beyond general observations and assumptions that all components of yield and quality appear to be inherited quantitatively.

Response to selection on components of yield is higher for number of shoots and weight of plucked shoot than rate of shoot growth. The quality of processed tea is positively correlated with the degree of pubescence on the underside of young leaves and with the 'greenness' of mature leaves (dark and pale green leaves give poor quality).

Separate selection of clones to serve as vigorous rootstock (with deep and extensive root system) and as high-quality scions is an effective novel approach in tea breeding first developed in Malawi and Kenya. The resulting composite clonal cultivars are higher yielding (mainly because they produce more harvestable shoots) without loss of quality in processed tea.

Prospects The world surplus of tea – due to steadily increasing production (2–3% per year) against stagnant consumption – will continue to put pressure on tea prices, which have been declining in real terms in recent years. An international tea agreement could stabilize tea prices to acceptable levels, but it appears to be entirely up to the main tea-producing countries to take effective steps in that direction. A strong association of tea-producing countries should also invest in promoting tea as an all-purpose and healthy beverage, in order to stem the present strong competition tea faces from other beverages such as herbal teas and soft drinks.

The economics of tea production can be improved considerably by increasing the inherent yield potential of cultivars, as well as by mechanizing of harvesting operations.

Much of the tea is still produced from old seed cultivars. Replacing these by high-yielding clonal cultivars, particularly those composite clones, would considerably increase economic returns. It also provides an opportunity of concentrating national tea production targets in smaller areas, thus releasing fertile land for alternative crop production. Molecular biology and genetic transformation could become an alternative approach for developing cultivars with host resistance to important diseases and pests, if such traits cannot be found in natural tea germplasm. Disease and pest management by chemical means will become increasingly difficult under the stringent rules for pesticide residues in processed tea.

Where tea is mainly a plantation crop and cost of labour is rapidly increasing, tea production will become completely uneconomic unless plucking is mechanized. Tractor-mounted and self-propelled machines capable of plucking tea without serious damage to leaves and stems in clonal plantations with uniform and strictly managed plucking tables have been developed for green-tea production and will soon be applied in black-tea production too, wherever quantity has priority over prime quality.

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A.F. Schoorel & H.A.M. van der Vossen

Chloranthus erectus (Buch.-Ham.) Verdc.

Kew Bull. 40(1): 217 (1985).
CHLORANTHACEAE
$2n$ = unknown

Synonyms *Cryphaea erecta* Buch.-Ham. (1825), *Chloranthus officinalis* Blume (1827) and perhaps *C. elatior* Link (1821).

Vernacular names Indonesia: keras tulang (Malay), uyah-uyahan (Javanese), harostulang (Sumatra). Malaysia: dikut-dikut, langut-langut (Sarawak), sambau paya (Peninsular). Philippines: barau-barau (Luzon), tul-an hinbad (Samar), tunggao (Tagbanua). Cambodia: kbâ:k dâmréi. Thailand: hom kai (northern), kraduk kai (central).

Origin and geographic distribution *C. erectus* is found in continental Asia from Nepal to Yunnan and the Andaman Islands, and throughout the Malesian region as far as New Guinea.

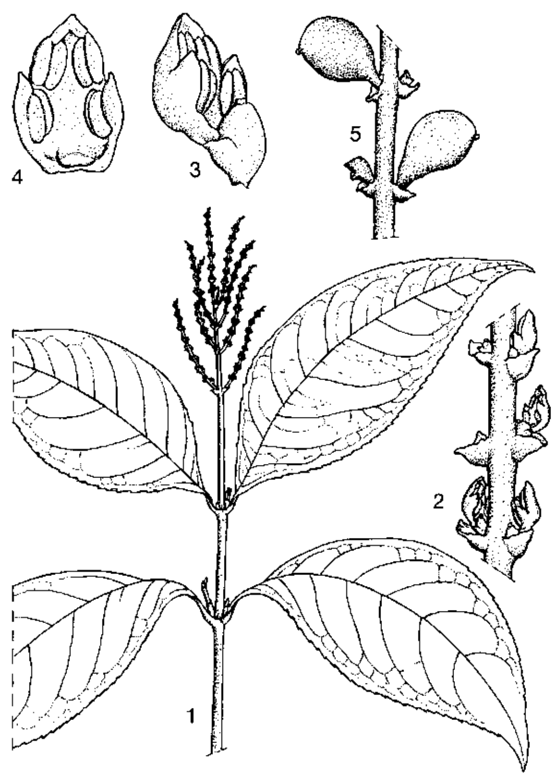
Uses All parts of *C. erectus* can be used to make a tea. Before *Camellia sinensis* (L.) Kuntze was planted in Java, the Javanese used dried leaves and roots of *C. erectus* to make 'tea', while the Sundanese used only the dried roots. In that period, dried stems, leaves and roots were sold in markets in Java. Nowadays, *C. erectus* parts are used only locally as a flavouring agent for home-grown tea. *C. erectus* plants are sometimes grown in Chinese-owned tea plantations and their leaves and flowers are added to drying tea leaves to impart a specific flavour and taste.

Tea made from the leaves or roots is drunk for medicinal purposes in Indonesia and Malaysia. It has sudorific activity and is especially used to treat fever and complaints accompanied by fever. A powder from boiled and dried roots is rubbed on the body to treat fever. Leaf extracts are used to cure venereal diseases. Root extracts are sometimes mixed with the bark of 'kulit lawang' (*Cinnamomum culitlawan* (L.) Kosterm.) as an antispasmodic during childbirth. Women in Kalimantan use a drink from boiled branches to prevent conception. In Java several farmers cultivate *C. erectus* in their home gardens as an ingredient for traditional herbal drinks ('jamu'). Tribal people in northern Thailand boil the roots of *C. erectus* (*C. elatior*), *C. nervosus* Collett & Hemsley and *Senna occidentalis* (L.) Link, and drink the liquid against malaria; they also use *C. erectus* (*C. elatior*) as a dye plant, producing dark blue or black colours. Because of its fragrant flowers and leaves, and its good response to shaping, *C. erectus* is also grown as an ornamental in Indonesia.

Production and international trade In the 19th Century the Dutch colonial government prohibited the cultivation of *Chloranthus* in Indonesia, in order to promote the planting and production of tea (*Camellia sinensis*). Since then *Chloranthus* has lost its popularity as a beverage, and now it is difficult to find dried material of 'keras tulang' on the market. Only small quantities of dried material are sold together with other ingredients for traditional medicines.

Properties All parts of *C. erectus* are fragrant and aromatic, especially the leaves, stems and roots when crushed. Crushed roots and branches have a camphor-like smell and a slightly peppery and rather bitter taste. The leaves contain an essential oil and the phenolic compound β-coumaric acid which is similar to that of *Piperaceae*.

Description A glabrous, aromatic, slightly woody herb or small shrub up to 3 m tall; nodes swollen, sometimes purplish. Leaves decussately opposite; petiole 1–1.5 cm long; stipules small, subulate; blade oblong-lanceolate to elliptical or ovate-oblong, 8–29 cm × 3–13 cm, base cuneate,



Chloranthus erectus (Buch.-Ham.) Verdc. – 1, flowering twig; 2, part of inflorescence; 3, flower; 4, organ bearing anthers; 5, fruits.

margin shallowly glandular-serrate, apex long acuminate, penninerved, bright green, glossy above. Inflorescence a terminal, peduncled panicle consisting of 5–13 spikes 2.5–5 cm long; bracts sheathing, ovate, acute; flowers much reduced, without perianth, bisexual; the male part a 3-lobed organ (fused stamens?) adnate to the upper half of the ovary, 1.2–1.6 mm long, with 3 anthers, median one 2-locellate, lateral ones 1-locellate, yellow, greenish-white or violet-white; the female part composed of a 1-locular ovary with a single ovule, partly enclosed by the male part, stigma subsessile, truncate. Fruit a drupe, subglobose or ellipsoid, 5–7 mm in diameter, fleshy, white-cream or rarely tinged violet or pinkish, glossy. Seed subglobose, yellow-white, minutely apiculate, narrow below, surrounded by a thin, fibrous endocarp; testa with lignified endotestal palisade cells.

Growth and development When *C. erectus* germinates the radicle appears first, followed a few days later by the plumule.

At the age of 1–2 months seedlings have 2–3 pairs of leaves and are 10–15 cm tall. Growth is sympodial. Flowering and fruiting starts when plants are 2 years old. At an age of 4–5 years, flowers and fruits are produced regularly throughout the year. The flowers are presumably pollinated by insects, whereas birds eat and disperse the ripe fruits.

Other botanical information The *Chloranthaceae* are generally regarded as a very primitive family. This is supported by the lack of vessels in the xylem of *Sarcandra* Gardner and the unspecialized vessels in *Chloranthus* Swartz, and by the presence of a gymnosperm type of lignin, guaiacyl lignin, in both genera.

The name *Chloranthus elatior* was published before *Cryphaea erecta* and would seem to have nomenclatural priority. However, the true identity of *C. elatior* remains doubtful since the only (sterile) specimen fragmentarily described by Link was destroyed in Berlin during the Second World War.

Ecology In the wild, *C. erectus* grows in primary and secondary tropical forest, at (20–)50–1450 (–2550) m altitude. At higher altitudes it is often found in *Araucaria* and *Nothofagus*–*Castanopsis* forest, often on limestone. Its lowland forest habitats include *Pandanus* and palm forest, riverine forest, and boggy areas.

Propagation and planting Both seeds and cuttings of *C. erectus* are used for propagation. Optimal germination is obtained by using ripe seeds, dried in the shade, and with the testa removed. Seeds are sown directly in moist and shaded nursery beds and germination follows within a week. Seedlings are ready to be pricked out into individual pots about 2 months later. They are kept in a shaded nursery for another 2–3 weeks and subsequently planted out in the field. Field planting should take place in the wet season to avoid moisture stress.

Cuttings 10–15 cm long are taken from internodes of branches with a diameter of about 5–8 mm. They should be placed in a shaded container or in a bin, and the soil and air should be kept moist by spraying. The cuttings are inserted in the planting medium to a depth of about 2 cm. Some growers use hormones such as indole-3-acetic acid (IAA) and indole-3-butyric acid (IBA) to stimulate root growth. After one week roots are about 1 cm long, and after 3 weeks the first pair of leaves have appeared. When 2–3 pairs of leaves have appeared, the plants are ready to be pricked out individually into pots. They need initial shade and are gradually hardened off before being planted out in the field.

Yield Although leaves and flowers of *C. erectus* are still used as a flavouring agent in small-scale tea industries, no yield data are available.

Handling after harvest Harvested parts of *C. erectus* are dried and stored. Dried parts gradually lose their aroma, but roots keep their odour and taste for a very long time if dried quickly and stored carefully.

Genetic resources *C. erectus* is found in primary and secondary forest, home gardens and village groves. As forest areas are continuously being cleared for new resettlement schemes or for plantations (oil palm, pulp and timber industries, etc.), *C. erectus* is threatened with extinction and germplasm collection is needed. In home gardens and botanical gardens some germplasm of *C. erectus* and its close relative *C. spicatus* (Thunb.) Makino is available in most countries of South-East Asia.

Prospects *C. erectus* may have potential as an alternative to tea and, as is evidenced by ethnobotanical information, as a phytomedicine. Its ability to grow in various habitats from low to high altitudes may stimulate this possible development.

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Harini M. Sangat

Coffea L.

Sp. pl.: 172 (1753).

RUBIACEAE

$x = 11$; $2n = 44$ (*C. arabica*); $2n = 22$ (all other *Coffea* species)

Major species and synonyms

- *Coffea arabica* L., Sp. pl.: 172 (1753), synonyms: *C. vulgaris* Moench (1794), *C. angustifolia* Roxb. (1814), *C. sundana* Miquel (1856).
- *Coffea canephora* Pierre ex Froehn., Notizbl. Bot. Gart. Berl. 1: 257 (1897), synonyms: *C. robusta* Linden (1900), *C. laurentii* De Wild. (1900), *C. ugandae* Cramer (1913).
- *Coffea liberica* Bull ex Hiern – see separate article.

Vernacular names General: coffee (En). Caféier (plant), café (product) (Fr). Indonesia, Malaysia and Papua New Guinea: kopi. Philippines: kapé (Tagalog), kahana (Sulu), kapi (Ifugao, Iloko, Tagalog). Thailand: kafae. Vietnam: c[af] ph[ee].

- *C. arabica*: arabica coffee, Arabian coffee (En). Caféier arabica (Fr). Vietnam: c[af] ph[ee] ch[ef].
- *C. canephora*: robusta coffee (En). Caféier robusta (Fr). Vietnam: c[af] ph[ee] v[oos]i.

Origin and geographic distribution Wild plants of most species of *Coffea* are components of the understorey of tropical forests in Africa. Whereas many forms of *C. canephora* can be found in the equatorial lowland forests from Guinea to Uganda, the centre of genetic diversity of *C. arabica* is restricted to the south-western highlands of Ethiopia.

Arabica coffee of Ethiopian origin was already cultivated in the 12th Century in Yemen. From there it was taken to India and Sri Lanka in the 16th and 17th Centuries by Arabian travellers. The first commercial coffee production outside Arabia started in Java (Indonesia) shortly after 1699, when coffee plants originating from Yemen but raised on the Malabar coast of India were introduced by the Dutch East India Company. In the course of the 18th Century coffee spread into the Caribbean and South America through mediation of the Botanic Garden of Amsterdam which distributed plant material obtained from Java in 1710.

All the coffee plants distributed to Asia and Latin America mentioned above were of *C. arabica* var. *arabica*, usually called *typica* (syn.: *C. arabica* var. *typica* Cramer). The coffee introduced by the French from Yemen, first to the island of La Réunion (formerly Bourbon) in 1715, then to Latin America and eventually in the 19th Century to Africa, was different, namely *C. arabica* var. *bourbon* (B. Rodr.) Choussy. It has a more compact and upright habit, is higher-yielding and generally produces better-quality coffee than *typica*.

By 1860 world trade in coffee involved some 250 000 t per year, mostly from Brazil, Indonesia and Sri Lanka. On account of its superior cup quality, arabica coffee would certainly have continued to be the exclusive producer of coffee, had it not been so vulnerable to diseases, particularly to coffee leaf rust (*Hemileia vastatrix*) when grown at lower altitudes in equatorial zones. Coffee leaf rust had virtually wiped out coffee cultivation in Asia by 1890. Whereas in Sri Lanka coffee was replaced by tea, Indonesia continued to be a major coffee producer, switching to another coffee species, *C. canephora*, which proved to be resistant to leaf rust epidemics.

Robusta coffee was first introduced into Java in 1900 from Congo. Selection programmes in East Java resulted in high-yielding plant material, which formed the basis for robusta coffee production not only in Asia – major producers being Indonesia, Vietnam and India – but even in tropical Africa.

In South-East Asia, the cultivation of arabica coffee is now restricted to high-altitude areas particularly in Papua New Guinea, but also in Indonesia, Vietnam, the Philippines, northern Thailand and Burma (Myanmar).

Uses The stimulating effect of the coffee beverage is largely derived from the alkaloid caffeine, but cured beans have to be roasted and finely ground to bring out the characteristic coffee aroma. The habit of drinking coffee as a hot watery extract from roast and ground beans is still prevalent in many countries. Vacuum-sealed packets of whole roast beans or ground coffee prepared from top quality arabicas, or various blends of arabica with robusta coffee are available, especially to the European consumer. In some producer countries it is very common to roast locally available coffee in the home and to prepare the brew (called 'kopi tubruk' in Indonesia) by pouring hot water over freshly roast and ground coffee. Over the last 40 years, instant coffee as soluble powder, prepared by dehydrating extracts of roast and ground coffee, has become a very important commodity. Globally about 20% of all coffees are consumed as instant coffee. Higher rates are found in the United Kingdom (80%), Japan (40%) and the United States (30%). Although arabica coffee gives a beverage of better quality, robustas are in great demand by the instant coffee industry because of the higher yields of soluble solids. About 10% of the world's exportable coffee is decaffeinated.

Roast and ground coffee is a constituent of traditional medicines in South-East Asia, e.g. to alleviate stomachache and diarrhoea, to increase blood pressure, and as a diuretic and antidote. It is extensively used to flavour candies. In Java, it is often used to mask the odour of a corpse before funeral. Coffee pulp and parchment are applied as manure and mulch.

Production and international trade Total world production of coffee (raw beans or green beans) was about 5.9 million t/year from 10.6 million ha over the period 1995–1999. About 70% of this is arabica coffee, mostly from Latin America (but also eastern and central Africa, India, Indonesia and Papua New Guinea), 30% is robusta from Africa and Asia and less than 1% is obtained from *C. liberica* and other coffees. For at least 20 of the 60 producing countries coffee contributes more than 20% to the total value of exports. Some 75% of all coffee is exported, more than 90% of it to Europe, the United States and Japan. At least half of the world population drinks coffee, average per capita annual consumption varying from 0.1 (India) – 4.5 (Brazil) kg in coffee-producing countries to 2.8 (Japan) – 10.9 (Finland) kg in consuming countries.

The price elasticity of supply is low and prices have fluctuated from US$ 1.0–5.5 per kg green coffee, with top arabicas usually fetching 50–100% more than robusta coffees. The total value of the international trade in green coffee was estimated at US$ 13.5 billion in 1997 against US$ 9.5 billion in 1996.

Coffee production in Indonesia increased from 180 000 t in 1971 to 480 000 t in 1996, mostly robusta coffee except for some 40 000 t arabica mainly from Aceh, North Sumatra, East Java, South Sulawesi, Bali and eastern Timor. *C. liberica* (liberica and excelsa coffees) are also grown on a limited scale, producing some 4000 t annually. Indonesia has become the third largest coffee producer after Brazil (1.5 million t arabica and 0.3 million t robusta) and Colombia (750 000 t arabica). Vietnam has shown a remarkable recovery and further expansion of its coffee production from a mere 3000 t in 1986 to 400 000 t in 1998 (95% robusta). It is now the second largest robusta-producing country, after Indonesia but before Brazil, Uganda and Ivory Coast. Papua New Guinea, with 60 000 t, is the largest arabica coffee producer in South-East Asia. The Philippines produce some 55 000 t (25% liberica and 5% arabica), Thailand 75 000 t (99% robusta), Malaysia 8000 t (50% robusta and 50% liberica coffee), all for local consumption. Altogether South-East Asia currently produces about 20% of the world coffee and 51% of all robustas.

In most countries coffee is a smallholder crop. For instance, in Indonesia there are about 60 000 ha of government and private coffee estates (size 30–1500 ha), while the remaining 1 100 000 ha of coffee are smallholder farms of 0.3–2.0 ha. Smallholdings also dominate in Malaysia (90%), Thailand (90%), Papua New Guinea (70%) and the Philippines (60%). In Vietnam coffee used to be mostly produced by government-controlled plantations or collective farm units, but as much as 50% of the coffee is now produced by smallholders.

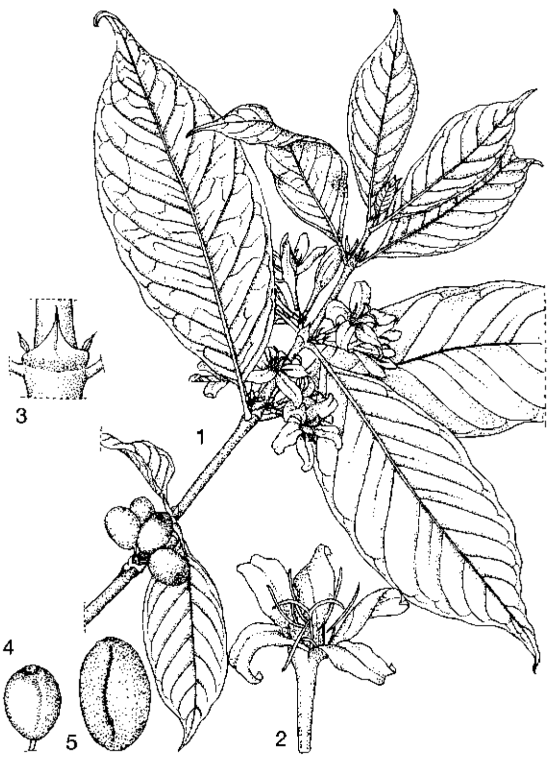
Four main classes of coffee are distinguished in the international coffee trade. They are, in descending order of quality:

- Colombian milds, indicating washed arabicas from Colombia, Kenya and Tanzania;
- other milds that are also washed arabicas;
- dry-processed or hard arabicas (e.g. Brazil, Ethiopia);
- robustas, washed or dry-processed.

Properties The coffee bean consists largely of endosperm with the following approximate composition per 100 g dried beans: water 10–13 g, proteins and free amino acids 11–16 g, lipids 12–14 g, sucrose and reducing sugars 5–9 g, cellulose and other polysaccharides 32–48 g, chlorogenic and other acids 10–15 g, ash and minerals 4 g. The caffeine content in arabicas ranges from 0.6–1.7%

and in robusta coffee from 1.5–3.3%. During roasting most of the water evaporates, the sugars caramelize, the polysaccharides carbonize and many compounds are converted into volatiles (so far about 700 have been identified).
Coffee quality is determined by experienced tasters: visual assessment of the raw bean is followed by trial roasting, brewing and organoleptic evaluation of the beverage. The liquor of high-quality washed arabicas (raw beans typically have a bluish-green colour) will be richly aromatic (flavour) with a pleasing acidity; dry-processed arabicas will be less acid but with more body. Raw beans of washed or dry-processed robustas are brownish in colour and the liquor will have a neutral flavour at best, little acidity, considerable body but a somewhat harsh, bitter and astringent taste.
The 1000-seed weight (18% moisture and with parchment) is 450–500 g for arabica and about 400 g for robusta coffee.

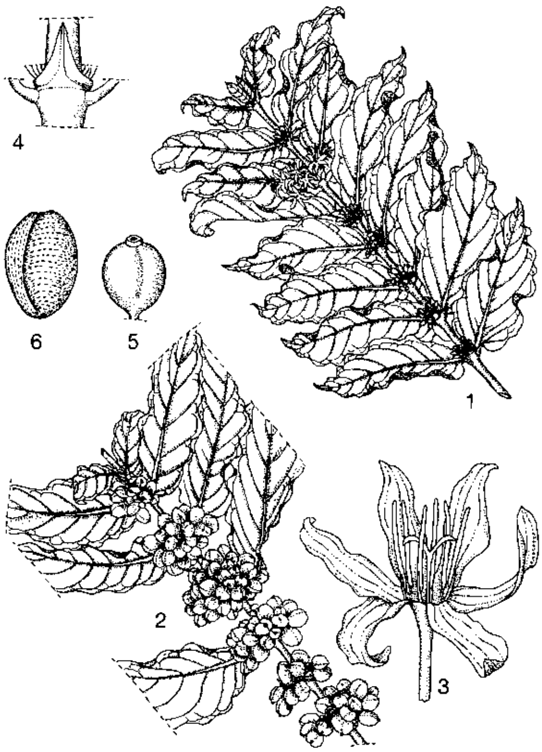
Description Shrubs or trees. Leaves opposite, usually with characteristic, connate, interpetiolar, subtriangular stipules. Inflorescence consisting of axillary clusters of cymes in both axils of a leaf pair or terminal; flowers bisexual, often white; calyx tubular with 4–5(–8) small teeth or lobes; corolla tubular, 4–8-lobed; stamens inserted in throat or lower, exserted or enclosed; ovary inferior, 2-celled, with 1 ovule per cell; style filiform, stigma with 2 linear branches. Fruit a drupe (in coffee often called 'berry'), with red to black exocarp, usually fleshy mesocarp and horny endocarp containing 2 stones usually. Seed (in coffee often called 'bean') plano-convex, on the flat side usually grooved.



Coffea arabica L. – 1, twig with flowers and fruits; 2, flower; 3, stipule; 4, fruit, 5, seed.

- *C. arabica*. Evergreen, glabrous shrub or small tree, often multi-stemmed, 4–5 m tall, in cultivation pruned to 1.8–2.5 m. Taproot often less than 1 m long, but some lateral roots may grow downwards to depths of 3–4 m for firm anchorage; 90% of feeding roots in the top 30 cm of the soil. Leaves decussate; petiole up to 2 cm long; blade ovate, (5–)10–15(–25) cm × 5–10 cm, acute at base, margin somewhat undulate, apex acuminate, glossy, dark green above, lighter green beneath, with domatia (small cavities) beneath at insertion of lateral veins, giving slight protuberances above. Flowers in axillary clusters, 10–30 per node, hermaphrodite, fragrant, creamy white, with short pedicel; calyx small and 5-denticulate; corolla tube 10 mm long, lobes 5, ovate, 8 mm long, white; stamens 5, inserted on corolla tube between lobes, anthers bilocular, opening lengthwise; pistil with bilocular ovary, style 12–15 mm long. Fruit ovoid-ellipsoidal, 12–18 mm × 8–15 mm, initially green but turning red at maturity, mesocarp fleshy, endocarp (parchment) fibrous, surrounding seeds. Seed ellipsoidal, 8–12 mm long, 2 per fruit; testa thin (silver skin), endosperm abundant, embryo at base of the seed, small. Seedling with epigeal germination.
- *C. canephora* differs from *C. arabica* in the following characteristics: Larger tree, up to 8–12 m tall, with long flexible branches, shorter taproot and shallower rooted. Leaves 15–30(–40) cm × 5–15 cm with corrugated surface and petiole 1–2 cm long. Flowers white, up to 80 flowers per node, with 5–7-lobed corolla; stamens and style well exserted. Fruits smaller, 8–16 mm long. Generally *C. canephora* is a more vigorous grower than *C. arabica* and shows a much higher polymorphism.

Growth and development Coffee has no seed dormancy. At ambient temperatures seed viability is lost within 3–6 months, but when stored moist at 15°C it can be maintained at 90% for 15 (robus-



Coffea canephora Pierre ex Froehn. – 1, flowering twig; 2, fruiting twig; 3, flower; 4, stipule; 5, fruit, 6, seed.

ta) to 30 (arabica) months. Longer storage by cryopreservation may soon prove possible. After sowing in wet sand, germination is complete within 6–8 weeks. Removal of the parchment halves the germination time. The cotyledons unfold and the first pair of leaves appears 10–12 weeks after sowing. Subsequent leaf pairs, always at right angles to the pair below, are formed at 3–4-week intervals. The first pair of side shoots emerges at the node of the 5–9th leaf pair. Seedlings 30–40 cm tall are ready for field planting 7–9 months after sowing for robusta and 11–15 months for arabica.

Coffee develops according to the architectural model of Roux, which is characterized by a continuously growing monopodial orthotropic stem with plagiotropic opposite branches. A series of buds is found in the axil of each leaf on the orthotropic seedling stem. The highest bud ('head of series') produces a plagiotropic side shoot ('primary'), while the lower buds remain dormant; when forced, orthotropic suckers grow out. The series of buds present in the axil of each leaf of plagiotropic shoots give rise to inflorescences or plagiotropic side shoots ('secondaries'); buds on plagiotropic shoots cannot develop into orthotropic shoots.

Under ideal conditions a 3-year-old unpruned arabica tree (2 years in the field, producing its first crop) is cone-shaped with 25–30 pairs of primary branches on a main stem 150–180 cm tall. Annual shoot growth on primaries may be 22–35 cm with 10–12 new nodes. The fruit of such a tree is borne on the nodes close to the main stem of the lower 15–20 primaries. Nodes flower only once; within a few years the crop on the younger primaries high on the main stem is beyond the reach of pickers, while the crop lower in the tree dwindles as shoot vigour declines. To restrict tree height and maintain vigour in the basal parts, strict juvenation pruning is needed. Cutting back the main stem stimulates the emergence of orthotropic suckers from serial buds, especially below the cut and at the base of the stem. One or several of these basal suckers can replace the main stem, starting a new cycle of productive years.

Coffee shoots tend to grow continuously, but their growth rate is readily slowed down to a virtual standstill by adverse external (e.g. drought) or internal (e.g. a good fruit crop) factors. Growth is rapid at the beginning of a rainy season.

During rapid extension growth no flowers are initiated, but as shoot growth subsides, floral development starts on 5–7-month-old nodes and gradually proceeds towards the shoot tip. Daylength (12–18 h photoperiods) has little influence on floral initiation in coffee. Flower buds become dormant before they are fully developed and as the season progresses more flower buds enter dormancy. Flower bud dormancy is progressively decreased by continued water stress; rapid rehydration – usually accomplished by the first showers at the onset of the rainy season – induces blossoming 6–12 days later. Young buds that are still dormant are triggered by subsequent showers. The more or less simultaneous release from dormancy synchronizes flowering and fruit growth.

C. arabica is self-fertile – less than 10% of the flowers are naturally cross-pollinated – and fruit set is high. The fruitlets hardly grow during the first 6–8 weeks ('pinhead' stage). Since flowering follows the early rains this means that fruit growth is delayed until the rainy season has set in and shoot growth has resumed. In bimodal rainfall areas flowering occurs at the beginning of both rainy seasons and the associated fruit growth periods overlap. The fruits are mature in 8–9 months.

Coffee fruits are strong assimilate-accepting sinks and the tree is unable to regulate the crop load effectively by shedding fruitlets. The key issue in coffee growing is therefore the prevention of excessive cropping that leads to biennial bearing or even shoot dieback. The use of shade trees has a tempering effect on shoot growth, improves leaf retention, but also reduces flower initiation. Without shade, fruiting is much heavier, with up to 20 fruits per node. At least 20 cm^2 leaf area (one leaf = 30–40 cm^2) is needed to support each fruit without affecting vegetative growth. Crop husbandry is therefore aimed at maintaining enough foliage to sustain the crop, as well as new shoot growth throughout the season by pruning, mulching, irrigation, fertilizing, control of diseases and pests and 'tonic' sprays of fungicide. The latter treatment improves leaf retention by 2–3 months, particularly in climates with distinct periods of water stress, resulting in progressive yield increases of 50–100%.

The growth of robusta is comparable with arabica, except that primaries become longer and produce few secondary branches. Flower initiation follows shoot growth more closely and flowering periodicity becomes less distinct, especially when rainfall is well-distributed over the year. Nodes on robusta branches may flower twice: first in the season in which the shoot is formed and again two years later. In the intervening year the fruits at these nodes should prevent repeated flowering. *C. canephora* is allogamous, with a gametophytic system of self-incompatibility. Robusta fruits take 9–11 months to mature.

Other botanical information *Coffea* belongs to the subfamily *Ixoroideae* and the tribe *Coffeae*. Recent taxonomic studies, including the application of molecular marker technologies to chloroplast and nuclear DNA extracted from several species, confirm a monophyletic origin of all species of the genus *Coffea*. The process of differentiation into clusters of related species coinciding with geographic regions in Africa has not yet progressed into strong genetic barriers and, therefore, does not justify the distinction into sections as applied in earlier taxonomic classifications. Altogether about 100 species (taxa) of the genus *Coffea* have been identified so far. They are without exception indigenous to the forests of tropical Africa and Madagascar and all are diploid species, except the allotetraploid *C. arabica*, which has its origin in the highland forests of south-western Ethiopia. Species close to *C. eugenioides* S. Moore and to *C. canephora* (or *C. congensis* Froehner) are the most likely maternal and paternal progenitors respectively of *C. arabica*.

There are numerous cultivars of the *typica* and *bourbon* varieties of arabica coffee (preferably classified as cultivar groups), but all originate from the genetically very narrow base population of Yemen: 'Typica National', 'Bourbon', 'Mundo Novo', 'Caturra', 'Blue Mountain', 'Maragogipe', 'sL 28', 'N 39', 'Kent', 'Padang' and 'Blawan Pasumah'. Some cultivars are selections from spontaneous interspecific hybrids, e.g. S (288, 333, 795) and BA selections from 'India' and 'Hibrido de Timor', or from germplasm collections in Ethiopia and nearby Sudan such as 'Geisha', 'Abyssinia' and 'Rume Sudan'. 'Catimor', from a cross between 'Caturra' and 'Hibrido de Timor', is a compact cultivar resistant to most races of coffee leaf rust. 'Icatu', developed in Brazil from an interspecific cross between *C. arabica* and (tetraploid) *C. canephora* followed by backcrossing to *C. arabica* and selection, is also highly resistant to coffee leaf rust.

In the polymorphic *C. canephora* two subpopulations (cv. groups) are distinguished:

- 'Congolese', with erect growth habit and large leaves, of Central African origin, including robusta forms; and
- 'Guinean', with a more spreading growth habit and smaller leaves and fruits, of West (Guinean coast) and Central African (Uganda) origin, including 'nganda' and 'kouilu' forms.

Important robusta cultivars (clones or seedlings) are the BP and SA selections of Java, 'S274' and the BR series of India, the INEAC selections of Congo, and the IRCC selections of Ivory Coast.

Interspecific hybrids such as 'Congusta' of Java and the C × R cultivar of India (between *C. congensis* and *C. canephora*) and 'Arabusta' (between *C. arabica* and tetraploid *C. canephora*) also have potential for robusta coffee production at medium to low altitudes.

Ecology Arabica coffee requires an average daily temperature of 18–22°C with a maximum not exceeding 30°C. This restricts its cultivation to high altitudes in equatorial (0–7°N/S) areas (1000–2100 m) or lower altitudes (300–1100 m) further from the equator, as in India, Vietnam, Thailand, and South America (9–23°N & S). Temperatures near 0°C will kill the leaves immediately, while long periods of hot (and dry) weather will cause wilting, even at high soil moisture. In the humid lowland tropics, arabica coffee will show poor flowering (star flowers) and shoot dieback. Annual rainfall requirements are 1400–2200 mm with no more than 3 months of less than 70 mm. Lower rainfall can be compensated for by irrigation (e.g. East Africa).

Robusta coffee is well adapted to the warm and humid equatorial climates with average temperatures of 22–26°C, minimum not below 10°C at altitudes of 100–800 m, and well-distributed annual rainfall of 2000 mm or more.

Coffee is able to grow on a wide range of soils provided these are deep (at least 2 m), free-draining loams with a good water-holding capacity, fertile and slightly acid (pH 5–6). The topsoil should contain at least 2% organic matter. The parent material of the major coffee soils may be lava and tuff (e.g. Kenya), volcanic ash (Indonesia, Central America), or basalt and granite (Brazil, West Africa, India). An exception is the western highlands of Papua New Guinea, where high rainfall well distributed over the year permits successful coffee production on clay soil of just 20–30 cm deep over compacted clay of volcanic origin.

Propagation and planting Most cultivars of the self-pollinating arabica coffee are practically pure lines, propagated by seed. In Kenya F_1 hybrid seeds are produced by hand pollinating new disease-resistant arabica cultivars. Robusta coffee is cross-pollinating and is often propagated from seed obtained from biclonal or polyclonal gardens. Vegetative propagation of high-yielding robusta clones is applied on a limited scale in Java (grafting and rooted cuttings), in Congo, Ivory Coast and Uganda (rooted cuttings). New methods of in vitro multiplication in arabica (hybrid cultivars) and robusta coffee, including micro-propagation and somatic embryogenesis, are gradually being applied as well. Seedlings or plants from rooted cuttings are raised on beds or in polythene bags in shaded nurseries.

In South-East and South Asia, coffee is grown either in pure stands with temporary or permanent shade trees, or in association with perennial crops (coconut palms, rubber, clove, fruit trees and pepper), or in home gardens with food crops, bananas and perennial crops. In East Africa and South America, arabica coffee is usually grown without shade.

Young plants of 7–15 months old are planted in the field in large holes (60 cm × 60 cm × 60 cm) refilled with topsoil, organic material and rock phosphate. Various spacings and rows (right lines and squares) are used in densities of 1300–2800 trees/ha for arabica and 1100–1400 trees/ha for robusta coffee. High density planting of 3300–5000 trees/ha, as applied in Latin America and East Africa with compact arabica cultivars like 'Caturra', 'Catimor', and the F_1 hybrid 'Ruiru 11', is also common in Indonesia and in Papua New Guinea. On slopes of more than 30° it is necessary to plant along contour lines or on terraces to prevent erosion.

Common shade trees are *Leucaena leucocephala* (Lamk) de Wit, *Erythrina subumbrans* (Hassk.) Merrill, *Gliricidia sepium* (Jacq.) Kunth ex Walp., *Paraserianthes falcataria* (L.) Nielsen and *Grevillea robusta* A. Cunn. ex R. Br. If cultivation is intensive and inputs are optimal, higher yields are obtained with unshaded coffee but at lower standards of crop management or sub-optimal ecological conditions shade will prevent overbearing and shoot dieback.

Husbandry Pruning is essential in coffee production: (a) to achieve a tree of the desired shape, (b) to maximize the amount of new wood for the next season's crop, (c) to maintain a correct balance between leaf area and crop, (d) to prevent overbearing and thus reduce biennial production, and (e) to facilitate disease and pest control. The main pruning systems are:

- single-stem capped at 1.5–1.8 m (Indonesia, Malaysia) eventually resulting in an umbrella-shaped tree;
- multiple-stem on 2–5 orthotropic capped or uncapped stems (Papua New Guinea, Vietnam, Thailand);
- agobiado, which is a multiple-stem system on a main stem that has been bent over at an early age (Philippines);
- rejuvenation when trees are old and yields are low, by stumping to 30 cm above the ground to encourage new orthotropic shoots.

It is very important to suppress noxious weeds, particularly couch grass (*Digitaria scalarum* (Schweinf.) Chiov.), by careful tillage without damaging the superficial feeder roots, herbicides, mulching and/or leguminous cover crops.

Fertilizer requirements depend on crop yield and nutrient status of the soil. Nutrients removed by harvesting 6 t of fruits of robusta coffee, equivalent to 1 t of green beans, are: 35 kg N, 6 kg P_2O_5, 50 kg K_2O, 4 kg CaO, 4 kg MgO, 0.3 kg Fe_2O_3 and 0.02 kg Mn_3O_4. Fertilizer applications should be based on the nutrient status of the tree, which can be accurately determined by foliar analysis. Generally, nitrogen fertilizers at rates of 50–100 kg N per ha per year give clear yield responses. Responses to potassium fertilizer vary from zero in mulched coffee grown on volcanic soils rich in potassium (e.g. East Africa) to highly significant on soils with a low K status: 0–400 kg K_2O per ha per year. Very high K application may induce Mg deficiency. Phosphate is often applied as compound fertilizers (2-1-2), but its effect is greatest in foliar applications. Calcium in the form of lime is used to correct soil acidity. Magnesium deficiency is best corrected by foliar applications, as are minor elements such as boron and manganese. Organic manures – stable manure, cover crops, mulch and decaying coffee pulp – are not only alternatives to chemical fertilizers, and often the only fertilizers available to smallholders, but are also essential to maintain the humus content of the soil and to improve the soil texture.

Diseases and pests Coffee leaf rust (*Hemileia vastatrix*) is the major disease in arabica coffee and is present in all coffee-producing countries, including South-East Asia. It reached Papua New Guinea in 1986. Control by spraying is more effective using copper-based than using systemic fungicides. A new development is the application of granular systemic fungicides to the soil. The very destructive coffee berry disease caused by *Colletotrichum kahawae* (syn. *C. coffeanum*) of arabica coffee is still restricted to Africa, although climatic conditions in certain high-altitude areas of Latin America and Asia are thought to be favourable to epidemic outbreaks. Robusta coffee is usually resistant to both diseases. Diseases of both coffee species include brown eye spot (*Cercospora coffeicola*) on leaves of young coffee, tip dieback caused by *Rhizoctonia* spp., vascular wilt disease or tracheomycosis caused by *Fusarium xylarioides* (perfect stage: *Gibberella xylarioides*), root diseases caused by *Fusarium solani, Armellaria mellea, Fomes noxius, Rosellinia* spp. and *Rigidoporus lignosus*, particularly on recently cleared land or where shade trees have been removed, and damping-off in coffee nurseries caused by *Rhizoctonia solani*.

Several important nematodes attack both arabica and robusta coffee: *Meloidogyne* spp. causing root knots and galls, *Pratylenchus coffea*, *Radopholus similis* and *Rotylenchus* spp.

Over 900 insect species are known to infest coffee. Major pests on coffee in South-East Asia are, in order of importance: coffee berry-borer (*Stephanoderes hampei*) particularly in robusta coffee, various stem-borers (*Xyleborus* spp., *Xylotrechus quadripes, Zeuzera coffeae*), shot-hole borer (*Xylosandrus compactus*), green scale (*Coccus viridis*), brown scale (*Saissetia coffea*) and mealy bug (*Planococcus citri*). Integrated pest management (IPM) in coffee, based on early warning systems in combination with chemical, cultural and biological (parasitoids, predators, pathogens and sex-pheromone traps) control, is more effective than frequent application of broad-spectrum and persistent insecticides. Maintenance of the right microclimate is also essential for effective IPM in coffee.

Harvesting Selective picking of ripe fruits of coffee at 7–10 day intervals is common in Java, Sumatra, Sulawesi and Papua New Guinea, where harvesting extends over a period of 7–9 months. Where the harvesting season is shorter or the cost of hired labour higher, as in South Sumatra and in most other regions in South-East Asia, whole branches are stripped when the majority of fruits are ripe. Costs of harvesting are 2–3 times higher for selective picking than strip picking: 8–9 kg coffee/man-day are hand-picked in Aceh (North Sumatra), whereas 20 kg/man-day are obtained in Lampung (South Sumatra) by stripping. In Java, coffee beans are sometimes collected from marten ('luak') droppings and marketed as 'kopi luak'. This coffee is regarded as being of high quality because it is certain to have been derived from ripe coffee fruits.

Yield Yield may vary from 200 kg green coffee beans per ha from low-input smallholder plots to 2 t/ha for arabica and 3.5 t/ha for robusta coffee at conventional spacings and without shading. Yields of 5 t/ha have been obtained in high-density experimental plots of arabica coffee in Colombia and Kenya. Average yields/ha of robusta coffee per region in Indonesia are: East Java 600 kg (mostly estates), Central Java 350 kg, Lampung 750 kg and Aceh 600 kg. For arabica coffee, average yields per ha vary from 800 kg in East Java to 950–1000 kg in Aceh and South Sulawesi. The national average in Vietnam and in Papua New Guinea is about 1.3 t/ha.

Handling after harvest There are two methods of post-harvest handling in coffee.

- The wet process: ripe fruits are pulped within 12–24 hours after harvesting, fermented to degrade the mucilage, washed, carefully dried in the sun (7–10 days) or mechanically (6–20 hours) or by a combination of both methods, and stored as dry (11–12% moisture content) parchment coffee. This process is carried out in coffee factories owned by estates and smallholder cooperative societies, or with small hand-pulpers and basins by individual smallholders.
- The dry process: fruits from strip picking – various stages of green, ripe and overmature fruits – are dried directly for 3–4 weeks in the sun on platforms or mechanically (2–3 days). Dry-processed coffee is more difficult to store than parchment coffee because of its strong hygroscopic properties.

Curing of dried parchment coffee – including hulling to remove the parchment, polishing to remove remains of silver skin and grading – takes place in central coffee mills. Dry-processed coffee is treated in a similar manner, but requires a different type of huller. The clean coffee is graded according to international standards of size and shape of beans, colour and percentage defects (broken beans, stones, husks). The clean green coffee is exported in bags of 60–70 kg, and can be stored under dry and cool conditions for 1–2 years without loss of quality. The final stage of coffee processing – blending, roasting and packaging as whole beans or ground coffee – always takes place close to the consumer market, to assure optimum quality. About 20% of the green coffee is processed into instant coffee.

Genetic resources Systematic collections of wild and semi-cultivated *C. arabica* in the primary centre of genetic diversity in Ethiopia were made by the FAO coffee mission in 1964/65, by a coffee mission of the 'Institut de recherche pour le développement' (IRD, formerly ORSTOM) in 1967 and by the Ethiopian Institute of Agricultural Research since 1970. This valuable material is preserved and being studied at coffee research institutes in Ethiopia, Kenya, Tanzania, Ivory Coast, Cameroon, Madagascar, Costa Rica, Brazil, Colombia, India and Indonesia. IRD has made several collections of germplasm of *C. canephora* and other diploid species in primary centres of genetic diversity in West and Central Africa since 1975 and in Madagascar since 1960. This material is now available at research institutes in Ivory Coast, Cameroon, the Central African Republic and Madagascar. The Indonesian Coffee and Cocoa Research Institute (ICCRI) maintains germplasm collections for *C. arabica*, *C. canephora* and other *Coffea* species at 3 locations in Java (2000 accessions). Absence of strong genetic barriers between species of the genus *Coffea* offers considerable prospects of introgressing desirable characters from wild into the two most important cultivated species by interspecific hybridization.

The International Plant Genetic Resources Institute (IPGRI) emphasizes the great urgency for intensifying germplasm collection within the still existing wild populations of *Coffea* species, in tropical Africa and Madagascar, before the natural habitats disappear.

Breeding Arabica coffee represents a rare example of a woody perennial to which breeding methods common to self-pollinated crops have been applied successfully. Most of the cultivars currently grown in the world are pure lines developed by selection within genetically narrow source populations.

Breeding for resistance to coffee leaf rust started in India in the 1920s but was later also taken up in Angola, Brazil and Colombia. Much of the fundamental work on *Hemileia vastatrix* – identification of physiological races of the pathogen and the genetics of resistance in the host – was performed and coordinated by the Coffee Rust Research Centre at Oeiras in Portugal. One result was the new cultivar Catimor, certain lines of which are homozygous for dominant resistance genes SH_6–SH_9, making this cultivar resistant to all known races of coffee leaf rust. The grave threats posed by coffee berry disease (*Colletotrichum kahawae*) to arabica coffee in Africa prompted an entirely new breeding programme in Kenya in 1971, resulting in F_1 hybrid cultivars resistant to both diseases in 1986. Selection for resistance to coffee berry disease is also being carried out in natural coffee populations in Ethiopia. The demand for resistance to both diseases to be combined with high yield and bean quality, as well as with compact growth for high-density planting, led to fundamental studies being carried out in Kenya on the inheritance of resistance to coffee berry disease and of yield and quality components.

Robusta coffee is a strictly cross-pollinating species; inbreeding is prevented by self-incompatibility. All plants in a seedling population will be highly heterozygous, and desired genotypes can only be fixed by vegetative propagation. Plots of cross-compatible robusta clones may outyield fields established from seedlings by 40–50%. However, in response to poor farmer take-up and major logistic problems connected with conventional methods of vegetative propagation, coffee breeders in Indonesia, Congo, Ivory Coast and Vietnam eventually adopted breeding plans based on recurrent selection, leading to polycross seed from clonal gardens.

Large-scale in vitro propagation by embryogenesis has been proven feasible and could overcome these problems. The possibility of developing pure inbred lines through haploidy, as a basis for F_1 hybrid seed cultivars, is currently being studied in Ivory Coast. Such a breeding plan also includes interpopulation hybrids with a high yield potential.

Earlier expectations that arabica × robusta interspecific crosses, such as the Arabusta hybrids developed in Ivory Coast, would increase quality in traditional robusta production in the tropical lowlands of Africa and Asia have not materialized so far.

Prospects The exploitation of genetic resources in *Coffea* did not start until recently, and therefore there are high hopes for further improvement in yield, disease and pest resistance and other desirable characteristics, by conventional and innovative breeding methods. Molecular markers are increasingly being applied in coffee for the detection of genetic diversity and in marker-assisted selection. In the long term genetic transformation could contribute to host resistance to important pests (e.g. berry borer). In South-East Asia, ecological conditions are favourable for coffee and production per ha could be increased considerably by more intensive crop management.
On the other hand, the high probability of continuous overproduction of coffee at mondial level and the pressure to shift land use on fertile land to food crop production to feed the ever-increasing population would make further expansion of coffee production a questionable policy. However, the spectacular yields obtained in close-spaced and intensively managed coffee become a realistic proposition with new compact-growing and disease-resistant cultivars. This would mean that national coffee quotas could in future be met from less than half of the land currently under coffee. Land would thus become available for food cropping and possibly other land-use systems.

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Coffea liberica Bull ex Hiern

Trans. Linn. Soc. London, Bot. 1: 171, t. 24 (1876).

RUBIACEAE

$2n = 22$

Synonyms *Coffea dewevrei* De Wild. & T. Durand (1899), *C. arnoldiana* De Wild. (1900), *C. klainii* Pierre ex De Wild. (1900), *C. dybowskii* De Wild. (1901), *C. excelsa* A. Chev. (1903), *C. abeokutae* P.J.S. Cramer (1913).

Vernacular names Liberica coffee, Liberian coffee, excelsa coffee (En). Caféier liberica (Fr). Indonesia: kopi nangka. Philippines: kapeng barako (liberica cultivars). Thailand: kafae-baiyai (central). Vietnam: c[af] ph[ee] d[aa]u da, c[af] ph[ee] m[is]t.

Origin and geographic distribution Liberica coffee is native to tropical West and Central

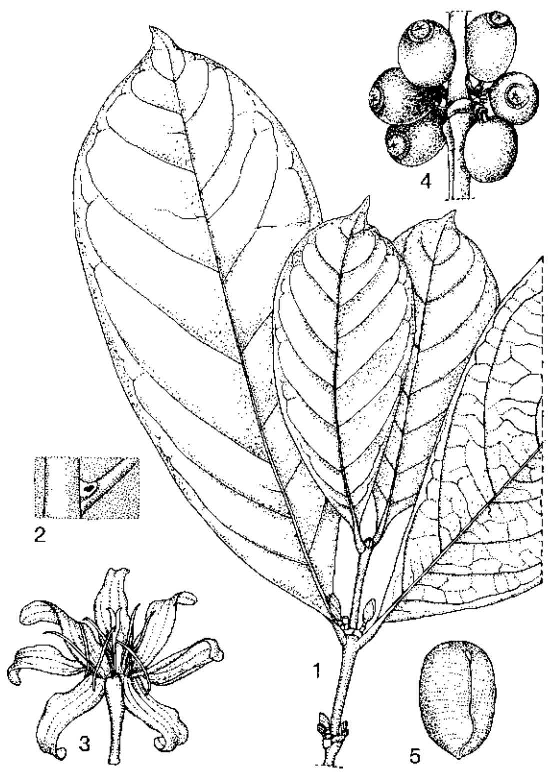
Africa. Nowadays, it is fairly widely cultivated especially in Guyana, Surinam, Bioko (Fernando Po), Sao Tomé, Liberia, Malaysia and the Philippines, and to a lesser extent also in Sierra Leone, Ivory Coast, Nigeria, Congo (Brazzaville), Mauritius, Sri Lanka, India, Thailand, Vietnam, Taiwan and on Timor. The first plantation of liberica coffee was established in Liberia in 1864, but reports of its cultivation go back to 1792. Its supposed resistance to coffee leaf rust disease resulted in a rapid introduction all over the world during the late 19th Century; it reached India in 1872 and Indonesia in 1875. In Indonesia it was cultivated quite extensively, but when it, too, proved to be susceptible to coffee leaf rust it was replaced by robusta coffee. In Peninsular Malaysia commercial cultivation started in 1880–1890.

Uses Coffee, the hot watery extract from roast and ground seeds ('beans'), from *C. liberica* has a more bitter taste than that of the well-known arabica or robusta coffees. Although this is appreciated by certain groups in southern Peninsular Malaysia and Sabah, and in Africa, liberica coffee is generally drunk with lots of sugar and milk to mask the taste. It is also blended with other coffees, or used in mixtures with other liquids. The taste of excelsa coffee, which originates from a botanical variety of *C. liberica*, is less bitter than that of true liberica coffee.

Production and international trade Although liberica coffee contributes only about 1% to world coffee production, it is very important in Malaysia; there it is the most important coffee, with an estimated 12 000 ha in 1989, 80% of the total area under coffee. Centres of cultivation in Malaysia are Selangor, Johore, Malacca, Perak and eastern Sabah. In the Philippines about 22 000 ha or 25% of the total area under coffee is liberica coffee, mainly in Luzon. Indonesia produces some 4000 t of liberica coffee annually.

Properties On a dry matter basis liberica coffee beans contain about 0.5–1.8% of caffeine. The average composition per 100 g is: water 11 g, protein 14 g, sucrose and reducing sugars 8 g, cellulose and polysaccharides 42 g, lipids 12 g, chlorogenic acids 7 g, ash 4 g, and caffeine 1.6 g.
The 1000-seed weight with parchment is about 575 g.

Description An evergreen shrub or tree up to 20 m tall; branchlets glabrous. Leaves opposite; stipules interpetiolar, triangular-ovate to almost truncate, 2–4.5 mm long, obtuse or sometimes acute; petiole 0.8–2 cm long; blade narrowly obovate to obovate or elliptical to broadly elliptical,



Coffea liberica Bull ex Hiern – 1, twig with flower buds; 2, domatium; 3, flower; 4, infructescence with leaves removed; 5. seed.

14–38 cm × 5.5–20.5 cm, acute to cuneate at base, margin entire, rounded to shortly acuminate at the apex, with domatia situated at the base of the (7–)8–13 lateral veins below. Flowers in axillary clusters, 4–30(–50) per axil, borne in 1–3(–5) congested fascicles, 5–9-merous; peduncle very short or absent; calyx tubular, 1.7–2.5(–3.6) mm long; corolla white, tube 4–13 mm long, lobes contorted to the left in bud, oblong, 8–16 mm × 3–6 mm; stamens attached to the corolla throat; disk annular; ovary inferior, 2-locular with a single ovule in each cell, style exserted, with 2 stigmatic arms. Fruit an oblong-ellipsoid drupe (commonly referred to as 'berry'), 1.2–2.2 cm × 0.9–1.6 cm, red or yellow and red streaked or occasionally entirely yellow when mature, with 2 seeds; mesocarp fleshy; endocarp fibrous. Seed (commonly referred to as 'bean') 0.7–1.5 cm long, grey-brown-green, with a groove on the inner surface; testa thin, silvery. Seedling with epigeal germination; cotyledons emergent, persistent, leafy, roundish with a wavy margin; hypocotyl slightly elongated; all leaves opposite.

Growth and development Liberica coffee seeds take about 50 days to germinate. The trees develop, like all coffees, according to the architectural model of Roux, which is characterized by a continuously growing monopodial orthotropic stem with plagiotropic opposite branches. The first fruits are produced 2–3 years after planting out in the field. After 5–6 years the plants are in full bearing. The economic life span is about 25–30 years. Flowering and fruiting may take place throughout the year, but flowering is triggered by heavy showers; the flower buds grow to a certain size and then rest until stimulated by continued water stress and rapid rehydration, resulting in simultaneous blooming. *C. liberica* is self-incompatible. Fruit maturation takes 10–12 months, depending on the locality.

Other botanical information (See also under *Coffea* L.) Botanically seen, *C. liberica* represents a variable complex of forms that have often been treated as 'species' in the past. The forms are generally distinguished by growers and breeders who are aware of the crop and its different habits. It is still uncertain whether excelsa coffee, comprising the former taxa *C. dewevrei* and *C. excelsa*, should be regarded as a separate species. For now, it is recognized as a distinct variety, var. *dewevrei* (De Wild. & T. Durand) Lebrun, distinguished by a 5–6(–8)-merous corolla, tube slightly widened at the throat, lobes usually 2.5–7 mm wide, fruit 12–20 mm × 8–16 mm. Var. *liberica* has a 6–9-merous corolla, tube distinctly widened at throat, lobes usually 5–10 mm wide, fruit 20–25 mm × 17–21 mm. Moreover the fruit of var. *liberica* has a thicker, more leathery pericarp and is often more tapered towards the base than that of var. *dewevrei*.

Ecology Liberica coffee occurs in lowland to lower montane rain forest, gallery forest, forest margins and even in open scrub vegetation, up to about 1300 m altitude. In Malaysia plants are reported to thrive up to 1200 m altitude, in the Philippines up to 900 m. It grows well at low elevations under warm, humid conditions, but especially excelsa cultivars are drought-tolerant. Liberica coffee grows best under light shade, on well-drained clayey to sandy soils, but in Malaysia it is generally grown in full sunlight. It does not tolerate waterlogging, but is known for its tolerance of acid and poor soils, and can grow without liming on alluvial muck soils with a pH of about 4.0. In the equatorial lowland tropics liberica coffee performs better than arabica and robusta. It can grow on heavy clays unfavourable to robusta, it is more drought-tolerant and flowers more frequently.

Propagation and planting Liberica coffee is mainly propagated by seed. Sometimes seedlings are collected from under the trees. Until recently no improved seed was used apart from superficial selection of open-pollinated seedlings. Floating fruits are discarded, others are depulped and dried before sowing. The seeds show recalcitrant storage behaviour, with only 6% of them surviving desiccation to 11.3%. Seeds are sown in seedbeds prepared from alluvial sand, about 1.5 cm deep and 5–8 cm apart or in rows 30 cm apart. Seedlings are planted in polythene bags 8–12 weeks after sowing when they have 2–4 pairs of leaves. They are transplanted into the field when they have developed 6–8 pairs of leaves, which under normal circumstances will be 8–10 months after sowing. The time of transplanting should ideally coincide with the onset of the rainy season. Planting is done in holes of 0.6 m × 0.6 m 0.6 m and should not be too deep. In Malaysia the recommended planting distance is 2.5 m × 3 m, but 3 m × 3 m is still widely practised. In the Philippines spacings of 4–5 m × 4–5 m are applied. *C. liberica* seedlings can be used as rootstock for arabica coffee (*C. arabica* L.) and robusta coffee (*C. canephora* Pierre ex Froehn.); cleft grafting gives 65–75% success. Liberica coffee is sometimes grown in mixed plantations with coconut palm, oil palm and/or bananas. Intercropping with bananas is generally at the expense of an early crop of coffee. Catch cropping has been successful: shallow-rooting crops like gourds, tobacco, chili peppers, long beans and ginger can be planted in between the coffee shrubs when these are still small. Care must be taken that the catch crops are no closer to the coffee than 1 m in the first year and 1.25 m in the second year. Crops that require deep digging for harvesting, such as cassava, are unsuitable.

Husbandry In Malaysia, liberica coffee is maintained as capped single-stem shrubs about 1.5 m tall by regular pruning, eventually resulting in an umbrella-shaped treelet. Sometimes the multiple-stem system is applied on 2–5 orthotropic capped or uncapped stems.

Highest yields of liberica coffee are obtained without shade, but in practice light shading is applied to protect the plants during periods of water and heat stress. Weeding requires special care, so as not to damage the superficial roots of coffee. Mulching significantly increases yields by improving soil texture, water infiltration and nutrient management. Fertilizer application is often based

on soil and foliar analyses. In the Philippines a general recommendation in the absence of soil or foliar analyses is to apply annually an equal amount of NPK fertilizer ranging from 200–450 g for a non-bearing tree to 1 kg of 10:5:20 NPK fertilizer for a bearing tree. Additionally, ammonium sulphate is applied as a top dressing at a rate of 250–300 g/tree per year. The recommended NPK ratio is 7-12-20 for sandy soils and 11-40-5 for clay soils. On peaty soils the presence of copper as a trace element has been found essential.
In Peninsular Malaysia old and unproductive stands are rehabilitated by top-working: this entails regrafting the top of the coffee shrub.

Diseases and pests Liberica coffee has proved to be susceptible to coffee leaf rust (*Hemileia vastatrix*), although much less than the other coffees. The first sign of attack is the formation of small, circular, yellowish, translucent spots on the leaf, rapidly followed by the production of orange-yellow spores on the underside. In Malaysia half yearly application of Coprantol at 0.1% active ingredient gives protection against coffee leaf rust. Pink disease (*Corticium salmonicolor*) attacks the woody parts of liberica coffee and sometimes causes serious damage. Some Liberica plants are immune to the fungus *Ceratocystis fimbriata* whereas others are killed instantly; the immune plants contain more polyphenolic compounds.
The beehawk moth (*Cephanodes hylas*) considerably reduced the area under coffee early this century, and is still an important pest in Malaysia. *Gardenia* trees are an alternative host to the beehawk moth and should not be allowed to grow near coffee fields. The coffee berry borer (*Stephanoderes hampei*) is another serious insect pest; the female beetle bores into the fruits, where the complete life cycle takes place. In Peninsular Malaysia, liberica coffee is much less susceptible (1–5% of the fruits bored) than robusta coffee (16–77%). Endosulfan, one of the few insecticides penetrating the coffee bean and killing the insect larvae, gives protection against coffee berry borer when applied at 0.1% active ingredient. Recent reports from New Caledonia, however, indicate resistance to this insecticide. Therefore, its widespread use may increase the risk of resistance developing in other coffee-growing areas. Generally, liberica coffee is less susceptible to nematodes than robusta coffee, but in Java *Pratylenchus coffea* once affected about 60% of liberica coffee in six months.

Harvesting There are two methods of harvesting coffee, i.e. selective picking of the ripe berries and strip picking of whole branches resulting in a mixed harvest of green, ripe and overmature fruits. Coffee growers are said to prefer excelsa cultivars over liberica ones as the fruit is easier to pulp and the flavour of the beans is less bitter. Harvest is generally twice a year.

Yield The weight of dry 'green beans' is about (7–)10% of that of fresh fruits. Annual yields of 750–900(–1100) kg/ha of green beans can be obtained from well-maintained holdings but in Malaysia annual yield figures vary between 300 and 700 kg/ha. Improved cultivars have a potential annual yield of 1.7 t/ha and selected clones even 2.1–2.3 t/ha. In Malaysia production peaks in November–February.

Handling after harvest Coffee fruits can be processed either by the 'dry process' or the 'wet process'. Generally, liberica coffee is processed dry, although the relatively thick fruit pulp would suggest that wet processing is more appropriate.

- The wet process: ripe fruits are pulped within 12–24 hours after harvesting and fermented to degrade the mucilage, washed, carefully dried in the sun (7–10 days) or mechanically (6–20 hours) or a combination of both, and stored as dry (11–12% moisture content) parchment coffee. This process is carried out in coffee factories owned by estates and smallholder cooperative societies, or with small hand-pulpers and basins by individual smallholders.
- The dry process: fruits, usually from strip picking, are dried directly for 3–4 weeks in the sun on platforms or mechanically (2–3 days). Dry-processed coffee is more difficult to store than parchment coffee because of its strong hygroscopic properties.

Liberica coffee fruits present difficulties in pulping because of the large fruit size and the hard fruit skin. However, improvement of planting material in Java early this century through selection gave softer fruits which were easier to pulp. Besides, excelsa cultivars also have softer fruits than liberica cultivars.
Curing of dried parchment coffee – including hulling to remove the parchment, polishing to remove remains of silver skin and grading – takes place in central coffee mills. Dry-processed coffee is treated in a similar manner, but requires a different type of huller. The clean coffee is graded according to international standards of size and shape of beans, colour and percentage defects (broken beans, stones, husks). The clean green coffee is exported in bags of 60–70 kg, and can be stored under dry and cool conditions for 1–2 years without loss of quality. The final stage of coffee

processing – blending, roasting and packaging as whole beans or ground coffee – always takes place close to the consumer market to assure optimum quality.

Genetic resources Spontaneous populations of *C. liberica* can be found in humid tropical lowland forests in West and Central Africa. The collected material is preserved in field collections in Ivory Coast. In Java the Indonesian Coffee and Cocoa Research Institute (ICCRI) maintains a *Coffea* germplasm collection of some 2000 accessions, including liberica coffee.

Breeding The genetic basis of cultivated liberica coffee in Peninsular Malaysia is narrow, but variations in yield, fruit and bean size among individual plants and progenies are significant. In 1992 the Malaysian Agricultural Research and Development Institute (MARDI) released improved seed from a polyclonal coffee seed garden under the name 'MKL 1'. The selection of superior clones of liberica coffee continues. In Indonesia in the past several breeding experiments with *C. liberica* and *C. arabica* resulted in offspring with arabica-like beans and promising resistance to coffee leaf rust. However, plants had to be propagated by grafting, percentage empty seeds was high, and yields were disappointing. 'Kalimas' and 'Kawisari' are natural hybrids of *C. arabica* and *C. liberica*. Several other breeding experiments involving *C. liberica* and *C. canephora*, *C. congensis* Froehner, *C. eugenioides* S. Moore and *C. stenophylla* G. Don have been performed recently, notably by the 'Institut de recherche pour le développement' (IRD, formerly ORSTOM), but no new cultivars have resulted so far.

Prospects Because of its bitter taste, the market share of liberica coffee will remain low. The excelsa cultivars are superior in this respect. First results from experiments carried out by MARDI to develop superior cultivars are positive: several promising clones with higher yield potential have been identified.

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M.S.M. Sosef & E. Boer

Cola Schott & Endl.

Melet. bot.: 33 (1832).
STERCULIACEAE
$x = 10$; $2n = 40$ (*C. acuminata*, *C. nitida*)

Major species and synonyms

- *Cola acuminata* (P. Beauv.) Schott & Endl., Melet. bot.: 33 (1832), synonyms: *Sterculia acuminata* P. Beauv. (1804), *Sterculia macrocarpa* G. Don (1831), *Cola macrocarpa* (G. Don) Schott & Endl. (1832).
- *Cola nitida* (Vent.) Schott & Endl., Melet. bot.: 33 (1832), synonyms: *Sterculia nitida* Vent. (1804), *Cola vera* K. Schum. (1900), *C. acuminata* (P. Beauv.) Schott & Endl. var. *latifolia* K. Schum. (1900).

Vernacular names General: kola, kola nut tree, cola (En). Colatier, kolatier (plant), noix de cola (product) (Fr). Indonesia: kola. Vietnam: c[oo] ca.
- *C. acuminata*: Abata kola (En). Kolatier sauvage (Fr).
- *C. nitida*: Gbanja kola, bitter cola (En).

Origin and geographic distribution *Cola* has its centre of diversity in West Africa. There are three areas with relatively greater concentrations of species: Sierra Leone/Liberia, Nigeria/Cameroon and Gabon. *C. nitida*, the common kola, originated in West Africa in the region of Sierra Leone to Benin, and has its main area of distribution in the rain forest area of Ivory Coast and

Ghana. The distribution area of *C. acuminata* is further east: from Togo to the rain forest areas of eastern Nigeria, Cameroon, western Democratic Republic Congo and Angola.

The kola nut (botanically not a nut, but the seed, usually with 2 (*C. nitida*) or 3–6 (*C. acuminata*) cotyledons) was taken to many parts of the tropics by traders, although large-scale cultivation remained limited to West Africa. *C. nitida* was reported from Trinidad and Jamaica as early as 1680, and also from India, Indonesia, Peninsular Malaysia and Singapore in the early 19th Century. It occurs in Australia and is widespread in South America. *C. acuminata* has been reported from Brazil, Venezuela and Colombia. Both species were probably introduced into Central and South America during the times of the slave trade.

Fresh kola nuts have long been an important commodity in the northern savanna region of West Africa and trade in kola nut was common. From the 17th Century onwards nuts were shipped along the West African coast from the more westerly areas towards the harbour of Lagos in Nigeria and then inland to northerly areas. This intensive trading was later stimulated by the establishment of road and rail connections, which led to *C. nitida* cultivation being introduced in the hinterland of Lagos harbour, to replace the occasionally grown *C. acuminata*. The result was unprecedented growth in the production of *C. nitida* nuts, virtually all for export towards the northern savanna areas, thus replacing imports. *C. acuminata* remained of local interest only.

In Indonesia, *C. nitida* trees were used for shelterbelts early in the 20th Century, and were intercropped with cocoa on Java and Sumatra. Although growth was satisfactory and nuts were produced, no trade developed in the nuts and later most of the trees were felled to provide more space for cocoa. However, some large kola trees still remain and kola is sometimes still used as a shade tree in young cocoa and coffee plantings. The wood is used for small carpentry objects and construction.

Uses Chewing fresh kola nuts (seeds) has a pleasant stimulating effect. Locally, dried nuts are sometimes used for the preparation of stimulating infusions. In West Africa, kola nuts play an important role in social life, ceremonies (e.g. weddings) and religious customs. In traditional medicine they are used as a stimulant, tonic and astringent. The trees yield durable wood, which is used to make canoes. Extracts from dried *C. nitida* nuts have been added to beverages; the cola soft drink originally included extracts from *Cola nitida* and coca (*Erythroxylum coca* Lamk or *E. novogranatense* (Morris) Hieron.). Most of the kola for this purpose was obtained from South and Central America; no interest was shown in West Africa for the trade in dried nuts, as the trade in fresh ones for immediate use for chewing proved much more lucrative. Cola soft drinks are nowadays usually prepared from artificial cola flavourings, caffeine, and coca leaves from which the cocaine has been removed.

Production and international trade West Africa is the major player in kola production and trade. In the early 20th Century, world total annual production was around 20 000 t, 75% of which was accounted for by *C. nitida*. In the 1960s annual production rose to 175 000 t, of which 120 000 t came from Nigeria, 50 000 t from the area between Sierra Leone and Benin and some 3000 t from South and Central America (with a Jamaican production of about 1000 t). In the 1980s total production rose to 200 000 t per year with a similar distribution. Elsewhere, kola was not registered in production statistics. West African kola is mainly produced by smallholders.

At the retail level in West Africa fresh kola nuts are priced individually. In 1995 the price was at the equivalent of US$ 0.04–0.08 depending on the size of the nut. As the average weight of fresh nuts is around 17 g, the value per t of fresh nuts was equivalent to about US$ 3500. Dried nuts intended for the preparation of beverages command a much lower price: in the 1960s and 1970s this was 10% of current prices when calculated on a fresh weight basis.

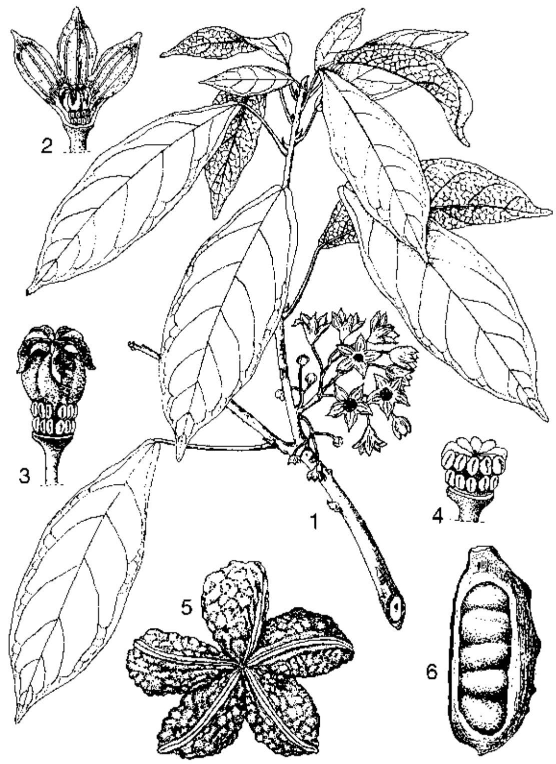
Properties Kola nut mainly owes its stimulating effect to the rather high caffeine content, which in the fresh nut occurs partly in association with catechin and with tannins. It is not known how far the stimulating effect is influenced by other alkaloids present in much smaller quantities, such as theobromine and betain. Dry *C. nitida* nuts contain per 100 g: water 16 g, protein 11 g, fat 2 g, carbohydrates 52–53 g, fibre 8–9 g, caffeine 1–3 g, tannins 4 g and ash 3 g. When masticated, the tannins of the fresh nut are astringent in the mouth, though this soon disappears and turns to a sweet taste as the tannins lose their effect. At the same time the alkaloids are released by the influence of enzymes and provide their stimulating effect.

Oral tumours and gastro-intestinal malignancies occur relatively often in regions where kola nut

chewing is common, especially in northern Nigeria, and it has been suggested that kola nuts may be carcinogenic because of their high tannin content or the presence of other carcinogenic compounds, such as amines.
The 1000-seed weight is 500–3500 g.

Description Evergreen trees, mostly small or medium in size. Leaves alternate or whorled, simple or digitately compound, entire or lobed, petiolate. Inflorescence an axillary raceme, panicle, cluster or whorl, usually with male and bisexual flowers; calyx widely campanulate, deeply 4–6-lobed, white or coloured; corolla absent; male flower with androphore bearing 5–20 stamens which are joined in a column; bisexual flower with a gynandrophore, bearing a single or double ring of 5–6 anthers each at the base of the ovary, ovary with several (usually 5) coherent carpels and free styles. Fruit composed of 4–5 longitudinal dehiscing follicles. Seeds up to 14 per carpel, obtuse-angular, up to 5 cm × 3 cm, with 2 or more cotyledons and no endosperm.

- *C. acuminata*: slender tree, 7–10(–13) m tall, often branching near the base. Leaves alternate but sparse and confined to tips of branches; petiole about 4 cm long; blade elliptical to oblanceolate, 16(–27) cm × 5.5(–11) cm, rounded at the base, at apex acuminate and often twisted downwards, dark green, rather fleshy, often curled, lateral veins not prominent. Inflorescence several- to many-flowered, flowers not whorled, rotate; bisexual flower up to 2.5 cm in diameter, male flower smaller; calyx lobes united for nearly half their length, white with red splash inside at base. Fruit composed of up to 5 follicles; follicle sessile, at right angles to peduncle, horizontal, 20 cm × 6 cm, not knobbly, rough to touch, with up to 14 seeds, brownish. Seed up to 4 cm × 2.5 cm, with a thin, white testa, with 3–6 pink, red or sometimes white cotyledons.
- *C. nitida*: robust tree, 8–12(–25) m tall; bole up to 4(–12) m long, up to 50 cm in diameter, with narrow buttresses up to 1 m high; crown dome-shaped; bark fissured longitudinally, grey. Taproot reaching 120 cm in depth; lateral roots developing profusely in top layer of the soil, largely in the first 15 cm, extending to about 5 m from the trunk; sinker roots penetrating up to 1 m are formed on the lateral roots. Leaves alternate, simple, not confined to tips of branches; petiole 1–10 cm long, with a prominent pulvinus at base and top; blade broadly oblong to broadly elliptical or sometimes elliptical-oblanceolate, 9–32 cm × 3.5–13 cm, cuneate to rounded at base, shortly acuminate at apex, glabrous or nearly so. Inflorescence an axillary panicle of cymes with 5-merous flowers; calyx slightly cup-shaped, lobes united up to about one third, white or cream with a small red mark at base, puberulous outside; male flower up to 2.5 cm in diameter; androecium composed of 2 whorls of 10 pollen sacs each, reddish, on a short androphore of 1 mm; gynoecium rudimentary; bisexual flower 3–5 cm in diameter; androecium reduced, superimposed by the 5 carpels, each with 10–12 ovules, style short, stigmas radiating, linear. Fruit composed of 5(–6) follicles on a short peduncle; follicles horizontal or recurved, roughly ovoid, 8–13 cm × 4–8 cm, with a short curved beak, knobbly, dehiscing along the ventral suture, with 4–8(–10) seeds, green. Seed up to 5 cm long, with a tough, white to pink testa, with 2(–3) white, pink or red cotyledons.



Cola nitida (Vent.) Schott & Endl. – 1, flowering twig; 2, opened bisexual flower; 3, bisexual flower with calyx removed; 4, male flower with calyx removed; 5, fruit; 6, opened follicle showing seeds.

Growth and development Kola seed passes through a dormancy period of some weeks to several months. When planted after the dormancy period, it germinates within a few weeks. At this time the radicle emerges from amongst the cotyledons and at the same time the hypocotyl elongates and pushes out the plumule. Subsequently, the root elongates rapidly, 8 cm within the first week, and the plumule straightens out. Thereafter, growth slows down; the root depth is 15 cm after 9 weeks. Shoot growth shows a similar pattern: 1–2 weeks of rapid growth (6–11 mm per day) followed by slower growth (1–2 mm per day). The cotyledons remain turgid and are retained for up to 9 months after germination as a store of reserves. The seedling develops monopodially until the 3rd–4th year when it changes to the adult phase with sympodial growth and discontinuous growth in 'flushes'. The terminal buds remain dormant, abort or develop into a shoot with one or few leaves at the time of the next flushing period. The tree may flower from this time onwards, but usually not until the 6th–7th year. Regular flowering occurs once a year. In Nigeria, *C. nitida* flowers in the rainy season in July and August and its fruits become available in November, whereas *C. acuminata* flowers in the dry season from December to February, giving fruits in April or May. *C. nitida* in Java has been reported to flower throughout the year. The number of hermaphrodite flowers per inflorescence seems to diminish with their position on a flush, the more apical inflorescences having fewer hermaphrodite flowers. The hermaphrodite flowers are receptive for some 4 days; the male ones produce viable pollen mainly the first two days of anthesis. It is thought that the sticky pollen may be transferred by a midge (*Forcipomyia* sp.). Artificial pollination has revealed that kola may be self- or cross-incompatible. When applied in certain combinations the success of artificial pollination proved to be as high as 33%. Fruits mature in 120–135 days, and full production is achieved when trees are 15–50 years old. *C. acuminata* produces flowers and fruits in the Bogor Botanical Garden in Java.

Other botanical information The genus *Cola* comprises some 125 species and has been subdivided into 5 sections. The section *Cola* includes the species with edible seeds. The seeds of certain cultivated kola species other than *C. acuminata* and *C. nitida* are also used as a stimulant, e.g. *C. anomala* K. Schum. ('Bamenda kola') from Cameroon and *C. verticillata* (Thonn.) Stapf ex A. Chev. ('Owé kola') from the rain forest of West and Central Africa.

Ecology Wild kola occurs in the West African rain forest. Kola needs a regular supply of water and is usually found in areas with more than 1250 mm annual rainfall in at least eight rainy months (>50 mm of rain), unless water is available from other sources. Temperatures in the range of 25–30°C and high relative humidity are favourable; low relative humidity may lead to leaf shedding. Kola is commonly planted on red ferrallitic or ferruginous soils, and does not tolerate waterlogging. Young kola plants need overhead shade.

Propagation and planting Kola is usually propagated by seed. Nursery-raised plants lead to a more complete stand in the orchard than seeds sown at stake. Seed for propagation should be as large as possible, as this strongly influences the rate of development. *C. acuminata* seed has been reported to germinate faster than that of *C. nitida*. Seed should be sown in the nursery about 6–12 months before the start of the rainy season, depending on the length of seed dormancy, to allow for transplanting in the early part of the rainy season. Seed may be planted 5–10 cm deep in a horizontal position. To speed up germination it should be placed on top of a moist planting medium, covered with polythene and illuminated. Pregerminated seed should be potted with the cotyledons exposed. As seedlings depend on their taproot for up to 9 months, containers should be 40–45 cm deep; otherwise, plants should be raised in a seedbed. When 12 months old, seedlings will have developed secondary roots and be capable of being transplanted with a desirable rootball. At transplanting, seedlings should be about 50 cm tall and have 12–14 expanded leaves. Seedlings that have been in the nursery for up to 12 months carry 17–20 leaves, and should be pruned back to 50–60 cm.

Propagating high-yielding trees through stem cuttings is a useful method, with up to 90% success, but the results for individual trees may vary considerably. Rooted cuttings ('ramets') from plastic-covered rooting bins need to be hardened off during their nursery period prior to transplanting. Such plants remain in their adult, sympodial growth pattern and are capable of immediate flower formation. Young trees are planted out at spacings of 7.5–9 m × 7.5–9 m, depending on soil fertility. When establishing an orchard with ramets, which are productive within two years, it is advisable to use spacings of 3.5–4.5 m × 3.5–4.5 m and to thin out trees in the sixth year to achieve optimum plant density.

Husbandry Though kola benefits from light shading, during the first two years of its development, it needs sunlight thereafter and a guaranteed supply of adequate moisture in order to develop well. It is essential to keep an area of 80–100 cm around the stem of young kola plants free from weeds. To avoid root damage, the use of tools in this circle should be restricted. Mulching of the ring around the young plant promotes the development of lateral roots and provides the required soil protection, which is later given by the canopy of the tree itself.

The removal of nutrients through the harvested kola nuts is quite small: for a very high production level of 3 t/ha it amounts to 13 kg N, 10 kg K, 2 kg Mg and 1 kg P. The use of fertilizers is therefore not advised, unless specific soil problems arise.

Diseases and pests On clear-felled land young kola plants may be affected by a root disease caused by *Fomes lignosus* and *F. noxius*. However, the main losses from fungal diseases may occur if nuts have been freshly harvested and are not handled properly during their dormancy period. Kola trees may be attacked by the kola stem borer (*Phosphorus* spp.); coppicing and regeneration may then be required. Kola fruit fly (*Ceratitis colae*) may cause serious losses in the number of fruits. Severe problems are caused by curculionid kola weevils (*Balanogastris kolae* and *Sophrorhinus* spp.). These ravage kola nuts before harvest but cause even more serious damage later, which is why it is essential to remove any affected nuts from stored lots.

Harvesting Fruits of *C. nitida* should be cut before dehiscence, to prevent insect attack. Any fallen fruit should be picked up immediately. The follicles are opened and the seeds, in their fleshy seed-coat, are put in heaps that are frequently sprinkled with water. The seed-coat then decays rapidly and after some days the nut can be wiped off, leaving the nut clean and without any external injury that would reduce its value.

Yield Yields of *C. nitida* range from 500–1000 kg of fresh kola nuts per ha, i.e. 200–400 nuts per tree (being 5–10 fruits). Observations have indicated that most of the production is obtained from only a few trees in a given population. Individual trees, observed in Nigeria for 7–10 years, have produced on average up to 1872 kola nuts per year.

Handling after harvest The kola nuts are kept in baskets and are regularly stirred and checked for insect damage. During this period, which lasts several days, the nuts dry out and go into dormancy. They are then placed in baskets lined with fresh leaves, which are replenished at intervals of 2–3 weeks. It has been suggested that polythene sheet may replace the green leaves as lining for containers once the nut has entered dormancy. Keeping nuts in airtight containers may further reduce metabolism because of the build-up of CO_2, and, in addition, prevent development and attack by kola weevils.

In Indonesia and South America, the harvested seeds are usually treated like those of cocoa. Sometimes they are even dried artificially, as the appearance of the product is unimportant here.

Genetic resources There are no known substantial germplasm collections of *C. acuminata* and *C. nitida*.

Breeding Highly productive trees of *C. nitida* in Nigeria have been intercrossed and the resulting progenies planted in di-allele cross experiments. Early results have confirmed that the most productive cross is AA 231 and that it has potential as a parent for future selections. Combining selection with clonal propagation of the best trees is proving to be a fruitful strategy. Large-scale selection of outstanding trees in western Nigeria from about 150 000 trees on 537 farms, followed by observations on yield performance during 4 years, has led to the identification of 140 trees as potential heads of clones. These selected trees showed an average yield of 1750 nuts per tree over 4 years and about 40% of them were successfully propagated by cuttings.

Prospects The future of kola depends very much on the improvement of its productivity per unit of land. It seems possible that productivity could be tripled or quadrupled by selecting suitable parent trees for clonal propagation. Controlled pollination may further advance productivity. If these improvements are realized, a possible consequence could be a reduction of the area under kola in the current production areas. Although growth and production are satisfactory in South-East Asia, especially Indonesia, the prospects for expansion in the region are not very good, because of the availability of other stimulants like areca nut, coffee and tea.

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C.L.M. van Eijnatten & Roemantyo

Ilex paraguariensis A. St.-Hil.

Mém. Mus. Hist. nat., Paris 9: 351 (1822).

AQUIFOLIACEAE

$2n = 40$

Synonyms *Ilex mate* A. St.-Hil. (1824), *I. paraguensis* D. Don (1824), *I. domestica* Reissek (1861).

Vernacular names Maté, Brazilian tea, Paraguay tea (En). Maté, thé du Paraguay, thé des jésuites (Fr). Yerba mate, té de los jesuitas (Sp).

Origin and geographic distribution *I. paraguariensis* is of South-American origin and is indigenous to the forest regions drained by the upper Paraná, Paraguay and Uruguay rivers in Argentina, Brazil, Paraguay and Uruguay. The preparation of a beverage from the leaves of wild *I. paraguariensis* and related species must have been an ancient custom, but under the influence of Spanish missionaries local people started to cultivate maté for economic production after 1670. At present, maté exceeds tea (*Camellia sinensis* (L.) Kuntze) in popularity in South America. Large quantities of maté are produced in plantations in southern Brazil, north-eastern Argentina and in Paraguay. So-called 'native maté' is still collected to some extent from the wild in the forests of southern Brazil.

Uses The leaves of *I. paraguariensis* are the source of the well-known beverage maté, obtained by infusing the dried leaves and twigs in hot water, just like tea. The beverage, called 'mate cimarrón' is light green, has a pleasant aroma and a slightly bitter taste. Sugar and lemon are often added to adjust its taste. A cold maté beverage ('tereré') is very common in Paraguay and north-eastern Argentina. Maté is also used medicinally as a diuretic, depurative, and a general tonic to relieve mental and physical fatigue. In Europe, maté is used to achieve weight loss, as it reduces appetite. Maté extracts are also used to flavour other products like liqueurs, ice-creams, desserts, and in perfumery to introduce a pronounced greenness in floral bouquets.

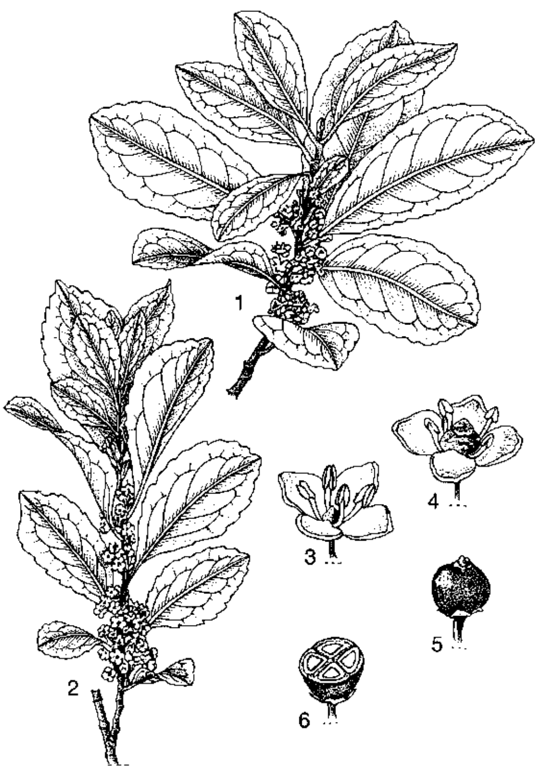
Production and international trade Annual world production of processed maté leaves averaged 450 000 t from 0.5 million ha over 1994–1997. Argentina is the largest producer (45% of world total) followed by Brazil (35%) and Paraguay (15%). About 15–20% of their production is exported to other Latin American countries, in particular to Chile and Uruguay, and to the United States, Japan, Europe (Spain, Italy, Germany) and the Middle East (Syria). The maté industry in Argentina alone represents a value of about US$ 500 million.

Properties The composition of commercial maté leaves varies widely. About 35–50% of the components are extractable in water. Per 100 g commercial maté leaves contain 0.6–1.6 g caffeine. Other constituents include water 7–10 g, protein 10 g, fat 3–7 g, carbohydrates 7–11 g, fibre 14 g, ash 5–7 g (P 0.11%, Ca 0.68%, Mg 0.39%, K 1.34%), tannin 7–11 g, essential oil 0.08 g, carotene 1.17 mg, thiamine 215 µg, riboflavin 422 µg, nicotinic acid 6.9 mg and ascorbic acid 11.5 mg. Besides caffeine,

maté also contains small amounts of theobromine, theophylline, vanillin, chlorogenic acid, citric acid, malic acid and saponins. In addition, maté is a rich source of minerals and contains 15 amino acids. The aroma and flavour of maté depend on the time of collection of branches, and maximum aroma is obtained when harvestable trees bear nearly ripe fruits. The flavour is retained even when maté is exposed to the atmosphere.
The 1000-seed weight is about 7.5 g.

Adulterations and substitutes *Ilex cognata* Reissek is a poorly known wild relative of maté, occurring very locally in the same area of distribution as *I. paraguariensis*. It is called 'cha do mato' and is used to adulterate maté. Other wild *Ilex* species sympatric with *I. paraguariensis* have sometimes also been used to adulterate maté.

Description An evergreen, dioecious shrub or tree, up to 18 m tall in the wild state, in cultivation pruned to a 3–6 m tall multi-stemmed and highly branched bush. Leaves alternate, coriaceous; petiole 1 cm long; blade obovate, 10–12 cm × 5–6 cm, tapering towards the base, with serrate margin and obtuse apex, dark green and glabrous. Inflorescence an axillary, corymboid fascicle with 3–11 male or 1–3 female flowers; flowers small, pedicellate, with 4-lobed persistent calyx and 4 white petals; 4 stamens in male flower; pistil in female flower superior, ovary 4-locular with 1–2 ovules per cell. Fruit a reddish to blackish, globular drupe, 0.5–0.8 cm in diameter, with 4 pyrenes, each containing one seed. Seedling with epigeal germination.



Ilex paraguariensis A. St.-Hil. – 1, branch with male flowers; 2, branch with female flowers; 3, male flower; 4, female flower; 5, fruit; 6, fruit in cross-section.

Growth and development Seeds (pyrenes) of maté remain viable very briefly and should therefore be sown soon after harvesting. Germination takes a long time and the germination rate is generally below 50%. Seed stored at 5°C for 11 months showed only 2–7% germination. Flowering starts 3–4 years after germination and occurs in South America in October–November. Pollination is by insects and fruits mature in 5–6 months. Seeds are dispersed by birds feeding on the red fruits. Cultivated trees reach full productivity at about 10 years, and the economic lifetime of a well-maintained maté plantation is 20–30 years.

Other botanical information *I. paraguariensis* is a variable species and in the past many varieties have been distinguished based on different leaf forms. At present, 2 botanical varieties of *I. paraguariensis* are distinguished, mainly based on hairiness, both co-occurring in limited areas in Brazil:
- var. *paraguariensis*: almost completely glabrous; cultivated;
- var. *vestita* (Reissek) Loes.: densely pubescent; not suitable for cultivation, but sometimes collected.

Ilex kudingcha C.-J. Tseng from northern Vietnam and southern China has been used to prepare 'Kuding tea'. It has gained interest, and its properties and propagation are currently being investigated.

Ecology Maté grows naturally in humid forests, preferably near streams, under subtropical conditions, between 18°S and 25°S latitudes, but has been cultivated as far south as 30°S. It requires at least 1200 mm of well-distributed rainfall per year with 250 mm during the driest season. The main limiting factor in its natural distribution is water shortage. The mean annual temperature in the maté region is 21–22°C. Established trees tolerate temperatures as low as −6°C and also snow, and temperatures as high as 40°C or more. Maté grows well on slightly acid (pH 5.8–6.8), medium- to fine-textured oxisols. Maté does not tolerate lime-rich soils or waterlogging.

Propagation and planting Maté is usually propagated by seed. In South America the fruits are harvested from February–April. Poor storability and low germination rates are likely to have been important factors in restricting maté cultivation beyond the limits of its main areas of origin in South America. Propagation by grafting, cuttings and layering is possible, but not much practised. Cuttings from young branches do not root easily. In vitro cultivation of maté is in an experimental stage in Brazil and Argentina, and may be promising. Planting densities vary from 1000–4000 plants/ha, but are lower in semi-natural cultivation.

Husbandry In general 3 systems of maté cultivation can be distinguished:

- Collecting from natural maté vegetation. Cultivation practices are few and harvesting is manual. It is common in Brazil.
- Enrichment planting. This involves supplementing natural maté populations by interplanting and by replacing of dead maté trees. This is called 'densifying the maté plantation' and is the most common method applied in Brazil.
- Establishing maté plantations. This system came into general use in Argentina around 1915. High yields are obtained as a result of improved cultural practices such as weed and pest control, application of fertilizers and mechanization. Young trees are pruned annually up to the third or fourth year to maintain a proper shape and height of 3–6 m. Weed control is usually carried out mechanically, but sometimes herbicides are applied as well.

Diseases and pests Damping-off disease caused by *Fusarium*, *Rhizoctonia* and *Alternaria* spp. is a serious problem in maté seedlings and can be prevented by the application of fungicides. In plantations, maté can be severely damaged by a number of insect pests. The 'psilido' (*Methaphalara spegazziniana*) lays eggs inside the buds and causes deformation of the leaves. The 'acaro del bronceado' (*Dichopelmus notus*) induces abundant leaf fall. Other pests are the beetle *Hedipathes betulinus*, the moth *Perigonia lusca* and the wax scale *Ceroplastes grandis* (Homoptera).
Wherever economically feasible, chemical control methods are used. However, 'organic' maté cultivation has been successful at Misiones in north-eastern Argentina.

Harvesting Maté is harvested by cutting large branches from the trees with a machete or other tools. Harvesting may be done every one, two or three years. Mechanized harvesting is applied only in a few large plantations. In Argentina, the traditional harvesting time for maté extends from April to July. In Brazil wild maté trees are usually allowed to recover for about 3 years.

Yield Maté yields vary strongly with the system of cultivation and plant density. At 1000–1500 plants/ha, annual yields of 1000–1800 kg/ha of dried leaves can be obtained. At 2500–4000 plants/ha, annual yields increase to 2100–3300 kg/ha.

Handling after harvest The branches with green leaves of maté are brought to central places, where for 30–90 seconds they are passed through a rotatory furnace at flame temperatures of 250°C. This process preserves the green colour of the leaves and reduces their moisture content to 25%. A second drying is needed to reduce the moisture content to about 3%, and can be achieved either quickly in 15–60 minutes, or more slowly (12–24 hours). Drying is followed by a coarse grinding process. The product is then usually stored for a few months, which improves the aroma and flavour. Subsequently, the raw material is cleaned, ground, and the leaves are separated from the twigs and branches by sieving. The different fractions are collected and stored, and later on mixed in maté mills to obtain the desired blends. The final products are sold in tins. In southern South America, maté is a common product, like tea or coffee, and it is sold in grocery shops, markets and supermarkets. In other parts of the world, however, it is only found in health and herbal shops.

Genetic resources and breeding *I. paraguariensis* is at risk due to the gradual disappearance of its natural forest habitat in South America. Clonal gardens and seed-propagated germplasm collections have been maintained since 1974 by the 'Instituto Nacional de Tecnología Agropecuaria' (INTA) at Misiones, Argentina. Some selection work is in progress based on comparative field trials, and INTA has been distributing clonal seed, and to a lesser extent also clones of high-yielding genotypes. A modest selection programme for maté types with low or no caffeine content is under way.

Prospects Maté is an interesting tree crop and product. It seems worthwhile to investigate the prospects for a market and possibilities of maté cultivation in South-East Asia. Some attempts were made in the past in Malaysia.

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S. Brotonegoro, M. del Campo Gigena & G.C. Giberti.

Matricaria recutita L.

Sp. pl.: 891 (1753).

COMPOSITAE

$2n = 18$ (diploid), 36 (tetraploid)

Synonyms *Matricaria chamomilla* auct., non L. (1753), *M. courrantiana* DC. (1838), *Chamomilla recutita* (L.) Rauschert (1974).

Vernacular names German chamomile, matricaria, true chamomile (En). Camomille d'Allemagne, camomille vraie, petite camomille (Fr). Indonesia: teh kembang (Sundanese).

Origin and geographic distribution *M. recutita* is native from Europe to Afghanistan and northern India (Punjab). It was introduced, probably with wheat, to North and South America, central Asia and Australia, where it has naturalized. In the 19th Century the Dutch brought German chamomile to Indonesia, where it was cultivated, especially in West Java around Garut. German chamomile is currently cultivated in many European countries (e.g. Germany, Hungary, Russia and Slovakia), the United States, Egypt, Cuba, Argentina, India and Korea. Cultivation trials have been conducted in Japan, Kenya and Canada.

Uses The tea made from the flower heads of German chamomile is becoming increasingly popular and sometimes those flower heads are added to teas to increase flavour and bulk. However, the most widespread use of chamomile flowers on the market is as a herbal remedy. Medicinal infusions have been prepared from German chamomile since Antiquity. German chamomile is widely used medicinally as an anti-inflammatory, antibacterial, antispasmodic and sedative agent. Hydrophobic and hydrophillic components of German chamomile relax smooth muscles. Extracts are reputed to have deodorant and astringent properties, and to alleviate pain and irritation. Infusions, made by steeping fresh or dried flowers in water, are used both internally and externally. Large doses of a warm infusion are used as an emetic, whereas cold infusions are used as a digestive aid and against colic, fevers and flatulence. Infusions are applied externally as a fomentation or to wash wounds and sores.

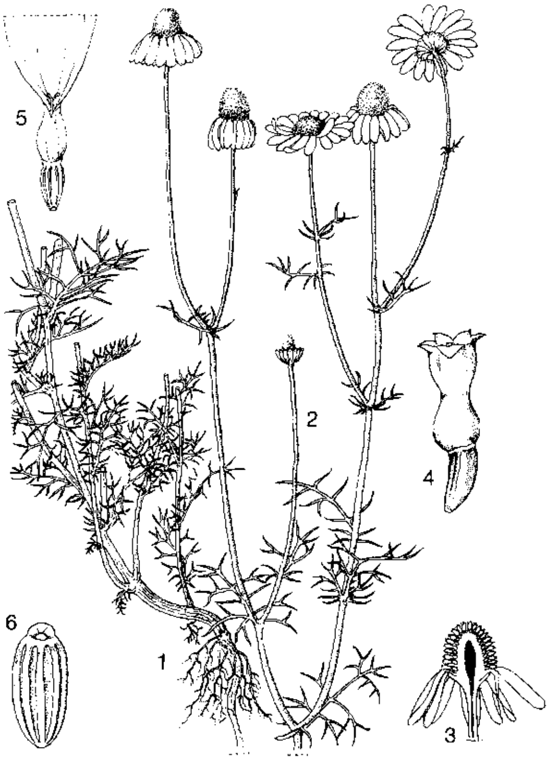
The whole plant yields an essential oil which is sparingly used as a flavouring agent in liquors, particularly of the French type, and in confections, desserts, jellies, ice cream, candy, baked goods and chewing gum. It is also used in perfumes, where it imparts pleasing and warm tonalities, and in shampoos, hair dyes and other cosmetics.

Production and international trade Production and trade statistics for German chamomile are often combined with those for Roman chamomile (*Anthemis nobilis* L.). More than 4000 t of chamomile (German and Roman) were produced annually in the 1980s, with German chamomile accounting for most of the tonnage. This figure had increased to as much as 20 000 t in the 1990s.

The value of the world production of 'blue chamomile oil' (presumably mainly originating from *M. recutita*) in 1993 was valued at US$ 5.4 million. Argentina, Egypt and Hungary are the major German chamomile producers, with Germany being the prime producer of pharmacological chamomile preparations.

Properties The medicinal value of German chamomile is primarily due to the essential oil present in the flower heads (0.3–1.5%).
Freshly distilled essential oil is blue, but exposed to light and air it gradually changes to green and finally brown. It has a strong characteristic odour and a bitter aromatic flavour. The constituents of the oil include sesquiterpenes, flavonoids and azulenes. More than 50% of the oil consists of the sesquiterpenes bisabolol and its oxides, which have anti-inflammatory and spasmolytic properties and counteract gastric ulcerations. The flavonoids are particularly concentrated in the ligulate flowers; they include the flavone glycoside apigenin, which has a spasmolytic activity, and flavonols such as luteolin, quercetin and isorhamnetin. The azulenes include matricin, the precursor of the chamazulene that is responsible for the blue colour of the oil and has a strong anti-inflammatory activity. It is not only the genetic influence on essential oil composition that is important, but also many other factors such as plant age, environmental variations, management practices and post-harvest handling. Individuals allergic to ragweeds (*Ambrosia* spp.) or with known sensitivity to other members of the *Compositae* family should avoid contact with German chamomile and its products. Chamomile hypersensitivity is rare, however. The main components of the essential oil of Roman chamomile are esters (particularly the isobutyl ester of angelic acid), sesquiterpene derivatives (e.g. the lactone nobilin but no sesquiterpenes of the bisabolane type) and flavonoids (e.g. apigenin). The weight of 1000 seeds of German chamomile is 0.02–0.03 g.

Description An annual, aromatic herb, 10–60(–90) cm tall; root thin, spindle-shaped; stem erect, usually branched, glabrous, cylindrical. Leaves arranged spirally, exstipulate, 2–3-times pinnatisect, oblong in outline, 1–10 cm × 0.5–3 cm, glabrous; ultimate segments linear, acute, about 0.5 mm wide. Flowers in solitary heads 18–25 mm in diameter, heterogamous; involucre 6–8 mm wide, with 20–30, 2–3-seriate involucral bracts; receptacle hollow, hemispherical at first but elongating to a conical shape, acute, finally 5–7 mm × about 2.5 mm, without scales; corolla of disk



Matricaria recutita L. – 1, basal part of plant; 2, upper part of flowering plant; 3, flower head in longitudinal section; 4, disk flower; 5, ray flower; 6, achene.

flower yellow, 5-toothed, about 2 mm long; ray flowers 10–20, with white corolla, ligule first pointing upwards, then patent, and finally reflexed, 7–10 mm × 2–3 mm. Fruit a conical to oblong achene, 1–2 mm long, ribbed on one side; pappus absent or represented by a short rim.

Growth and development Seedlings usually emerge in 5–10 days. In India, plants sown in the nursery in the second half of September and planted out in the field in November, flower in March–April. In Java, German chamomile flowers throughout the year, in western Europe from May to July. Flowers of German chamomile are mainly pollinated by flies, occasionally by other Hymenoptera and beetles. A single plant can produce up to 45 000 achenes a year. The achenes are mainly dispersed by animals and by human activities.

Other botanical information Difficulties in nomenclature have caused much confusion in the botanical literature between *M. recutita* and scentless mayweed (*Tripleurospermum mariti-*

mum (L.) Koch sensu lato; synonyms: *Matricaria maritima* L., *M. inodora* L., *M. perforata* Mérat, *Tripleurospermum inodorum* (L.) Sch. Bip.). The confusion arose because it was unclear to which species the frequently used name *Matricaria chamomilla* L. had to be applied, because Linnaeus made an error, which he later corrected himself, though not in accordance with the (later) rules. Further confusion appears in non-botanical literature dealing with 'chamomile' which sometimes refers to *M. recutita*, but sometimes to *Anthemis nobilis* (synonyms: *Chamaemelum nobile* (L.) Allioni, *Chamomilla nobilis* (L.) Godr., *Matricaria nobilis* (L.) Baillon), the Roman chamomile, which is also cultivated and used for many similar applications. Therefore, when dealing with information on 'chamomile' or on '*M. chamomilla*' one has to check carefully which species is actually meant. German chamomile differs from Roman chamomile in being an annual, up to 1 m tall, glabrous, with flower heads arranged in a corymb, and a hollow receptacle. Roman chamomile is a perennial with creeping stem up to 25 cm tall and slightly hairy, with single terminal flower heads which have a solid receptacle. Some well-known Slovakian German chamomile cultivars are: 'Bohemia', 'Bona', 'Goral', 'Rubomille and 'Manzana'.

Ecology *M. recutita* is a weedy species preferring sunny sites (slightly shaded sites are tolerated) and found on wasteland, roadsides and fields (mainly of wheat, sugar beet and oilseed rape). Abundant moisture is desirable for commercial cultivation but in the wild dry conditions are tolerated. In Europe it occurs up to 2300 m altitude; in tropical regions it grows in both lowland and montane habitats. The optimum temperature for flowering is about 20°C; at higher temperatures the blooming period is shortened. Young seedlings withstand mild frost.

German chamomile grows in poor soils but prefers soils rich to moderate in nutrients, sandy or loamy to slightly clayey with a pH of 4.5–7.5. It avoids lime as well as heavy metals, but tolerates salinity. It is sometimes grown on soils considered too poor for any other crop.

Propagation and planting German chamomile is grown from seed. In Europe it is sown in autumn or winter. Spring sowing is unreliable and results in lower yields. The sowing rate is 2–5 kg per ha. Seeds are scattered on the soil surface or sown in rows 10–60 cm apart, and gently tamped down. The optimum temperature for germination is 20–25°C. Small seedlings (e.g. 2.5–5 cm tall) can be transplanted, but larger ones often die. German chamomile can be intercropped with other crops or is grown as an early or late sole crop.

Husbandry German chamomile is reported to take up 53 kg N, 21 kg P_2O_5 and 85 kg K_20 for the production of 1 t of inflorescence. In Indian experiments with 4 nitrogen levels (0, 20, 40 and 60 kg/ha), flower yields, oil content and oil yields increased linearly with the amount of nitrogen applied. In Australia, German chamomile occasionally becomes a noxious weed.

Diseases and pests German chamomile is susceptible to the root-knot nematode *Meloidogyne incognita*.

Harvesting German chamomile should be harvested when most of the flowers have already opened. The essential oil content of the inflorescence reaches its maximum when the ligulate flowers are horizontal, and declines with further ripening. The essential oil content is highest around noon on sunny days. Harvesting in full sunlight is also recommended to avoid a high moisture content. In Cuba flower heads of *M. recutita* are harvested manually 2–2.5 months after transplanting. In Europe, harvesting is sometimes mechanical, but yields may be 15–20% lower than with hand picking.

Yield In Cuba up to 2000–2500 kg/ha of fresh flower heads of German chamomile have been obtained in experiments. In Europe, 300–500 kg/ha is normal, but as much as 1200 kg/ha is possible.

Handling after harvest The flower heads of German chamomile should be dried immediately, at temperatures not exceeding 40°C. Drying at 55°C may reduce the oil content by about 30%. The flower heads should be stored in closed containers in the dark.

Genetic resources Several institutes in the world hold germplasm collections of German chamomile. There are large collections in Germany (Genebank of the Institute for Plant Genetics and Crop Research in Gatersleben, 10 accessions) and in Portugal (Portuguese Genebank, Braga, 20 accessions). Since German chamomile is very common and widely distributed, there seems to be no need to pay special attention to the conservation of its genetic resources.

Breeding Tetraploid cultivars are preferred for commercial use, because they have larger flower heads. In Slovakia several newly bred cultivars, such as 'Bona', 'Kosice-1' and 'Kosice-2', contain twice the essential oil content of the older 'Bohemia' and certain cultivars with high contents of a useful chemical constituent are being developed.

Prospects The market for German chamomile as a tea appears to be stable, but its pharmaceutical trade is increasing. Therefore, the prospects for the cultivation of German chamomile in South-East Asia are promising.

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S. Brotonegoro

Mesona palustris Blume

Bijdr. fl. Ned. Ind.: 839 (1826).

LABIATAE

$2n$ = unknown

Synonyms *Geniosporum parviflorum* Wallich ex Benth. (1830), *Mesona wallichiana* Benth. (1848), *M. parviflorum* (Wallich ex Benth.) Briq. (1897).

Vernacular names Black cincau (En). Indonesia: cincau hitam (Indonesian), janggelan (Javanese), cincau hideung (Sundanese).

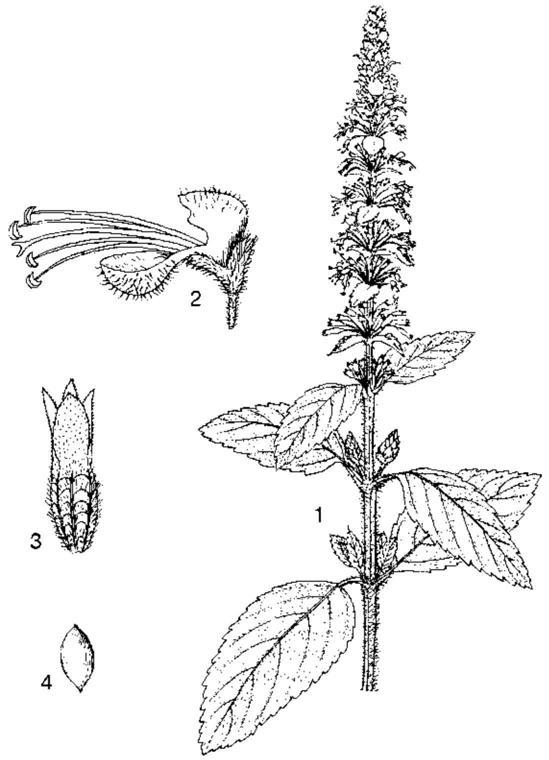
Origin and geographic distribution *M. palustris* originated in the region from India and Burma (Myanmar) to Indo-China. From there it spread into the Malesian region, particularly into Central Sumatra, the whole of Java, the Lesser Sunda Islands (Bali, Lombok, Sumbawa), Sulawesi, the Philippines (northern half of Luzon) and East New Guinea (Wau). *M. palustris* is cultivated in Java.

Uses In Java, the dried leaves of *M. palustris* are used to prepare a gelatinous, cool drink. In West Java 'cincau hideung' is popular: a decoction of dried leaves, to which ash of burned rice culms is added to give it a blacker colour, is mixed with sago or cassava starch and cooked. After cooling, the gel is cut into cubes, which are made into a pleasant drink by the addition of coconut milk and sugar syrup. In China 'cincau' means cool leaves or medicine. The leaves are applied medicinally against dysentery, enteritis, abdominalgia, hoarseness and leucorrhoea. *M. palustris* is also planted for soil conservation.

Production and international trade There is some local trade in dried leaves of *M. palustris* in Indonesia. Small amounts are exported to Singapore.

Properties Per 100 g, fresh leaves of *M. palustris* contain approximately: water 66 g, protein 6 g, fat 1 g, carbohydrates 26 g, Ca 100 mg, P 100 mg, Fe 3 mg, vitamin A 10750 IU, vitamin B1 80 mg and vitamin C 17 mg. The energy value is about 510 kJ per 100 g. The pectin content is about 11%. The leaves also contain saponins, flavonoids and tannins. It is assumed that the blackish colour is due to the presence of tannic acid bound to the pectin and other unidentified compounds.

Description An annual, erect, aromatic herb, 30–50 cm tall, with a well-developed root system. Stem slender, obtusely quadrangular, often branched from the base, unbranched or only sparsely branched at the apex, thinly to densely covered



Mesona palustris Blume – 1, flowering stem; 2, flower; 3, fruiting calyx; 4, nutlet.

with short curled hairs. Leaves decussately opposite; petiole 0–1.5 cm long; blade oblong-elliptical or narrowly obovate-elliptical, 2–8 cm × 1.2–3.5 cm, base narrowly acute or rounded, margin crenate or serrulate, apex acute or obtuse. Inflorescence axillary or terminal, raceme-like, 5–20 cm long, composed of many-flowered verticillasters; pedicel 5–6 mm long; calyx campanulate, 2–2.5(–3) mm long, 8-veined, covered with white hairs, upper lip 3-lobed, lower lip oblong, rounded, in fruit calyx tubular-urceolate, 4–5 mm long; corolla pink or lilac-white, 4–5 mm long, limb 2-lipped, upper lip with 3 obtuse-rounded lobes, lower lip concave, obtuse; stamens 4, in 2 pairs, filaments long-exserted, 2 anterior ones longest, posterior pair appendaged at base; ovary 4-locular, style briefly 2-fid; disk gibbous, on the anterior side shortly tongue-shaped. Fruit a nutlet, ellipsoid, flattened, 1 mm × 0.4–0.7 mm, finely granular.

Growth and development In Malesia, *M. palustris* flowers from March to November. Pollination is effected by insects, mainly bees and bumble-bees.

Other botanical information *M. palustris* is a variable species. In the Philippines it has congested flowers, a less inflated fruiting calyx tube with less conspicuous cross-bars and pits and corresponds with plant material from Java. Intermediate types exist in Sulawesi and the Lesser Sunda Islands. In Central Java, 3 types of *M. palustris* are distinguished: black 'janggelan' with dark purple stems and petioles with brownish hairs; purple 'janggelan' with purple stems and petioles with purplish hairs; and white 'janggelan' with pale green stems and petioles with whitish hairs. *M. procumbens* Hemsley from Taiwan may be conspecific with *M. palustris*.

Ecology *M. palustris* grows on roadsides, along ditches, on open grassy slopes, in forest margins, on dry fields of rice, and around springs, from sea-level up to 2300 m altitude. It may be locally common and tolerates both per-humid and seasonal conditions.

Propagation and planting *M. palustris* is easily propagated by stem cuttings 20 cm long, planted on small ridges in well-prepared, loose soil. They are planted 25–30 cm apart on ridges at 40 cm spacing. Near Bogor (West Java), *M. palustris* is planted as an intercrop with *Capsicum* pepper, soya bean, or maize.

Diseases and pests Around Bogor, diseases and pests are rarely encountered in *M. palustris*. Livestock shun the crop.

Harvesting *M. palustris* is harvested before flowering, when 3 months old. After cutting the stems at 10 cm above the ground the soil is loosened and weeded. A second harvest is possible 1 month later. If no third harvest is intended the plants are then uprooted. The third and last harvest is possible one month after the second harvest, but by then the pectin content is very low.

Yield In Ngrayun district in East Java, which is one of the production centres in Indonesia, annual yield of dry *M. palustris* herb is 500–1500 kg/ha.

Handling after harvest The leaves of *M. palustris* are dried in the open air and turn brownish black. When properly dried they should be stored under dry conditions.

Prospects In Indonesia *M. palustris* is a traditional intercrop which may provide additional revenue to farmers. Research may generate more information on cultivation, processing, genetic resources and breeding.

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U.A. Dasuki & S. Sunarti

Nicotiana rustica L.

Sp. pl.: 180 (1753).
SOLANACEAE
$2n = 48$

Synonyms *N. rugosa* Miller (1768), *N. asiatica* Schultes (1809), *N. humilis* Link (1821).

Vernacular names Nicotine tobacco, tobacco, small tobacco (En). Tabac rustique, petit tabac (Fr). Indonesia: tembakau. Malaysia: tembakau. Vietnam: thu[oos] l[af]o.

Origin and geographic distribution *N. rustica* is of South American origin but is only known from cultivation. It can sometimes be found in a semi-wild state in the Peruvian, Bolivian and Ecuadorian highlands. It was widely cultivated in Mexico, North America and on the Caribbean Islands in pre-Columbian times, and it was the first tobacco cultivated by Europeans in North America and Europe in the 16th Century. Later it was replaced by *N. tabacum* L. because this had a milder taste and flavour. *N. rustica* was also introduced in Asia, Africa, the Russian Federation, the Balkans and the Middle East, but has now lost its importance as tobacco producer in most countries.

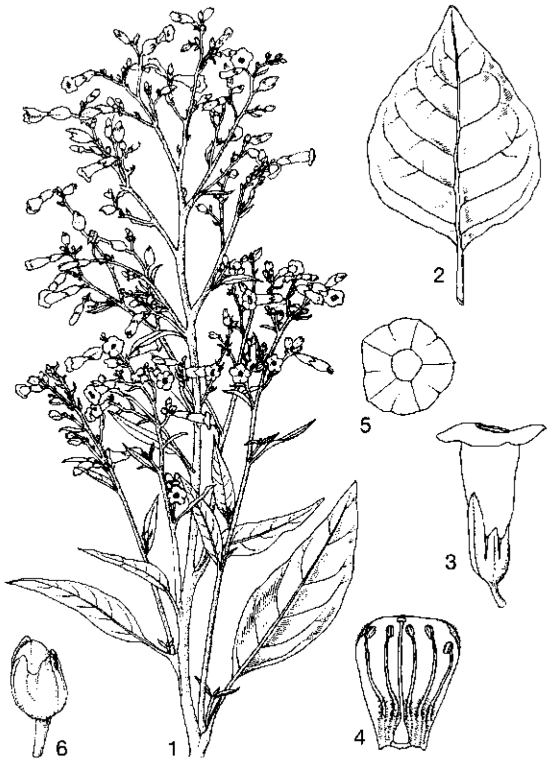
Uses Leaves of *N. rustica* are used for smoking, chewing or snuffing, because of their taste and flavour, but particularly because of the stimulating and mildly narcotic effects of the alkaloid nicotine. In Pakistan for instance, certain cigarette types may contain a blend of 40% *N. rustica* and 60% *N. tabacum* (Virginia) tobacco producing a very strong taste and flavour. Before the advent of synthetic insecticides (after 1945), *N. rustica* was also widely grown for nicotine extraction. Extracts from *N. rustica* leaves are sometimes applied in traditional medicine.

Production and international trade Less than 3% of the present world tobacco production (6.6 million t) is estimated to come from *N. rustica* and very little of that reaches the international trade. In Pakistan about 25% of all tobacco produced is *N. rustica*. It is also of importance in northern India, Bangladesh, the Russian Federation and some North African countries.

Properties Cured leaves of *N. rustica* contain: water 12–15%, protein 3–15%, carbohydrates 10%, sugar 3%, and ash up to 25%. Its nicotine content, 4–9.5%, is higher than that of *N. tabacum*, giving the smoke a much harsher taste.
The 1000-seed weight is 0.08 g.

Description Erect, branched, annual herb, up to 1.8 m tall, bearing multicellular, viscid-glandular hairs. Root system extensive but rather superficial. Leaves alternate, 15–20 per plant, rather variable; petiole 5–6 cm long, not winged; blade ovate, elliptical or subcircular, 10–70 cm × 8–25 cm, base obtuse, margin somewhat undulate, apex acuminate, surface often rugose. Inflorescence a terminal, slender or compact panicle of monochasial or dichasial branches; pedicel 3–10 mm long; calyx tubular, 8–16 mm long, ending in 5 small, subtriangular, unequal lobes; corolla tubular, tube 10–18 mm long, widening above into 5 half-circular, green-yellow lobes 3–7 mm long; stamens 5, inserted near the base of the corolla tube and not exserting, 4 about equally long, 1 a little shorter; pistil with superior ovary, long style and 2-lobed stigma. Fruit an ovoid to globose capsule, about 7–17 mm long, enclosed by the calyx. Seed ellipsoid to ovoid, about 1 mm long, testa brownish and finely pitted. Seedling with epigeal germination.

Growth and development Seeds of *N. rustica* require light for germination. Seedlings are ready for transplanting to the field 35–45 days after



Nicotiana rustica L. – *1, flowering branch; 2, basal leaf; 3, flower; 4, opened corolla tube; 5, corolla limb; 6, fruit.*

sowing, when they are 15–20 cm tall, with a rosette of 4–5 leaves. The root system is extensive but rather shallow and plants are susceptible to lodging under strong wind. Flowering starts 50–60 days after field planting. The anthers dehisce when the flower unfolds and at that time the stigma is also sticky and receptive. Self-pollination takes place normally, but nectar-collecting insects may cause 4–10% cross-pollination. The fruits are mature 3–4 weeks later.

The dormant axillary buds will only develop into lateral branches, called suckers, after topping or when the plant has lodged. Cultivated nicotine tobacco has an economic life span of about 4–5 months.

Other botanical information *N. rustica* is thought to be an allotetraploid, and probably evolved from diploid *N. undulata* Ruiz & Pavon and *N. paniculata* L. Compared with *N. tabacum*, plants of *N. rustica* are generally shorter with much darker green, broader and thicker leaves. *N. rustica* is rather variable and numerous subclassifications exist, often mainly based on differences in leaf and inflorescence morphology. Because *N. rustica* is only known from cultivation, it seems more appropriate to classify the variability into cultivar groups and cultivars. No such classification exists, however. In Pakistan the two main groups of *N. rustica* are the dark 'naswari' and the lighter 'saffaid' or 'white pattar'. In northern India and Bangladesh, hookah (water pipe) cultivars are also grown.

Ecology The climatic requirements of *N. rustica* are comparable to those of *N. tabacum*, though the former is more resistant to cold than the latter. *N. rustica* thrives on well drained and well aerated heavy soils.

Propagation and planting Propagation of *N. rustica* is by seed (10 g/ha). Seed remains viable for over 10 years when stored dry and cool. There is no dormancy, except that freshly harvested seed should be allowed a post-ripening period of 3 weeks. It will then give 95% germination within 5 days after sowing. Seedlings are raised in seedbeds under shade. Seedlings should be thinned and hardened off by gradual removal of the shade, before transplanting to the field at a density of about 20 000–25 000 plants/ha.

Husbandry *N. rustica* fields are regularly hoed to remove weeds and improve soil aeration. For high yields and heavy broad leaves the crop needs appropriate soils, heavy manuring and large nitrogen dressings. Recommendations for *N. rustica* in North Bengal include 10 t/ha of manure and 112 kg/ha of N fertilizer. In Pakistan, 'white pattar' is given an average application of 168 kg N, 90 kg P and 90 kg K per ha, whereas 'naswari' receives a large dose of manure plus 224 kg N, 200 kg P and 112 kg K per ha. Tobacco should be grown on the same land for no more than 2 years in succession, to check the incidence of diseases and pests (e.g. bacterial wilt and root-knot nematodes).

Diseases and pests *N. rustica* is subject to the same diseases and pests as *N. tabacum*. They include: seedling damping-off (*Pythium* spp., *Rhizoctonia solani*), bacterial wilt (*Pseudomonas solanacearum*), black shank (*Phytophthora nicotianae*), frog-eye on leaves (*Cercospora nicotianae*), virus diseases like tobacco mosaic virus (TMV), cucumber mosaic virus (CMV), tobacco leaf curl virus (TLCV) and tobacco etch virus (TEV), root-knot nematodes (*Meloidogyne* spp.), aphids (*Myzus persicae*), whiteflies (*Bemisia tabaci*), thrips (*Thrips tabaci*), leafworms (*Spodoptera litura*) and budworms (*Helicoverpa* spp.).

Harvesting Most *N. rustica* is stalk-cut at

100–130 days after planting. Only the hookah cultivars in India are primed (harvesting of individual leaves).

Yield It should be possible to obtain 1.5–2 t/ha of cured leaves of *N. rustica*.

Handling after harvest In Pakistan harvested plants of 'white pattar' or 'saffaid' are sun cured for about two weeks and turned once or twice to obtain a relatively light-coloured leaf. Harvested 'naswari' plants are left in the field for about six days to dry partially, before being gathered into heaps, which will be turned several times in the ensuing 1–2 months in a combined curing and fermentation process. The aim here is a dark, strong-smelling, rather thin tobacco. In Algeria harvested plants are wilted for a short period in the field and then air cured under roofed but open structures, often under lean-to roofs against houses or other buildings.

Genetic resources and breeding Germplasm collections of *N. rustica* are available in the main production centres. *N. rustica* is polymorphic with genetic variation present in numerous locally selected cultivars. In East Africa and the Russian Federation, selection efforts used to focus on increased nicotine content (up to 14%), but at present there is no longer any interest in the commercial production of nicotine as an insecticide.

Prospects The importance of *N. rustica* as a supplier of tobacco leaves for smoking is likely to decrease, since the rather harsh taste and flavour are not much appreciated beyond traditional users. However, it could be revived as a source of nicotine if interest in natural insecticides were to revive. For South-East Asia, interest in *N. rustica* will remain marginal.

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B.I. Utomo W. & E. Rahayu

Nicotiana tabacum L.

Sp. pl.: 180 (1753).

SOLANACEAE

$2n = 48$ (amphidiploid)

Synonyms *Nicotiana virginica* C. Agardh (1819), *N. mexicana* Schlecht. (1847), *N. pilosa* Moc. & Sessé ex Dun (1852).

Vernacular names Tobacco (En). Tabac, tabac commun (Fr). Indonesia: tembakau, tabako, bako. Malaysia: tembakau. Papua New Guinea: brus. Philippines: tabaco (general), tabaku (Sulu). Cambodia: thnam' chuëk. Laos: ya:, ya: dét. Thailand: yasup (general), chawua (Khmer-Surin). Vietnam: thu[oos]c l[as].

Origin and geographic distribution *N. tabacum* was domesticated in Central and South America more than 2000 years ago and does not appear to exist anymore in a truly wild state. This amphidiploid species probably evolved from interspecific hybridization between diploid parents (*N. sylvestris* Speg. & Comes and *N. otophora* Griseb. or *N. tomentosiformis* Goodsp.) occurring naturally in north-western Argentina. When the first Spanish explorers arrived in the Caribbean and Americas towards the end of the 15th Century they found that tobacco smoking was widespread among the local people. They quickly adopted the habit, initially for medicinal purposes but soon mainly for pleasure, and introduced tobacco cultivation throughout the world. The first tobacco was planted in Europe around 1560 and in North America (Virginia) in 1612. From the Philippines it was brought to Malaysia, Indonesia, China, Japan and India in the early part of the 17th Century. In Europe, pipe smoking became very popular and tobacco for this purpose was imported from the Americas: Virginia produced in the south-eastern states of North America and Spanish from Caribbean islands and South America. However, by the end of the 18th Century this profitable trade had declined due to increased domestic tobacco production in Europe. Most of the tobacco grown in Asia was used locally for chewing and for smoking in cheroots or traditional cigarettes. Very little was traded internationally until the development of the cigar tobacco plantation industry in Java and north-eastern Sumatra after 1860.

Cigarette smoking was first introduced into Europe after 1855 by soldiers returning from the Crimean war. The subsequent popularization of cigarettes on a global scale, particularly after World War I, was an important impulse for the tremendous expansion of world tobacco production: 2.4 million t in 1925 (Asia 55%, Americas 33%, Europe 10%), 3.8 million t in 1957 (Asia 43%, Americas 37%, Europe 17%) and 5.5 million t in 1980 (Asia 47%, Americas 30%, Europe 23%).

Uses Cured tobacco leaves are smoked, chewed or sniffed (as snuff) for their taste and flavour, but particularly also for the stimulating and mildly narcotic effects of the alkaloid nicotine. The final use of tobacco leaves is determined by several factors, including cultivar, climate, soil and methods of curing (drying) after harvesting. More than 90% of all tobacco is manufactured into cigarettes: mainly flue-cured, broad-leaf Virginia (mild), but also light air-cured Burley (thin-leafed) or Maryland types, which are stronger flavoured and often used for blending. Aromatic or oriental tobacco is produced from sun-cured small-leafed Smyrna, Samsun and Virginia types. The manufacturing of cigars requires three different types of dark air-cured tobacco leaves: filler (Brazil-Bahia, Havana, Kentucky, Criollo), binder (Havana, broad-leaf Connecticut and Java) and wrapper (Sumatra-Deli, Java shade grown, Havana, Cuba types). Pipe and snuff tobaccos may be prepared from blends between several types, including fire-cured Kentucky and Virginia, or air-cured Burley and Maryland. American cigarettes are made from a blend between Virginia, Burley, oriental and Maryland tobaccos, whereas English cigarettes contain Virginia tobacco only. The cigarette manufacturing process also includes steeping the leaves in special flavoured liquids (the recipes are company secrets), to improve the tobacco's flavour and curing properties. Indonesia produces the typical clove cigarette 'kretek', which is made from a blend of tobacco and shredded cloves (dried flower buds of *Syzygium aromaticum* (L.) Merrill & Perry) and first appeared in Java around 1890. Annual production of these clove cigarettes increased from 11 billion in 1934 to 170 billion in 1996. In Indonesia pounded fresh tobacco leaves are included in local medicinal solutions to treat wounds and ulcers. Nicotine extracted from leaves of *N. tabacum*, but especially those of *N. rustica* L., which have a higher nicotine content, was formerly used as an insecticide.

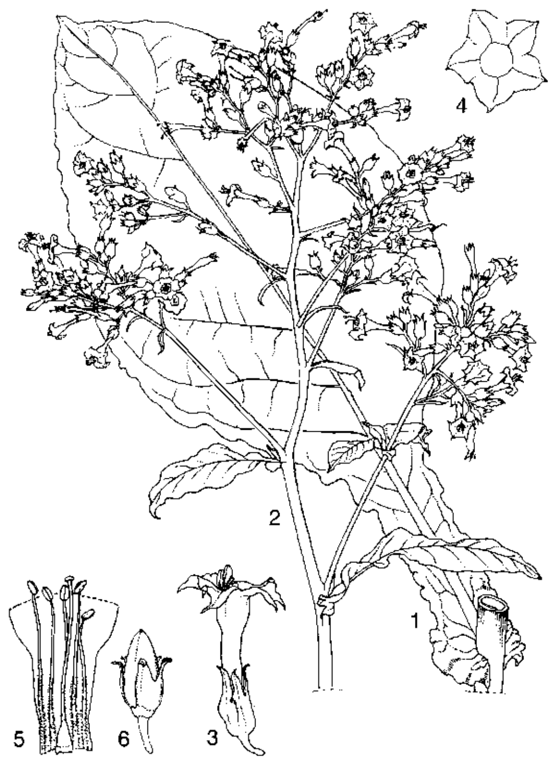
Production and international trade Tobacco is grown in some 110 countries on a total of 4.5 million ha. Averaged over 1994–1997 world production was about 6.6 million t per year of cured (dried) tobacco leaves, with Asia accounting for 58%, the Americas 21%, Europe 8%, Africa 7%, and West Asia and the Mediterranean area 5%. China alone produces 40% of the world's tobacco (exporting only 2%), the United States 9%, India 8%, Brazil 6%, Turkey 4% and Zimbabwe 3%.
With 155 000 t per year (215 000 ha) Indonesia is the 7th largest tobacco-producing country. Most of the Indonesian tobacco is consumed domestically (cigarette industry) and the 15 000 t exported consists mainly of high-quality cigar (wrapper, binder and filler) tobaccos. Other tobacco-producing countries in South-East Asia include: Thailand 60 000 t (47 000 ha), the Philippines 50000 t (37 000 ha), Burma (Myanmar) 38 000 t (37 000 ha), Vietnam 29 000 t (36 000 ha), Malaysia 12 000 t (11 000 ha), Cambodia 5000 t (9000 ha) and Laos 3000 t (4000 ha). Thailand exports 50% and the Philippines about 20% of its annual crop, but both countries also import tobacco. About 30% of the world crop is sold on the international market, representing an estimated value of US$ 3–5 billion per year (1994–1996). Prices for cured tobacco leaves may vary from US$ 0.40 to US$ 5.50 per kg, depending on country, type and quality of the product and the current market situation of supply and demand. For instance, flue-cured tobacco may cost US$ 0.90–1.50 per kg in China and Indonesia, but US$ 3.50–4.50 in the United States and Spain, or even US$ 19.00 in Japan. In some years Indonesian dark air-cured (wrapper and binder) cigar tobacco has fetched more than US$ 12.00 per kg. The major tobacco-exporting countries (accounting for 56% of world exports) are in descending order of importance: Brazil, Zimbabwe, the United States, Turkey, India, Italy and Greece. The largest importers (accounting for 35% of world imports) are the United States, Germany, the United Kingdom, the Netherlands and Japan. Average annual consumption of tobacco varies from 0.1–3.5 kg cured tobacco per capita: e.g. 0.1 in Malawi and Nigeria; 0.5 in India, Mexico and Italy; 0.8 in Egypt, Thailand, Burma (Myanmar) and Cambodia; 1.1 in Indonesia, the Philippines, Vietnam and Brazil; 1.8 in Japan, China, Turkey, the United Kingdom and Poland; 2.5 in the United States, Hong Kong and Belgium; and 3.0 or more in Singapore, Greece, Bulgaria and the Netherlands.

Properties Fresh tobacco leaves contain 85–90% water. This falls to 12–15% during the curing process. On a dry-weight basis flue-cured (cigarette) tobaccos contain sugars 18–20%, starch 5–8% and proteins 2%; air-cured (cigar) tobaccos contain only a few percent sugars, but proteins 3–15%. The major alkaloid in tobacco is nicotine. The nicotine content in air-cured cigar tobacco is

1.0–1.5%, in flue-cured tobacco 1.5–2.5% and in Burley tobacco up to 4%. Nicotine content determines the tobacco's strength, but flavour and quality of taste are more related to protein content. Essential oils and resins in the glandular hairs contribute to the tobacco aroma. Cured tobacco leaves have a high ash content: 12–25%. The quantity and composition of the mineral content affect quality and combustibility, e.g. chloride content in excess of 1% having a negative effect. Tobacco leaves also contain quantities of organic (citric, maleic and oxalic) acids, which react with calcium, potassium and other cations during the curing process to form salts. Air-cured tobaccos become reddish-brown because the polyphenols (tannins) present in the leaves oxidize. In flue-cured tobacco oxidation is largely prevented due to the rapid drying process, so the leaves retain a yellow colour. Nicotine mimics the action of acetylcholine at specific receptors in the central and peripheral nervous system. It stimulates the release of adrenalin, slows the heart rate and raises blood pressure. Nicotine is one of the most addictive drugs. Smoking cigarettes leads to the inhalation of tars, which are known carcinogens. There are well established correlations between smoking and lung and throat cancers, heart disease and respiratory ailments.

Seeds contain 32–42% semi-drying oil (60–75% linoleic acid) and 20% protein. The 1000-seed weight is 0.085 g.

Description Annual herb, 1–2.5(–3) m tall, with thick, unbranched (except when topped), erect stem, with well-developed taproot. Leaves and stem green (except for white Burley cultivars), covered with multicellular hairs, some glandular and sticky. Leaves arranged spirally, 20–35 per plant (higher numbers in certain indeterminate cultivars; number fairly constant for each cultivar), sessile; blade ovate-lanceolate or elliptical, 5–50 cm × 5–25 cm, entire, with slightly undulating margin, decurrent, usually with an auriculate base, pinnately veined. Flowers borne in a terminal thyrsoid panicle, up to 150 per inflorescence; pedicel 1–2(–2.5) cm long, subtended by a bract; calyx cylindric-campanulate, 1–2.5 cm long, with 5 unequal pointed teeth; corolla salver-shaped, tube 3.5–5.5 cm long with throat inflated, hairy, usually pale pink, rarely white or carmine red, limb 10–15 mm wide, acutely 5-lobed to pentagonal; stamens 5, inserted on the corolla tube, filaments of unequal length, anthers small, dehiscing longitudinally; ovary superior, 2-locular with a fleshy axile placenta carrying numerous ovules, style long, slender, with capitate, 2-lobed stigma. Fruit a 2-valved, ellipsoid to ovoid or globose capsule, 1.5–2 cm long, the greater part enclosed by the calyx. Seeds numerous, 2000–5000 per fruit, ovoid to globose, very small, 0.4–0.6 mm long, surface finely reticulate, light to dark brown. Seedling with epigeal germination.



Nicotiana tabacum L. – 1, leaf; 2, inflorescence; 3, flower; 4, corolla limb; 5, opened corolla tube showing stamens and pistil; 6, calyx with fruit.

Growth and development Tobacco seed remains viable for more than 10 years when stored dry and cool. There is no dormancy, except that freshly harvested seed should be allowed a post-ripening period of 3 weeks. It will then give 95% germination within 5 days after sowing. Seeds of most cultivars require light for germination. Seedlings are ready for transplanting to the field 35–45 days after sowing, when 15–20 cm tall, with a rosette of 4–5 leaves. The taproot is usually broken in transplanting and a mass of fibrous roots develops from several horizontal laterals. The mature root system is extensive but rather shallow and tobacco plants are susceptible to lodging under strong wind, particularly when bearing a full-size inflorescence. Flowering starts 50–60 days af-

ter transplanting. The anthers dehisce when the flower unfolds and at that time the stigma is sticky and receptive. Self-pollination takes place normally, but nectar-collecting insects may bring about 4–10% cross-pollination. The fruits are ready for harvesting 3–4 weeks later.
The first and lowest leaves are mature about 2 months after transplanting, when the colour changes from livid or bluish-green to yellowish-green, particularly along the edges. Dormant axillary buds will only develop into lateral branches, called suckers, after topping or when the plant has lodged. Tobacco has an economic life span of about 5 months.

Other botanical information The genus *Nicotiana* includes some 65 species, mostly endemic to the Americas and a few to Australia. Most are diploid ($2n = 24$) except for 9 amphidiploid species, including *N. tabacum* and *N. rustica*. At least 10 *Nicotiana* species have been used in the past by indigenous peoples for ritualistic, medical or hedonistic purposes because of their intoxicating nicotine content. A system of gametophytic self-incompatibility is common in many diploid *Nicotiana* species, but *N. tabacum* and *N. rustica* are self-compatible and largely self-fertilizing. Wild *Nicotiana* species have dehiscent capsules causing early dissemination of the seeds, whereas the cultivated *N. tabacum* and *N. rustica* possess indehiscent capsules as a result of human selection.

Ecology Tobacco is cultivated under a wide range of climatic conditions, from Sweden (60°N) to New Zealand (40°S). It requires a frost-free period of 90–110 days after transplanting and at high latitudes seedlings are therefore raised in glasshouses. Mean temperatures for optimum growth are 21–27°C, with lower and upper limits of 13°C and 37°C. Water requirements are 300–400 mm, evenly distributed during the growing season. Cigarette (e.g. Virginia) tobaccos need a dry period at the end of the season to obtain the required thickness and yellow colour of cured leaves. To produce thin and elastic leaves, wrapper tobacco needs a high humidity (70% at noon) and a reduced sunshine intensity (70% of maximum sunshine). Clouds occurring on rainy days act as a natural filter for the sunlight. The quality of Deli cigar wrapper tobacco is said to be determined in the first place by climatic conditions and only in the second place by soil conditions. To mimic the growing conditions of North Sumatra, cigar wrapper tobacco is now cultivated under shade not only in other parts of Indonesia (Java), but also in Connecticut (the United States).
In Central Java the main area of cigarette tobacco is on the Dieng plateau at about 1000 m elevation, where generally better quality is produced. Soils most suited to tobacco cultivation are light to medium loams with good water-retaining capacity and slightly acid reaction (pH 5.0–6.0). Soils must be well drained, since tobacco is very sensitive to waterlogging. Cigar-type tobaccos require more fertile soils than Virginia tobacco. Since combustibility is an essential quality component of cigar and cigarette tobacco, the chloride content in the soil should be low, preferably no higher than 40 ppm irrigation water should have a chloride content not exceeding 25 ppm.

Propagation and planting Tobacco is propagated by seed. Seedlings are raised on shaded beds. Generally 10 g of healthy seed are needed to produce enough seedlings to plant one hectare, but only one third of this amount is needed if the seed is pelleted. The medium for raising seedlings is a mixture of soil and compost, and should be steam-sterilized at 100°C for one hour to prevent infection by soilborne pathogens. NPK fertilizer is applied before sowing. The total area of seedbeds is usually 80–100 m^2 for each hectare of crop. Maintenance includes daily watering, manual weeding and control of diseases and pests. Thinning is carried out to remove weak and spindly seedlings. After thinning the number of seedlings should not exceed 400 per m^2. Plants are hardened off 7–10 days before transplanting by gradually removing overhead shade and reducing watering. Tobacco is planted in the field at 45–55 cm within the row and 75–110 cm between rows. Seedlings grown in small polybags or trays establish more readily than bare-rooted seedlings grown on traditional beds. The average plant density is 18 000–25 000 per ha for most tobacco types, except oriental tobacco (>60 000 plants/ha).

Husbandry Most tobacco is rain-fed. Sprinkler and furrow irrigation may be applied, to supplement inadequate rainfall. In low-lying and flat fields ditches are needed to improve drainage after heavy rainfall. The soil is tilled periodically to remove weeds, to increase soil aeration, to promote root growth and to ridge the soil around the plants. Topping by removing the developing inflorescence is general practice in most tobacco types (except wrapper and oriental tobaccos) to improve leaf yield and quality, but any suckers that develop subsequently should be removed. Proper fertilizer application is important to obtain high yields of high-quality tobacco. The type and rate of fertilizer application depend on the tobacco variety and soil conditions. Flue-cured tobacco, for example, needs lower rates of nitrogen and higher rates of phosphorus than cigar tobacco. Fertilizer rates are of the order of 20–60 kg N, 20–50 kg P_2O_5, and 30–70 kg K_2O, the latter to be applied as K_2SO_4. Crop rotation is essential to prevent the build-up of soilborne diseases (e.g. bacterial wilt) and pests (e.g. nematodes).

Diseases and pests In South-East Asia tobacco is subject to various major diseases and pests. They attack all plant parts at all growing stages. The most serious disease is caused by the soilborne bacterium *Pseudomonas solanacearum*, resulting in decay of the roots, followed by wilting. In the wrapper tobacco area near Medan, North Sumatra, only crop rotation can reduce the incidence of and damage by *P. solanacearum*. The duration of the non-tobacco cropping period and the type of crops included in the rotation are of great importance. In Java the wilting disease is less destructive because an annual crop rotation with irrigated rice reduces the pathogen level.

Black shank (*Phytophthora nicotianae* var. *nicotianae*) is an important and destructive root and stem disease in the South-East Asian tobacco areas. In Java losses are considerable and in the 1990s losses were also reported from North Sumatra. Plant sanitation and the use of resistant cultivars in combination with crop rotation and nematode control reduce the build-up of this soilborne disease. Soil application of metalaxyl reduced disease incidence in Java. Fusarium wilt (*Fusarium oxysporum* f.sp. *nicotianae*) is another root and stem disease occurring in the South-East Asian tobacco production areas, especially in rotations with sweet potato (*Ipomoea batatas* (L.) Lamk).

Frog-eye (*Cercospora nicotianae*), which produces white-brown spots on the leaves, can be a serious problem in wrapper tobacco during wet weather. The susceptibility to frog-eye increases with maturation of the leaves. Infection occurring a few days before harvest may result in green spots on the leaves after curing. Early leaf picking can prevent leaf damage when there are signs of an impending outbreak of frog-eye. A systemic fungicide (Benomyl) is sometimes used.

In seedbeds the major problem is damping-off of seedlings caused by *Pythium* spp. and *Rhizoctonia solani*. Soil sterilization and adequate aeration can considerably reduce damping-off. Another preventive measure is thinning seedlings to reduce air humidity around the plants. Once the soilborne fungus has arrived, via infested soil, agricultural equipment, surface or irrigation water or infected transplants, losses can be substantial. Seedlings in affected seedbeds should be destroyed and the seedbed soil should be steam-sterilized before it is used again.

Virus diseases such as tobacco mosaic virus (TMV), cucumber mosaic virus (CMV), 'krupuk disease' or tobacco leaf curl virus (TLCV) and tobacco etch virus (TEV or 'Rotterdam B') are of importance in almost all tobacco-growing areas of Indonesia. In the Philippines TMV is the most destructive virus disease. TMV is spread mechanically by humans, via implements and by contact from plant to plant during field operations. Cured leaves of mosaic-infected plants carry the virus for several years.

In South-East Asia insects cause considerable damage to leaves and stems and sucking insects such as aphids (*Myzus persicae*), whitefly (*Bemisia tabaci*) and thrips (*Thrips tabaci*) are also vectors of virus diseases. The leafworm (*Spodoptera litura*) and the budworm (*Helicoverpa* spp.) are the most predominant pests. In cigar tobacco areas in Java, integrated control of leafworm and budworm is practised by monitoring moth populations with sex pheromones, by scouting, and by removing egg colonies, hand picking of larvae, and spraying with pesticides whenever needed. The cutworm (*Agrotis ipsilon*) is found in areas where cabbage is grown in rotation with tobacco. The most important sucking insect is *Myzus persicae*, the vector of CMV and TEV. The whitefly is the vector of TLCV, and thrips is the vector of TSWV (Tomato Spotted Wilt Virus). Dry weather is favourable for the development of these insects. Therefore the occurrence of insect-transmitted virus diseases tends to increase during the dry season.

Cured leaves of tobacco can be infested by the tobacco beetle (*Lasioderma serricorne*). Control is carried out by monitoring insect populations in warehouses with red-light traps and in freight containers with sex pheromone (Lasio trap), and fumigating tobacco bales in the warehouse with phosphine. Root-knot nematodes (*Meloidogyne* spp.) are a worldwide serious pest in tobacco, only to be controlled by crop rotation or temporary inundation (e.g. after irrigated lowland rice).

Harvesting Harvesting is a critical factor in producing high-quality tobacco. In tropical areas harvesting starts 50–60 days after transplanting. Normally a leaf is considered mature when its tip has just turned yellow. Wrapper type cigar tobacco is harvested earlier to produce light-coloured leaves. Cigar filler and cigarette tobaccos are, however, harvested at a later stage to obtain a better flavour.

In South-East Asia all types of tobacco are harvested by individual leaf picking (priming), starting with the lowest leaves, 2–4 at the same time, at 2–5 day intervals. Leaf position on the stem determines the quality of tobacco. From the bottom upwards the leaves are classified into sand leaves or lugs (4–6), foot leaves or cutters (6–8), middle leaves (6–8) and top leaves (4–6 leaves). In cigar tobacco sand and foot leaves are the best to be used as high quality wrappers. In cigarette tobacco middle leaves may have a better taste and aroma than bottom leaves, but for producing low nicotin cigarettes lower leaves are more suitable. Leaves to be flue or fire cured must be fully mature before harvesting, but if they are to be air or sun cured, they are harvested before full maturity.

Yield World average yield of cured tobacco leaves is 1.5 t/ha. Average yields per ha are 2.5 t in the United States, Japan and Australia, 1.9 t in Zimbabwe, 1.7 t in China, 1.3 t in India and 0.8 t in Turkey and Malawi. National averages per ha in South-East Asia are: Indonesia 0.7 t, Vietnam 0.8 t, Malaysia and Burma (Myanmar) 1.0 t, Thailand 1.3 t and the Philippines 1.4 t. In Indonesia, low-input smallholder plots may produce only 400 kg/ha against 1.6 t/ha on large commercial estates. Seed yields are up to 25 g/plant, and potentially 450–600 kg/ha.

Handling after harvest Tobacco leaves are usually strung back-to-back on sticks before being placed on racks in enclosed barns for curing. There are several ways:

- flue curing (cigarette tobaccos), in ventilated brick barns, heated for 5–7 days by hot air generated by burning wood or other fuels, which passes through metal flues; temperatures are gradually increased from 35°C to 80°C during the yellowing, colour-fixing and final drying stages;
- air curing (cigar, Burley and Maryland tobaccos), in thatched, bamboo or wooden barns with ventilating hatches, over a period of 3–4 weeks; early wilting and yellowing is followed by increasing ventilation to promote gradual drying at temperatures not exceeding 45°C;
- fire curing (dark cigarette, pipe and chewing tobaccos), in thatched or wooden barns with small open fires in pits in the floor to provide smoke, over a period of 2–3 weeks; temperatures gradually increasing from 35°C to 50°C.

Sun curing for 2–4 days in full sunlight on wooden or bamboo screens is common for oriental (Turkish) and the traditional 'rajangan' (cut) tobaccos in Indonesia.

After curing, cigar tobacco should be fermented to improve its combustibility, aroma, colour and texture. By making a large heap of tobacco, the temperature inside the heap rises to 50°C and this facilitates optimum enzymatic changes. The heap is rebuilt 4–5 times after the critical temperature has been reached. The average fermentation period is 100 days. The next process is grading based on colour, thickness (body) and length of the cured leaves, and degree of leaf damage. The tobacco is then pressed into bales of 60–100 kg. In cigarette tobacco the process is finished after curing, however, during storage it undergoes aging. Virginia tobacco needs to be redried to reduce its moisture content to 12%.

Genetic resources The relative ease of introgression by interspecific hybridization allows the large genetic diversity, present in wild diploid *Nicotiana* species of Central and South America to be exploited to improve cultivated *N. tabacum*. For instance, *N. glutinosa* L. has been used extensively as a source of resistance to TMV, whereas *N. longiflora* Cav. and *N. plumbaginifolia* Viv. have been used for resistance to *Phytophthora nicotianae*. The United States Department of Agriculture (USDA) has assembled extensive collections of tobacco germplasm from several parts of the world which has been given TI (Tobacco Introduction) accession numbers. One of these is TI 245 which has a simultaneous resistance to TMV, CMV, tobacco ringspot virus, tobacco streak virus, tomato ringspot virus, turnip mosaic virus, and potato mottle virus. Intensive screening of world collections of *Nicotiana* for resistances to pathogens and insects is still in progress.

Breeding Since tobacco is a self-pollinating crop, most cultivars are pure lines developed by pedigree and backcross selection methods. On the one hand, tobacco is ideal for breeding, because of its easy self- and cross-pollination, the high rate of success of interspecific crosses, the abundance and longevity of its seeds, the large range of variability present for most plant characters and the extensive information accumulated from biometrical genetic studies. On the other hand, the specific demands on product quality by the well-established tobacco market and industry pose a considerable obstacle to the introduction of novel tobacco cultivars. Most of the tobacco is therefore produced by true-breeding selections of long standing. However, the hybrid vigour of crosses between cultivars of diverse origin and the advantages of hybrids that combine multiple disease resistances with yield and quality in one genotype has stimulated hybrid breeding in tobacco.

F_1 hybrids are now used to produce cigar tobacco in North Sumatra and Central Java. They combine high yield with good quality and resistance to black shank. Since soilborne and virus diseases are difficult to control by cropping methods, breeding for resistance is essential. Resistance to TMV, for example, is controlled by a dominant gene (N), derived from *N. glutinosa*, and based on hypersensitivity to virus infection (necrotic lesions on the infected leaves). Resistant cultivars with this type of resistance have been used commercially in the production of cigar tobacco on East Java. Resistance to black shank from *N. longiflora* is also controlled by a major gene.

In *N. tabacum* polygenic resistance to black shank is found in cultivar 'Florida 301' and cigar tobacco cultivar 'Timor' from Central Java. Resistance to bacterial wilt is found in some flue-cured tobacco cultivars, i.e. 'Dixie Bright 101' (popular in Indonesia since the 1950s), 'Oxford 26', 'NC 95', 'NC 2326', 'Coker 187', 'Coker 254', 'Coker 298' and 'Coker 316'. With the exception of 'Oxford 26' all these cultivars are resistant to black shank.

Prospects The prospects for tobacco cultivation in South-East Asia are good. Although smoking is now universally discouraged and considered to be a health hazard, it seems likely that the consumption of cigarettes will continue to increase. With the population growth in Asia and the urbanization near major production areas (e.g. North Sumatra, Central and East Java in Indonesia and Chiang Mai in Thailand), virus diseases will become more menacing because of the spread of infection from neighbouring backyard gardens. Moreover, the soilborne diseases like black shank and bacterial wilt deserve more attention, as proper crop rotation and soil management will deteriorate due to shortage of land. Tobacco has been a model plant in the development of biotechnology and is well placed to take advantage of molecular methods for genetic improvement, such as resistance to serious pests (e.g. Bt genes against tobacco budworm) and elimination of potentially hazardous constituents in tobacco smoke. Genetically modified tobacco also has great potential for yielding essential pharmaceutical and other compounds. As wood for flue-cured tobacco will become increasingly scarce, research on a more efficient use of renewable energy should be given higher priority.

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I. Hartana & H. Vermeulen

Paullinia cupana Kunth

Nov. gen. sp. 5: 91 (1821).

SAPINDACEAE

$2n = 14$

Synonyms *Paullinia sorbilis* Martius (1826).

Vernacular names Guaraná (En, Fr, Brazil).

Origin and geographic distribution *P. cupana* is indigenous to the tropical forests in the central and upper Amazon Basin of South America. It was taken into cultivation as a trimmed shrub, probably around 1850. Commercial production of *P. cupana* has become important since the 1970s and is largely confined to an area between Manaus and Maués in the Amazonas province of Brazil. It has been cultivated in the Economic Garden of Singapore, where it proved easy to grow.

Uses European travellers of the 18th Century noticed local people in the upper Amazon Basin using seeds of *P. cupana* to prepare a stimulant beverage for ritual and medicinal purposes. Traditionally, powder scraped from stick-shaped loaves of processed seeds is mixed with water to prepare a strongly invigorating, non-alcoholic beverage with bitter taste and a distinctive flavour mostly appreciated by the local people only. The loaves are sometimes shaped into various animal figures and sold as handicraft art objects. In modern times *P. cupana* has found industrial application in the preparation of an amber-coloured sweet and carbonated lemonade, or a concentrate that has become very popular in Brazil and to some extent also in Japan and the United States. Guaraná extracts are used to flavour cola drinks, alcoholic beverages and candy.

Production and international trade Almost all commercially grown *P. cupana* comes from Brazil. Annual production is no more than 1200 t from 4000 ha, with some 70% used by the Brazilian soft drink industry. There is a small export trade, mainly to Japan and the United States. The production is concentrated in the state of Amazonas but *P. cupana* is increasingly being grown in the states of Bahia and Rondônia too, because at present demand is greater than supply.

Properties The seeds of *P. cupana* are rich in xanthine alkaloids, caffeine in particular but also theobromine and theophylline. On average, caffeine represents (2.5–)3.5(–6)% of fresh weight. Other constituents include cellulose (47%), proteins (15.6%), tannins (5–11%) and amides (9.4%). Small amounts of saponins, choline and mineral salts are also present. *P. cupana* derives its stimulating effect from the relatively high caffeine content in the original product, but claims of additional curative properties have not been confirmed in formal medical tests.
The 1000-seed weight is 900–1000 g.

Description An evergreen, scandent, monoecious shrub, up to 3 m tall when growing in the open, or a woody liana when growing in shade. In cultivation it is pruned to a shrub 2 m tall and 2–4 m in diameter. Stem typically branching into 2 branches near the soil surface, bearing deep longitudinal furrows and axillary tendrils. Leaves alternate, imparipinnate, 5(–11)-foliolate, glabrous; petiole 7–15 cm long; leaflets elliptical to ovate, 10–20 cm × 4.5–9 cm, margin entire or grossly serrate with marginal discoid glands, apex acute to acuminate, shiny green above with lateral veins running undivided from midrib to leaflet margin.

Paullinia cupana Kunth – 1, flowering and fruiting branch; 2, female flower; 3, young fruit (3-lobed); 4, side view of a seed in a capsule.

Inflorescence an axillary, terminal or tendrillate racemose compound up to 30 cm long, consisting of sessile to elongated, occasionally scorpioid cincinni; pedicel 3–7 mm long; flowers 3–6 cm long, unisexual, male and female flowers on the same inflorescence; calyx unequally 5-lobed; petals 4(–6), oblong, about 5 mm long, white, with scale appendages; extrastaminal disk glands 4; stamens 8; pistil with glabrous ovary, fleshy style and trifid stigma. Fruit a 3-lobed subglobose capsule, 2–3 cm in diameter, yellow to red, containing 1–3 seeds; fruit stalk about 1 cm long. Seed depressed globose, 1.5–2 cm × 1–1.5 cm, dark brown, partly embedded in a white, pulpy aril; embryo about 1 cm long, cotyledons fleshy. Seedling with hypogeal germination.

Growth and development *P. cupana* has no seed dormancy and seeds germinate 1–4 months after sowing. Seed viability is quickly lost under dry conditions. The seedling produces a new leaf at monthly intervals, the first 6–10 being unifoliate. First flowering starts 1.5–2 years after seed germination. Inflorescences are borne on new wood developed during the rainy season. Flowering is extended over a period of one month during the early part of the dry season. Mature, multi-stemmed shrubs (4–5 years old) will bear hundreds of inflorescences. Open flowers on inflorescences of one branch are all of the same sex at any one time, pistillate on one particular day and staminate on the next, but each branch on the same plant follows its own pattern of sex synchronization during anthesis. The ratio of pistillate to staminate flowers is about 1 : 5. Pollination is by bees, wasps and possibly also ants. Fruits are mature and dehisce the seeds in about 75 days.

Other botanical information The genus *Paullinia* L. includes some 200 species, most of them of Amazonian origin. The cultivated *P. cupana* forms are often referred to as *P. cupana* var. *sorbilis* (Mart.) Ducke, which closely resembles the wild type var. *cupana*. It is better to classify the cultivated forms in a cultivar group, e.g. cv. group Guaraná. The caffeine-rich bark of the related species *P. yoco* Schultes & Killip is also used by local people of the Amazon basin to prepare a stimulant beverage.

Ecology The natural habitat of *P. cupana* is the humid tropics with average minimum and maximum temperatures of 22°C and 32°C respectively; annual rainfall of at least 2000 mm, but with a period of 2–3 relatively dry months (100 mm) for flowering and fruit ripening. In Amazonia *P. cupana* is cultivated on the 'terra firme', which are clay oxisols that remain free from flooding.

Propagation and planting Seeds of *P. cupana* are placed in moist sawdust and germinated seeds are planted in black polythene bags filled with topsoil and placed under heavy shade. One-year-old seedlings are planted in the field in the early part of the rainy season (January–February in Amazonia) at a density of 625–1100 plants/ha in a square arrangement of 3–4 m × 3–4 m. Palm leaves are placed over the seedlings as temporary shade to prevent sun scorching.

Vegetative propagation by softwood cuttings is possible, although rate of rooting success varies greatly with different genotypes. Mist propagation and application of indole-3-butyric acid (IBA) improves rooting.

Husbandry New plantings of *P. cupana* are usually established on land freshly cleared from forest. Leguminous cover crops (e.g. *Pueraria* spp.) are sometimes interplanted, but fertilizers are not generally applied in the main areas of cultivation in Amazonia. Maintenance operations include occasional weeding and pruning to control the size of the shrubs.

Diseases and pests The commonest and often severe disease in *P. cupana* is anthracnose from the black speckle fungus (*Colletotrichum guaranicola*) which causes large lesions on the leaves and inflorescences. *Fusarium decemcelallare* causes proliferation of buds resulting in masses of unproductive tissue; it can be severe in nurseries. Infected shrubs are uprooted and burned. Other diseases include red root rot (*Ganoderma philippii*) and black crust (*Septoria paulliniae*). Various parasitic nematodes attack the roots.

Harvesting In Amazonia *P. cupana* fruits from September to January ('dry' season) and ripe fruits are handpicked every other day.

Yield There is a large annual and between-plant variation in yield of *P. cupana*, ranging from 0.1–9 kg seed per shrub. Growers appear to obtain on average about 500 kg/ha, but 2–4 t/ha have been obtained on experimental stations.

Handling after harvest Seeds of *P. cupana* are washed to remove the white aril and dried to about 10% moisture content. Processing involves roasting the seeds in an oven for 2–3 hours, followed by milling. For local use the powder is mixed with water, kneaded into a paste and made up into round stick-like loaves, 11–18 cm long and 3–4 cm in diameter. These are dried in the sun or by fire and finally they are placed in a smoke house to harden for 40 days. In this form they will keep for years. Traditionally, when required, powder is filed off the loaf with the bony tongue of the pirarucú fish (*Arapalma gigas*). The soft drink industry uses an extract from the roasted and finely ground seed to prepare a carbonated beverage that also contains artificial flavourings and sweeteners.

Genetic resources and breeding Over 700 accessions of *P. cupana* from throughout the Amazon region have been collected by the Guaraná Research Institute of the 'Empresa Brasileira de Pesquisa Agropecuária' (EMBRAPA), near Manaus, Amazonas, which also has a gene bank with over 200 accessions in Bélem. The Guaraná Research Institute carries out research on cropping methods and on genetic improvement, for which *P. yoco* may be a promising related species. Several clones are being screened for vigour, yield and resistance to major diseases.

Prospects The popularity of *P. cupana* as a pleasant beverage is increasing. The Brazilian government is encouraging increased production and supporting agronomic research in an effort to capitalize on the expanding demand. *P. cupana* should have potential as a crop throughout the humid tropics, including South-East Asia.

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G.T. Prance

Piper betle L.

Sp. pl.: 28 (1753).

PIPERACEAE

$2n = 26, 32, 42, 52, 58, 64, 68, 78$

Synonyms *Chavica betle* (L.) Miquel (1844), *Piper pinguispicum* C. DC. & Koord. (1909).

Vernacular names Betel pepper, betelvine (En). Bétel (Fr). Indonesia: sirih (Indonesian), suruh (Javanese), seureuh (Sundanese). Malaysia: sirih (Malay). Papua New Guinea: daka. Philippines: ikmo (Tagalog), buyo (Bikol), mamon (Bisaya). Cambodia: mlu:. Laos: ph'u. Thailand: phlu (general). Vietnam: tr[aaf]u, tr[aaf]u kh[oo]ng.

Origin and geographic distribution Betel pepper is native to central and eastern Malesia and was taken into cultivation more than 2500 years ago throughout Malesia and tropical Asia. It reached Madagascar and East Africa much later, and was also introduced into the West Indies. Written Chinese sources from the period of the Tang dynasty (A.D. 618–907) described South-East Asia as a region of betel users. Betel chewing was widespread in South India and South China when the first Europeans arrived in the 15th Century.

Uses A mixture of betel leaves and other ingredients is used as a masticatory, which acts as a gentle stimulant and is taken after meals to sweeten the breath. The ingredients of the betel mixture (quid) can vary widely per country or region. The three basic ingredients are often the betel leaf, the seed ('nut') from the areca palm (*Areca catechu* L.) and lime, produced by burning seashells or slabs of limestone. In the Moluccas and certain regions of Papua New Guinea, the betel leaf is replaced by the inflorescence of *P. siriboa* L. Other possible ingredients include gambier (*Uncaria gambir* (Hunter) Roxb.), tobacco, palm sugar and various spices, such as cardamom (*Elettaria cardamomum* (L.) Maton) and clove (*Syzygium aromaticum* (L.) Merrill & Perry). The various mixtures provide a wide range of different tastes. Chewing the quid discolours teeth and stains saliva, mouth and lips red. It results in copious salivation, so users have to spit frequently.

Not just the chewing of betel mixtures, but also their preparation occupied a central position in the ritual and social life of people throughout Malesia. In the old days, betel chewing was central to the spiritual rituals of birth and death as well as the rituals of courtship and marriage. It was also widely associated with health and healing. In time, betel mixtures came to be associated with contracts, agreements, weddings or other celebrations. After contracts were signed, betel was chewed to signify the final 'sealing' of the agreement. In Thailand, a prospective bridegroom would ask for the hand of his beloved by presenting a special bowl full of betel leaves and areca nuts to his future in-laws.

The gradual demise of betel as a universal social grace can be traced to the advent of tobacco. Although initially more expensive and rarer than betel, South-East Asian men took to the new stimulant and by early 19th Century betel use had become increasingly associated with female usage, though even here tobacco was making inroads. Today the chewing of betel in South-East Asia is limited, by and large, to the older generation, although in Thailand it is still popular among young people. At the Chatuchak weekend market in Bangkok a popular betel quid includes a segment of the lime fruit, peanuts, shallots and palm sugar wrapped in betel leaves.

The leaves, roots and seeds are all used for medicinal purposes in Asia. The leaves are credited with, among others, carminative, stimulant, stomachic, expectorant, tonic, astringent, sialagogue, laxative, anthelminthic and aphrodisiac properties. Leaf preparations and leaf sap are used as an antiseptic and applied on wounds, ulcers, boils and bruises. Heated leaves are applied on the chest against cough and asthma, on the breasts to stop milk secretion, and on the abdomen to relieve constipation. Leaves are also used to treat nosebleed, ulcerated noses, gums and mucous membranes while the extract from the leaves is applied for wounds in the ears and as an infusion for the eye. A decoction of the leaves is used to bathe a woman after childbirth, or is drunk to lessen an unpleasant body odour. The essential oil has been used to treat affections of the mucous membrane of nose, throat and respiratory organs.

Production and international trade India is probably the largest grower of betel pepper with an estimated cultivated area of about 50 000 ha in 1986/1987. At that time, Bangladesh was reported to have a production area of about 12 700 ha, yielding 60 100 t of leaves. Thailand exported about 4 500 t in 1991, with a value of 3.7 million US$. No other production figures are available. In South-East Asia betel pepper is a typical smallholder product.

Properties Per 100 g chewable portion, fresh leaves of betel pepper contain approximately: water 80–85 g, protein 3 g, fat 0.8 g, reducing sugars (including glucose) 1.4–3.2 g, non-reducing sugars (including sucrose) 0.6–2.5 g, starch 1 g, fibre 2 g, ash 2 g (Ca 230 mg, P 40 mg, Fe 7 mg, ionizable iron 3.5 mg), vitamin A 9600 IU, thiamine 70 μg, riboflavin 30 μg, nicotinic acid 0.7 mg, vitamin C 5 mg, potassium nitrate 0.2–0.4 g, essential oil 0.1–1.8 g and tannin 1–1.3 g. The essential oil is yellowish brown, with an aromatic odour resembling that of creosote and tea, and a burning sharp flavour. Important constituents are the phenols eugenol, chavicol, methyl chavicol (estragol) and chavibetol (betelphenol; an isomer of eugenol). However, the composition of the essential oil varies strongly per cultivar. The essential oil and the sugars are responsible for the characteristic flavour which reflects the quality of the leaf of a particular cultivar. Leaves for chewing should preferably contain little starch and reducing sugars but a high proportion of sucrose. Leaves from the upper parts of the plant are said to contain more essential oil than those from the lower parts. The betel leaf is reputed to have tumour-inhibiting properties. Some other ingredients used in the quid, however, are carcinogenic and there are indications of interactions with allopathic medicines.

Leaf extracts and the essential oil have antibacterial and antifungal activity. The essential oil also has shown anthelminthic activity against tapeworms and hookworms. The antifungal activity of betel pepper has been related to the presence of eugenol.

Adulterations and substitutes The leaves of several *Piper* species are used as a substitute for those of betel pepper, e.g. *P. caninum* Blume in Malaysia. In the Philippines, the leaves of *Premna nauseosa* Blanco are sometimes used as a substitute, in Java those of *Acmena acuminatissima* (Blume) Merrill & Perry and *Gaultheria leucocarpa* Blume, and in northern Thailand those of *Rubus blepharoneurus* Cardot.

Description Dioecious, perennial, woody, glabrous climber, 5–20 m long. Stem swollen at the nodes; orthotropic branches vegetative, bearing adventitious roots for adhering in climbing; plagiotropic branches generative, without roots. Leaves alternate, coriaceous, rather variable; petiole 1–2.5 cm long; blade ovate to ovate oblong, 5–20 cm × 2–11 cm, base cordate, rounded or oblique, margin entire, apex acuminate, with 2–3 pairs of arcuate veins from the base and one pair from the midrib 1–3 cm above the base, shiny bright green. Inflorescence a cylindrical, pendulous spike, opposite a leaf; peduncle 1–6 cm long; male spike up to 12 cm long, crowded with small flowers with 2 stamens; female spike up to 5 cm 5 mm, crowded with female flowers with 3–5 stigmas. Fruit a fleshy drupe, only apex of fruit free, at base immersed in the rachis of the spike forming a green cylindrical fleshy body, up to 5 cm × 1.5 cm. Seed suborbicular, 3–5 mm in diameter.

Growth and development Under favourable conditions and appropriate management, stem cuttings of betel pepper grow fast and produce leaves of consumable size quite early (1.5 year after planting). Betel pepper grown under favourable conditions usually has larger and less pungent leaves. When a vine becomes 2 m long, it produces smaller and poorer quality leaves, so must be rejuvenated. The life of betel pepper plantations may vary considerably: from 3–4 years in

Piper betle L. – *1, flowering branch; 2, female inflorescence.*

temporary gardens to 30–50 years in permanent ones.

Other botanical information Although *P. betle* is only known from cultivation, it is a very variable species. Part of the variability can be explained by its dioecious nature. Moreover, it is a polyploid species ($x = 13$) with different ploidy levels within the species. Numerous cultivars exist with leaves differing in size, shape and colour, and in softness, pungency, aroma and bleaching response. Some cultivars have red veins and petioles. In Indonesia and Malaysia some cultivars have a clove-like flavour. In India 5 cultivars are known, differing in morphology and essential-oil composition: 'Bangla', 'Desawari', 'Kapoori', 'Meetha' and 'sanchi'. Closely related species and also only known from cultivation are *P. siriboa* L. (*P. betle* L. var. *siriboa* (L.) C. DC.) and *P. chuvya* (Miquel) C. DC.

Ecology Betel pepper thrives under per-humid forest conditions with high relative humidity and ample supply of soil moisture. It flourishes in areas with 2250–4750 mm annual rainfall and is cultivated at altitudes up to 900 m. It prefers shade and needs protection from wind. Betel pepper prefers deep, well-drained, friable loamy and clayey soils, rich in organic matter and with a pH of about 7–7.5.

Propagation and planting Betel pepper is propagated by 30–45 cm long cuttings taken from the tips of orthotropic shoots. Cuttings usually have 3–5 nodes and are planted with the lowest 2 nodes buried in the soil. The cuttings are planted in nurseries or, more commonly, directly in the field, where they are planted close together in pits or long mounds. When the cuttings begin to sprout and creep along, they are tied to the support.
In vitro micropropagation of betel pepper is possible with explants from shoot and leaf tissue, which form multiple shoots and regenerate into plantlets, either directly or through callus formation. In India, betel pepper is mainly cultivated in small plots, in a very labour-intensive manner. It is also often intercropped with coconut palm and areca palm. In South-East Asia, betel pepper is mainly grown on a very small scale near the homestead.

Husbandry Betel pepper needs support for its growth, which may be provided by trees, bamboo, wooden poles or concrete pillars. Where the vines are trained on live supports, the latter are thinned and pruned as required, to ensure optimal shade. Weeding is carried out when needed. Betel pepper is often irrigated, and in Indonesia ditches are dug for irrigation and drainage. It is usually heavily manured. A crop of 10 t of leaves will remove approximately 80 kg N, 14 kg P and 100 kg K. Betel pepper vines are seldom allowed to grow higher than 2–3 m in a plantation. Regular rejuvenation is achieved by taking the vines off their supports and burying the lower part in the soil. New roots form and the vigorous new sprouts are trained along supports. In Malaysia, the plants may be allowed to grow for 10–12 years without rejuvenation. In northern India, betel pepper gardens are usually hedged and covered over with thatch or roofed with jute matting to create a favourable microclimate.

Diseases and pests The occurrence of diseases is an important constraint in betel pepper cultivation. The most important diseases are foot and leaf rot, anthracnose, stem or collar rot and bacterial leaf spot. The causal agents of foot and leaf rot are one of several *Phytophthora* spp. *Phytophthora palmivora* MF4 which also causes foot rot in black pepper (*Piper nigrum* L.) has been isolated from Indonesian betel pepper. Symptoms of foot rot are leaf yellowing, wilting, with the vines finally drying up, and the main stem darkening at ground level. Leaf rot symptoms (circular dark brown spots, turning black and increasing in size) are mainly found during rainy periods when both temperature and humidity are high. If not controlled, foot and leaf rot may cause widespread damage and even total destruction of betel pepper plantations. Anthracnose caused by *Colletotrichum capsici* is an important foliage disease. It is characterized by brownish, circular leaf spots with a yellowish halo, which may coalesce into large lesions. On the stem, black specks appear under the bark; under humid conditions these grow in size and form streaks. When streaks combine and encircle the stem, the plant may wilt rapidly. Stem or collar rot is caused by *Sclerotium rolfsii*. Here the stem turns dark, the leaves droop and finally the plant withers and dies. Bacterial leaf spot is caused by *Xanthomonas campestris* p.v. *beticola*. Symptoms are minute lesions spread over the leaf blade, which coalesce to form brownish spots, surrounded by a yellow halo. Leaves may fall prematurely. Betel pepper is infested by a range of pests, including betelvine bugs (*Disphinctus politus*), mealy bugs (*Ferrisia virgata*), scales (*Lepidosaphes cornutus*) and whiteflies (*Dialeurodes pallida*).

Harvesting Leaf harvesting of betel pepper may begin 1.5–3 years after planting. Only leaves from plagiotropic branches are picked for chewing. Each vine is picked 3–4(–5) times a year. The pickings are so arranged that not all vines are harvested at the same time. Leaves are traditionally plucked early in the morning by cutting the petiole with a sharpened steel thumbnail. They should be kept out of the sun to preserve their aroma. Other factors determining chewing quality are cultivar, leaf position and plant age. The best leaves are large, yellow and grow on the upper lateral branches. In Malaysia leaves on the lower lateral branches are regarded as medicinal and are used in preparations applied on ulcers and wounds.

Yield Annual yields of betel pepper leaf are estimated on 6–10 t/ha. Each vine yields 40–50 leaves per year.

Handling after harvest Leaves of betel pepper are consumed or marketed as soon as possible after harvest. When grown for commercial purposes in India, harvested leaves are washed, cleaned, graded according to size, colour, texture and maturity, and packed. Betel leaves remain fresh for 10–20 days, depending on maturity, age, quality, season and method of packing. Whereas fresh leaves are generally used for chewing, in some areas leaves are bleached before use. Bleached betel leaves normally fetch a higher price, as they are believed to possess some improved qualities (i.e. flavour). The bleaching process consists of moistening the leaves and allowing them to stand in a warm, ventilated place in the absence of sunlight. Leaves may also be bleached by packing them tightly in baskets lined with banana leaves and keeping them in the dark for several days. Leaves for bleaching should not be very tender and are taken from older vines with well-developed leaves. These have a dark green colour with a prominent midrib and a rather rough petiole and surface. In India, the whole process normally takes 10–15 days during the hot season and 15–20 days under cooler circumstances. Finally, bleached leaves are dried and packed for the market. Under optimal bleaching conditions, nitrate and tannin contents will remain the same, but starch and some sugars will disappear.

Genetic resources In India the National Botanic Research Institute has a betel pepper germplasm collection of 85 accessions, maintained at various research centres under the All India Coordinated Research Project on Betelvine.

Breeding Growers have selected cultivars that give high yields of palatable leaves suited to local taste and environment, but little scientific breeding work has been done. Before the discovery of male and female flowering plants in India in 1989, it was thought that only male plants were cultivated there. This belief was due to the usual absence of flowers. The discovery of male and female plants has opened the possibility of developing breeding programmes for betel pepper in India.

Prospects Because of the association of betel quid use with oral cancer, stimulation of betel quid chewing should not be encouraged from a public health point of view. However, betel pepper leaves alone may have tumour-inhibiting and other medicinal properties, and increased pharmacological use may improve the prospects for growing betel pepper.

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Stephen P. Teo & R.A. Banka

Piper methysticum G. Forster

Pl. escul.: 76 (1786).

PIPERACEAE

$2n = 130$

Synonyms *Macropiper methysticum* (G. Forster) Hooker & Arnott (1840), *M. latifolium* Miquel (1847).

Vernacular names Kava, kava-kava (En). Kava, kawa-kawa, ava (Fr). Indonesia: waghi, wati, bari (Irian Jaya). Papua New Guinea: koniak, keu, oyo.

Origin and geographic distribution *P. methysticum* probably originated in Vanuatu, since its greatest diversity occurs there. It is cultivated all over Melanesia and Polynesia, especially in Vanuatu, Fiji, Samoa, Tonga and Micronesia. In South-East Asia, *P. methysticum* occurs mainly in the southern part of New Guinea, both in the wild and in occasional cultivation. Its cultivation and use in New Guinea have declined considerably due to discouragement from former colonial and religious authorities.

Uses The main use of kava over the centuries has been as a traditional ethnic beverage. The beverage is prepared from the roots and basal stem, which are the plant parts containing the desired kavalactones that confer psychoactive properties to the beverage. To prepare the beverage, the plant parts are pulverized by grinding or mastication, suspended in water and then sieved to remove the residue. The resulting milky-brown liquid is the beverage. Considerable social and cultural rituals accompany its consumption. Kava is also used as a medicinal plant in both folk and modern medicine. In folk medicine, the roots and even the leaves are used to treat a range of maladies, including rheumatism, respiratory tract infections, tuberculosis, gonorrhoea, chills and headaches. In these cases, the pulverized plant material is drunk or applied topically. The pharmaceutical use of kava in modern mainstream and alternative medicine relies on the psychoactive properties of the kavalactones contained in the roots and stembase. Because of this, kava has become a valuable cash crop, supplying the growing international demand for pharmaceutical use of the plant. A less tangible but equally important use of kava is that it is often a medium of social and religious interaction. In kava-utilizing cultures, the plant is an important and indispensable item of gift-giving to other people, or for religious offerings to the spirits.

Production and international trade Total world production of kava is difficult to estimate, mainly because so much of what is produced is consumed locally, especially in Vanuatu, Fiji and Tonga. In 1994, over 420 t of kava entered into international trade, with the major exporters being Fiji (329 t), Vanuatu (89 t) and Tonga (5 t). The main importers are Germany, France, Australia and New Zealand. The price was about US$ 15 per kg. Kava production in Papua New Guinea occurs in isolated communities and is extremely informal; there is no export of kava from the country.

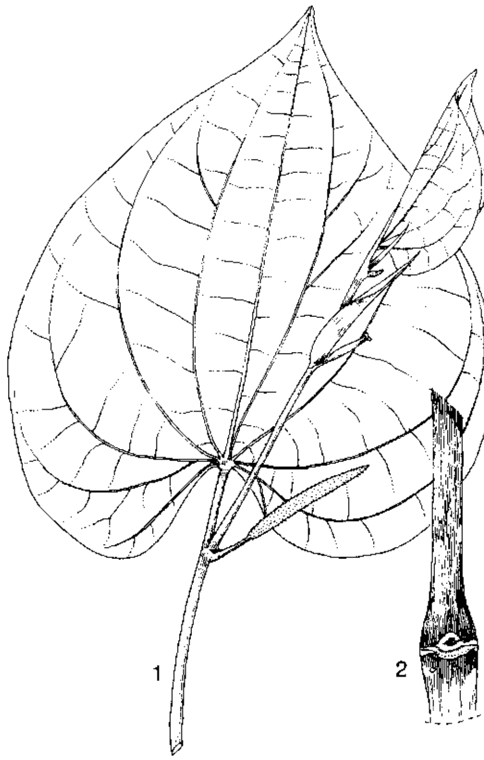
Properties The freshly-harvested used plant parts contain 80% water, but after drying, the water content is 12–15%. The composition per 100 g of the dry product is: water 12 g, protein 3.6 g, starch 43 g, sugar 3.2 g, fibre 20 g, ash 3.2 g, kavalactones 3–20 g. The kavalactones are the main active ingredient of kava, and the ones that are present in the highest concentration are yangonin, methysticin, dihydromethysticin, kavain, dihydrokavain and demethoxy-yangonin. Alone or in combination, these kavalactones are able to act as sleep inducers, painkillers, antibiotics, anaesthetics or muscle relaxers. These properties form the basis of the pharmaceutical use of kava. The effects of kava are likened to those of diazepam (valium). Overconsumption produces slight paralysis and skin lesions.

Adulterations and substitutes Kava powder made from the roots is often adulterated with similar looking powders that do not have the same effect. On several Pacific Islands (particularly the French-speaking islands) the traditional kava drink has largely been replaced by alcoholic drinks. In South-East Asia and the South Pacific kava can be substituted by *P. subbullatum* K. Schum. & Lauterb. (synonym *P. torricellense* Lauterb.). In tropical central America the roots of *P. medium* Jacq. are used to prepare a drink similar to kava.

Description A dioecious, woody, perennial shrub, 2–4 m tall, with a massive base at or just below the ground (crown or short rootstock) from which several shoots arise, giving the plant an overall rosette appearance. Each main stem is erect, 1–3 cm in diameter, green, red-brown or dark purple and looks jointed due to the swollen nodes and prominent scars left by abscission of leaves and branches. Leaves alternate, deciduous; stipules large, persistent; petiole 2–7 cm long; blade cordate, 10–30 cm × 8–23 cm, base cordate, margin entire, apex acute, glabrous to finely pubescent, palmately veined, principal veins 9–13, all except the 3 uppermost spreading from base. Inflorescence a spike, axillary or opposite the leaves but much smaller; peduncle 1.5 cm long; spike 3–9 cm long, with small unisexual flowers without sepals or petals; the male spike bears numerous flowers with 2 short stamens; the female spike bears flowers with a single basal ovule in an unilocular ovary topped by a stigma. The fruit is seldom produced; it is a berry, containing one seed.

Growth and development Once a kava plant has established the older stolons enlarge to form a crown (short rootstock), from which new shoots grow. Additional shoots continue to arise at the periphery of the crown throughout the life of a plant. Although *P. methysticum* is dioecious, most plants are male; female plants appear to be very rare. Occasionally monoecious plants have been found. Natural senescence occurs at 15–30 years after planting.

Other botanical information Because kava has been known and used for centuries over a



Piper methysticum G. Forster – 1, flowering branch with adult leaf and young lateral branch; 2, thickened node of a stem.

rather large area, variability is great. More than 120 cultivars exist. Some botanists believe that *P. methysticum* was derived from *P. wichmannii* C. DC. as a result of human selection of somatic mutants of the latter. Others believe that the ancestor of kava is *P. subbullatum*, which occurs in the Philippines, New Guinea and South-West Pacific Islands.

Ecology Kava is a shade-loving plant, especially in the first year of growth. It does best in the per-humid tropics with temperatures of 20–35°C, rainfall above 2000 mm, and high relative humidity. It requires deep well-drained soils with high organic matter content and pH 5.5–6.5. It is susceptible to damage by moderate to strong winds.

Propagation and planting Since fruits are seldom produced, kava is exclusively propagated by stem cuttings or suckers. Cuttings 15–20 cm long are planted directly in the field. Shorter cuttings of 2–4 nodes are first sprouted in a nursery before transplanting to the field. Intercropping is the rule, with the other crops (e.g. taro, bananas or maize) providing the necessary shade and wind shelter for the young kava. Field spacing varies widely, depending on the nature and intensity of the other crops, but 2 m 2 m (2500 plants/ha) is considered adequate.

Husbandry If kava is correctly spaced, weed control is necessary in the first 2 years only. Weeding with hand tools is the most common practice. Earthing up is essential to ensure massive proliferation of the rootstock. The crop requires a high nutrient supply. Manures and composts are most frequently used, but compound inorganic NPK fertilizer (12-12-20) or urea (with 46% N) are also used.

Diseases and pests Kava suffers from dieback disease caused by the cucumber mosaic cucumovirus transmitted by aphids. The symptoms are wilting and dieback of the shoot. There is no effective control measure, but intercropping and adequate field sanitation are helpful. Another disease of kava is anthracnose caused by *Glomerella* species which can be controlled with fungicides. The kava weevil borer is the most serious pest; it can be controlled with insecticides. Nematodes are controlled by careful field sanitation and hot water treatment of planting material.

Harvesting Kava is best harvested when 2–4 years old, but may be allowed to stand for up to a decade. Harvesting can be done any time of the year. It involves cutting off the stems and digging up the rootstock.

Yield Kava yields vary with age and cultivar. Fresh weight yields are 10–60 kg/plant, and 6.6 t/ha for kava intercropped with coconut.

Handling after harvest After harvesting, the kava rootstock is washed, chipped or peeled, dried, powdered, sieved and packed. Highest market value is for peels from the root and crown, followed by chips from the root and crown. These constitute the main commodities for export for pharmaceutical use. Chips from the bases of the stems are of much lower value. Kava for use as a recreational beverage (domestic or export) is usually pounded into powder and packaged. Adulteration is a frequent problem in the powdered product, and quality control is poor. In Vanuatu, the beverage is often made from the fresh root.

Genetic resources Collections of kava cultivars can be found at the Tagabe Research Station in Vanuatu, the Kerevat Experiment Station in Papua New Guinea, the Kauai Experiment Station in Hawaii and at various locations in Fiji and Samoa.

Breeding The main selection and breeding objectives should be for resistance to diseases and pests, especially the kava dieback disease, and for a higher content of the kavalactones.

Prospects With its emerging use in the modern pharmaceutical industry, the prospects for kava are bright. It is already a cash crop in several countries, and its importance is expected to increase. Research is needed to develop disease-resistant cultivars with a high kavalactone content, and to standardize the product.

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I.C. Onwueme

Poikilospermum Zipp. ex Miquel

Ann. mus. lugd.-bat. 1: 203 (1864).

CECROPIACEAE

x = unknown; $2n$ = unknown

Major species and synonyms

- *Poikilospermum amboinense* Zipp. ex Miquel, Ann. mus. lugd.-bat. 1: 203 (1864), synonyms: *Conocephalus amboinensis* (Zipp. ex Miquel) Warb. (1894), *Poikilospermum forbesii* (Moore) Merrill (1934), *P. hirsutum* (H.J.P. Winkl.) Merrill (1934).
- *Poikilospermum suaveolens* (Blume) Merrill, Contr. Arn. Arb. 8: 47 (1934), synonyms: *Conocephalus suaveolens* Blume (1825), *C. violaceus* (Blanco) Merrill (1905), *Poikilospermum amoenum* (King ex Hook.f.) Merrill (1934).

Vernacular names

- *P. amboinense*: Indonesia: tali ayer (Malay).
- *P. suaveolens*: Indonesia: mentawan (Malay), besto (Javanese), areuy kakejoan (Sundanese). Malaysia: akar setawan, centawan, mentawan (Peninsular). Philippines: anopol (Igorot, Bikol),

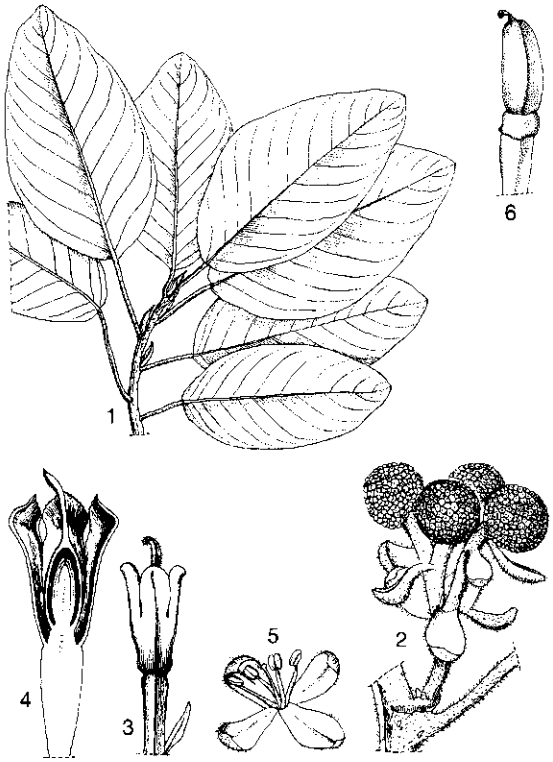
hanopol, kanupul (Tagalog). Cambodia: krâpë rôô. Thailand: airai (Bangkok), charai (peninsular), khaman (south-eastern). Vietnam: sung d[aa]y, rum th[ow]m.

Origin and geographic distribution *Poikilospermum* comprises some 20 species and is found from north-eastern India and southern China to New Guinea and the Bismarck Archipelago. It is absent from the Lesser Sunda Islands. *P. amboinense* is found in the Moluccas, New Guinea and the Bismarck Archipelago (New Britain). *P. suaveolens* is widespread and is found in India, Indo-China, south-eastern China, Thailand, the Nicobar Islands, Peninsular Malaysia, Sumatra, Java, Borneo, Sulawesi, the Moluccas and the Philippines.

Uses Both *Poikilospermum* species have limited use as a stimulant. Tribal communities smoke short sections of the aerial roots of *P. amboinense* as cigarettes. The aerial roots and stems may be used as a source of potable water in the forest. Medicinal applications are reported from Indonesia, Malaysia, Thailand and the Philippines. They include the use of the stem juice to cure eyesore, of decoctions and juice from pounded leaves to treat fever and kidney problems, and of poultices of leaves and roots to treat fever and itch. Leaves smeared with oil and heated are applied to the abdomen to treat complaints after childbirth. Furthermore, pounded stems are administered in a wash to exterminate head vermin, and aerial roots are smoked to cure nose ulcers. The fibrous bark is used as a rope.

Production and international trade *P. suaveolens* is not traded internationally. Production is from wild plants only. Dried sections of the roots are sold by local herbalists as traditional medicine. Tribal communities collect the roots for smoking.

Description Epiphytic, dioecious, evergreen, stout and woody climbers or scramblers. Leaves arranged spirally; stipules connate, intrapetiolar, grooved on the back; petioles grooved above; blade simple, usually coriaceous, margin entire, cystoliths of adaxial surface arranged in circular groups, those of the abaxial surface arranged along veins, either punctiform or elongate in shape. Inflorescence axillary, cymose, branched one to many times, capitate or non-capitate; peduncle bracteate; flowers unisexual, generally small; male flower with 2–4(–5) tepals; stamens 2–4, opposite the tepals; pistillode present; female flower with 4-toothed or 4-lobed perianth; ovary superior, 1-locular with a single ovule, stigma subsessile. Fruit a small achene with mucilaginous mesocarp.



Poikilospermum suaveolens (Blume) Merrill – 1, leafy twig; 2, inflorescence; 3, female flower; 4, female flower in longitudinal section; 5, male flower; 6, fruit.

- *P. amboinense*: Leaf blade elliptical or ovate to broadly ovate, (10–)15–30(–40) cm × (5–)10–15 (–20) cm, base rounded to distinctly cordate, apex acuminate, glabrescent. Flowers in agglomerations with a solitary terminal flower in the ultimate dichotomies; male flower sessile; tepals 4; stamens 4; female flower sessile to subsessile; perianth minutely 4-toothed; stigma peltate. Achene with persistent perianth at base.
- *P. suaveolens*: Leaf blade broadly ovate to elliptical or obovate, 10–40 cm × 6–25 cm, usually glabrous, base cuneate to distinctly cordate, apex acute to obtuse. Flowers in pseudo-umbellules; male flower sessile; tepals (2–)4, strongly incurved; stamens (2–)4; female flower pedicellate; perianth 4-lobed; stigma ligulate. Achene entirely covered by the persistent perianth.

Growth and development *Poikilospermum* species usually start as an epiphyte, developing a profusely branching root system. After their roots reach the ground the plants start scrambling from branch to branch on the host and to neighbouring trees as well. In Java, *P. suaveolens* has been observed bearing flowers in all months of the year. Pollination is presumably by wind. A single record from the Botanical Gardens in Bogor states that the flowers of *P. suaveolens* are visited by the olive-backed sunbird (*Nectarinia jugularis*). The mucilaginous mesocarp suggests epizoochorous seed dispersal, presumably by birds.

Other botanical information The two *Poikilospermum* species are distinctly different and belong to different subgenera. *P. amboinense* is characterized by a non-capitate inflorescence, female flowers with 4-toothed perianth, capitate stigma, and mature achene usually greatly exserted from the persistent perianth. *P. suaveolens* is characterized by a capitate inflorescence, female flowers with 4-lobed perianth, ligulate stigma, and mature achene usually entirely enclosed by the persistent perianth. *P. naucleiflorum* (Roxb. ex Lindl.) Chew (synonym *Conocephalus naucleiflorus* Roxb. ex Lindl.) has frequently incorrectly been treated as conspecific with *P. suaveolens*, from which it is distinct because of its greatly ramified inflorescence and its stigma being much shorter than the ovary. *P. suaveolens* is highly polymorphic and many taxa described as new species have proved to be conspecific with it. *Poikilospermum* seems to take a rather isolated position within the *Cecropiaceae*; it is sometimes classified in the *Urticaceae*.

Ecology *Poikilospermum* species are quite common in forests, often beside rivers and streams. *P. amboinense* occurs up to 550 m altitude, whereas *P. suaveolens* is found up to 1500 m. The latter prefers more open forest and brushwood, but is rare in monsoon forest.

Propagation and planting *Poikilospermum* can be propagated by seed and probably vegetatively by cuttings as well.

Diseases and pests In its natural habitat *Poikilospermum* grows very well with no evidence of any diseases or pests.

Harvesting Harvesting aerial roots from wild *Poikilospermum* plants for drinking water, traditional medicine or cigarettes does not cause any apparent harm to the plants. Roots regenerate quickly and new branches are formed near the cut ends.

Handling after harvest Aerial roots of *Poikilospermum* can be sun dried and should be kept under dry and airy conditions and free from insect pests.

Genetic resources and breeding There are no known germplasm collections and breeding programmes of *Poikilospermum*.

Prospects Since the use of *Poikilospermum* is very local, there are at present no prospects for its further development.

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H.C. Ong & Wardah

Senna occidentalis (L.) Link

Handb. 2: 140 (1831).
LEGUMINOSAE
$2n = 28$ (26)

Synonyms *Cassia occidentalis* L. (1753), *C. foetida* Persoon (1805), *Ditremexa occidentalis* (L.) Britton & Rose ex Britton & Wilson (1924).

Vernacular names Negro coffee, coffee senna, stinking weed (En). Café nègre, casse-café, casse puante (Fr). Indonesia: menting (Javanese), kasingsat (Sundanese), kopi andelan (Sumatra). Malaysia: kachang kota, ketepeng hutan. Philippines: balatong-aso (Tagalog), andadasi (Ilokano), duda (Bisaya). Cambodia: sânndaèk khmaôch. Laos: kh'ét, lang kh'ét. Thailand: khilek-thet (northern), khilek-pi (central), chumhet-thet (peninsular). Vietnam: v[oj]ng giang nam, mu[oof]ng c[oos]t kh[is].

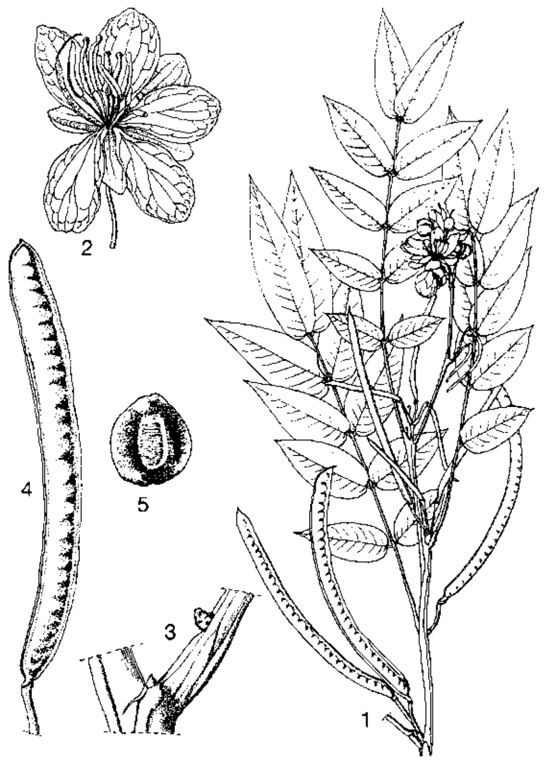
Origin and geographic distribution The origin of *S. occidentalis* is unknown; tropical South America and the Old World tropics are thought to be possible candidates. Now it is a common weed throughout the tropics and subtropics. In South-East Asia it occurs everywhere, so if it has been introduced this must have happened in ancient times. In Indonesia it is sometimes also cultivated.

Uses Roasted seed of *S. occidentalis* is used as a substitute for coffee (sometimes also for tea), pure or in a mixture with true coffee. In Indonesia young leaves and fruits are eaten steamed as a vegetable; the young fruits are also said to be consumed raw as a side-dish with rice. Non-woody plant parts are used as green manure and the plant has some ornamental value. It is not eaten by animals and the seed is deadly poisonous when eaten in quantity. In traditional medicine *S. occidentalis* is considered a panacea, especially in Africa its medicinal applications are numerous. All plant parts are said to have tonic, diuretic, stomachic and febrifuge properties and are especially used for dropsy, rheumatism, fevers and venereal diseases. An ointment prepared from *S. occidentalis* is also used to treat all kinds of skin diseases (e.g. ringworm, eczema). Although the seed is considered to contain the most effective ingredients, the roots are especially used as an anthelmintic and against malaria and haematuria. An infusion of the bark is applied as a remedy for diabetes. The leaves are used as a purgative and antiherpetic, and a poultice is administered against toothache in Indonesia and against headache in Malaysia.

Production and international trade In the past there has been some international trade in seed and medicinal products of *S. occidentalis*, e.g. between Africa and Europe. At present the only trade is local and there are no statistics.

Properties It is remarkable that the use of roasted seed of *S. occidentalis* as a coffee substitute has been established independently in America, Africa and Asia, even though the infusion does not contain caffeine. Fresh seed is poisonous but the toxicity seems to disappear after heating. The chemistry of *S. occidentalis* is badly known. Fresh seed is said to contain tannins, a toxalbumin, the alkaloid N-methyl-morpholine, chrysophanol (chrysophanic acid), chrysarobine, emodin, rhein, physcion and more anthroquinone derivatives, a fixed oil and a volatile oil. Several of those constituents are also present in the leaves and the roots. The cathartic and diuretic action of plant parts is explained by chrysophanol and chrysarobine, which are irritant to mucous membranes. Chrysarobine and the toxalbumin cause kidney and liver damage in livestock. The essential oil has shown antibacterial activity.

Description Erect, annual or perennial, malodorous, subglabrous herb, up to 2.5 m tall, with black roots. Stem obtusely angled or sulcate, often richly branched. Leaves arranged spirally, pinnately compound; stipules triangular to long lanceolate, more or less falcate, 3–13 cm × 1.5–5 cm, early caducous; petiole 2.5–5.5 cm long, grooved, bearing a large, sessile, subovoid, reddish gland at base just above the pulvinus; rachis 4–14 cm long, with 3–6 pairs of leaflets, size of leaflets increasing from base to apex of rachis; petiolule 2–4 mm long; leaflet ovate to ovate-oblong, 2.5–17 cm × 1–4 cm, more or less unequal-sided, base rounded, margin entire, apex acuminate, lower surface pruinose to finely puberulous. Inflorescence racemose, axillary or terminal, 2–4-flowered; peduncle 1–7 mm long; bracts lanceolate, 5–18 mm × 1–4.5 mm, caducous; pedicel 0.5–2 cm long; sepals 5, unequal, white, outer ones orbicular, 5–7.5 mm in diameter, inner ones ovate, 6.5–10 mm long; petals 5, obcordate (ventral one), obovate (2 lateral ones) or oblanceolate (2 dorsal ones), longest one 12–17 mm long, bearing a short claw, yellow with violet veins, 2 outer ones largest; stamens 10, unequal in size, 2 long ones with filaments 5–7 mm and anthers 4–7 mm long, 4 with filaments 2–3 mm and anthers 3–5 mm long, 4 staminodes with filaments 3–4 mm long and very small anthers; pistil with tomentose ovary, glabrous style (3–5 mm long) and small lateral stigma. Fruit a flattened-cylindrical legume,



Senna occidentalis (L.) Link – 1, flowering and fruiting branch; 2, flower; 3, petiole base with gland; 4, fruit; 5, seed.

8–13 cm × 0.7–1 cm, straight or slightly incurved, brown with pale margins, subglabrous, 30–45-seeded. Seed flattened-orbicular, 3–5 mm in diameter, olive-brown, with an elliptical areole on either side.

Growth and development In temperate or seasonal climates *S. occidentalis* is an annual and dies with the onset of the cold or the dry period. Under warm, humid conditions, it can become a much branched, subwoody shrub, living 2–3 years. Under favourable conditions it flowers throughout the year; in temperate climates it flowers in mid-summer and autumn.

Other botanical information In older literature *S. occidentalis* is best known as *Cassia occidentalis*. Until the beginning of the 1980s, *Cassia* L. was considered to be a genus with over 500 species. The large genus *Cassia* L. emend. Gaertner has since been subdivided into 3 genera: *Cassia* (trees, some filaments curved, bracteoles present, no areoles on seed), *Senna* Miller (herbs, shrubs or trees, all filaments straight, bracteoles present, areoles on seed) and *Chamaecrista* Moench (herbs or shrubs, all filaments straight, bracteoles present, no areoles on seed). *Cassia* now has about 30 species, *Senna* and *Chamaecrista* comprise about equal numbers of species.
S. occidentalis is sometimes easily confused with the also widespread *S. obtusifolia* (L.) Irwin & Barneby. The basal petiolar gland, the usually ovate leaflets and the shorter wider pod are distinctive for *S. occidentalis*.

Ecology *S. occidentalis* mainly occurs below 500 m, with 1750 m as its altitudinal limit. It grows as a weed in disturbed forest areas, on waste land, fields, roadsides and around villages and farms. It is especially abundant in ditches and seasonally wet depressions. Although it is resistant to dry conditions it grows best in a moist environment.

Agronomy *S. occidentalis* is predominantly a weed, so it is hardly cultivated. Propagation by seed is very easy. When needed, desired plant parts are collected from wild plants. Seeds are dried in the sun, roasted and pounded before being used as a coffee substitute.

Genetic resources and breeding There are no known germplasm collections and breeding programmes for *S. occidentalis*. Despite its wide geographical distribution, the plants seem to be rather genetically uniform.

Prospects *S. occidentalis* will continue to be used locally as a stimulant and in other ways. Most promising perhaps are its attributed medicinal properties, but more research is needed, e.g. on possible adverse side-effects.

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D. Sulistiarini

Theobroma cacao L.

Sp. pl.: 782 (1753).
STERCULIACEAE
$2n = 20$

Vernacular names Cocoa, cacao (En). Cacaoyer (plant), cacao (product) (Fr). Indonesia: cokelat, kakao. Malaysia: koko. Papua New Guinea: diwai kakau (Kilimeri). Philippines: cacao. Burma (Myanmar): kokoe. Thailand: koko. Vietnam: ca cao.
Note: In the current English literature the terms 'cacao' for the plant and 'cocoa' for its products have generally been replaced by 'cocoa' to encompass both meanings.

Origin and geographic distribution The primary centres of genetic diversity of *T. cacao* are in the upper basin of the Amazon and its headwaters (in Peru, Ecuador, Colombia and Brazil). Natural cocoa populations are also present in the understorey of the tropical rain forests in the lower Amazon basin, as well as along the Orinoco river in Venezuela and in the Guyanas. These populations in the upper and lower Amazon basin form the Forastero group and are distinct from the Criollo cocoa, which according to archaeological evidence must have been widely cultivated since ancient times by the Maya and other peoples in tropical Central America. However, the geographically isolated Criollo populations are presumed to have an Amazon-basin origin like all other cocoa forms. In Central America the valuable cocoa beans were used as currency in the local trade and also to prepare an invigorating beverage, called 'cacahuatl', by boiling a mix of ground roasted cocoa beans with maize, vanilla and chili peppers. They also played a role in rituals in Maya and neighbouring civilizations. Soon after conquering Mexico in the first years of the 16th Century, the Spanish discovered that a beverage based on ground roasted cocoa beans and sugar was more pleasing to their palate and this 'cocoa' or 'chocolate' drink was soon to become popular with the wealthy upper classes of Europe. The disintegration of the Central American civilizations caused a rapid decline in the traditional supply of cocoa beans. Cocoa cultivation was then introduced into the Caribbean area, first in Venezuela and on Trinidad around 1525 and subsequently to several other islands. Criollo dominated cocoa production until the end of the 18th Century, when Forastero cocoa began to be cultivated on a large scale in the Brazilian state of Bahia and in Ecuador. The Amelonado Forastero cocoa in Bahia originated in the lower Amazon basin, whereas 'Nacional' Forastero cocoa of Ecuador originated in the upper Amazon basin. Trinitario, a natural hybrid between Criollo and Venezuelan Forastero, replaced the earlier Criollo cocoa on Trinidad after 1800. The vast areas of cocoa production in West Africa (Ghana, Nigeria, Cameroon and Ivory Coast) are based on Amelonado (from Bahia) and Trinitario introduced during the 19th Century and Forastero from the upper Amazon basin introduced shortly after 1945. The Criollo cocoa of Sulawesi and Java can be traced back to the few seedlings taken from Central America to the Philippines by the Spanish around the year 1600. Other cocoa introductions of importance to the 20th Century cocoa industries of Asia, in particular in Indonesia, Malaysia and Papua New Guinea, included Trinitario and Forastero material from various Caribbean and South American origins. World cocoa production increased from 18000 t in 1850 (all from tropical America) to 370000 t in 1920 (tropical America 50%, West Africa 48% and Asia 2%) and 2500000 t in 1990 (tropical America 27%, West Africa 56% and Asia 17%).

Uses Until the middle of the 19th Century about the only cocoa product consumed in Europe and elsewhere was a chocolate drink. The cocoa press invented by C.J. van Houten in the Netherlands around 1828 to extract most of the cocoa butter, and the process to manufacture milk chocolate invented by M.D. Peter in Switzerland in 1876, had major impacts on the diversification of cocoa products and consequent increase in world consumption. The preferred cocoa powders for drinking chocolate contain 20–25% fat and are derived from cocoa liquor usually treated with alkali before pressing to improve flavour and dispersability (the 'Dutching' process, also invented by van Houten). Low fat (10–13%) powders are applied in confectionery, biscuits, ice-creams and other chocolate-flavoured products. Chocolate is made from a mix of cocoa liquor and butter to which sugar (and sometimes milk) has been added. Most cocoa butter is used to manufacture chocolates, but a minor volume also finds applications in cosmetic and pharmaceutical products. Milk chocolate in a variety of forms (bars, fillings, coatings) is still the backbone of the world cocoa industry.

Production and international trade Average annual production of cocoa worldwide over the period 1995–1998 was about 2.6 million t from a total of 6.1 million ha in 40 countries in tropical America (20% of world production), West Africa (63%) and Asia (17%). The following six countries produced 80% of all the cocoa: Ivory Coast 39%, Ghana 13%, Indonesia 11%, Brazil 7%, Nigeria 6% and Malaysia 4%.

In Indonesia production increased hundredfold from 3000 t in 1976 to an estimated 332 000 t in 1997 (610 000 ha), mainly due to cocoa expansion in Sulawesi and Sumatra. In Malaysia production rose from 10 000 t in 1974 to 240 000 t in 1990, but fell again to about 100 000 t (200 000 ha) in 1997, because of large increases in labour costs and falling world market prices. In Papua New Guinea production has remained stable at about 30 000 t per year (90 000 ha). The Philippines produces some 5000 t cocoa annually from 9000 ha.

About 85% of the world production is exported, mostly to Europe (the Netherlands being the largest importer, followed by Germany, the United Kingdom and France, among others) and the United States, as cured beans but also after conversion into cocoa liquor and butter.

Cocoa processing industries in 15 producing countries account for about 30% of world cocoa grindings. The present cocoa grinding capacity in Malaysia is 100 000 t per year, in Indonesia 70 000 t, in Singapore 60 000 t (all imports) and in the Philippines 15 000 t (exceeding local production).

In West Africa cocoa is a smallholders' crop with only 5% grown on plantations, mainly in Ivory Coast and Cameroon. Large-scale plantations are predominant in many tropical American countries, e.g. 55% in Brazil, but also in Asia, e.g. 80% in Malaysia and 40% of the area in Indonesia.

The trade in cocoa beans in most producing countries operates under a free marketing system except in Ghana (control by a marketing board). Almost all internationally traded cocoa is subject to conditions of cocoa merchants associations established in major consumer countries. The value of the world trade in cured cocoa beans, at an average annual price of US$ 1400 per t in 1997, is estimated at US$ 3.1 billion. Cocoa prices have fluctuated between US$ 3500 per t in 1976 to an all time low of US$ 800 per t in 1992, recovered to US$ 1600 per t by the end of 1997 and once more came down to US$ 850 in 1999, in response to large variations in supply (production and stocks) against only gradually increasing demand.

Cocoa consumption appears to be much more related to consumer income than to world market prices. Per capita annual consumption (cured beans equivalent) averages 2.5 kg in Western Europe (Switzerland 4.8, Belgium 4.2, Germany 3.1 kg), 2.2 kg in the United States, 2.0 kg in Australia and 1.1 kg in Poland. However, average cocoa consumption in Japan is only 0.9 kg per inhabitant. Cocoa consumption in most producing countries is very low, except in Brazil (0.7 kg) and Mexico (0.5 kg).

The cocoa market distinguishes two main types:
- 'fine' or flavour Criollo, Trinitario and the Nacional (Ecuador) cocoa, which account for less than 5% of the total production, and
- 'bulk' or ordinary cocoa produced worldwide from Forastero cultivars.

There is usually a significant price differential between fine and bulk cocoa. On the other hand, the carefully cured cocoa from Ghana (Amelonado and hybrid Forastero) has always been regarded to be superior in flavour to cocoa from Ivory Coast, Malaysia or Indonesia. Indonesia produces about 12 000 t fine cocoa annually in Java and Papua New Guinea another 10 000 t, both from Trinitario type cocoa. The fine cocoa or 'edel kakao' from Java is also well-known as Java 'A' light-breaking cocoa due to the almost white cotyledons.

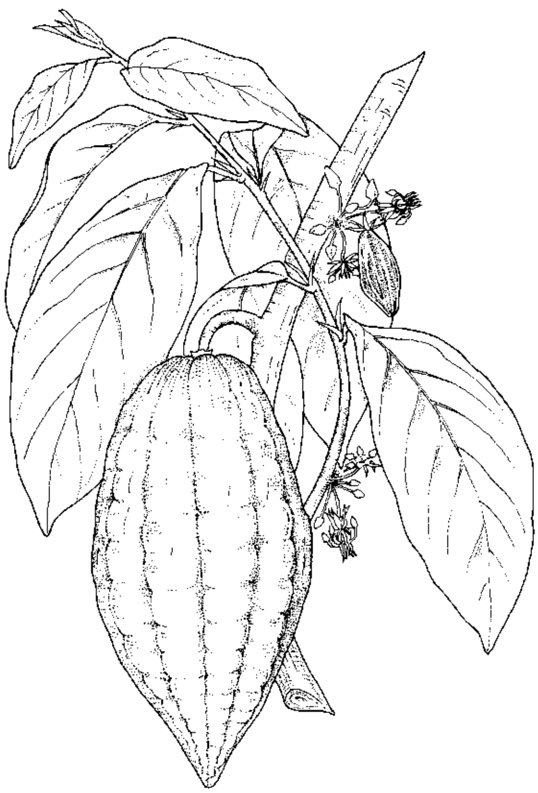
Properties Forastero cocoa beans with the testa removed have the following average composition per 100 g fresh weight: water 35 g, protein 8.4 g, fat 31.3 g, starch 4.5 g, sugars 6 g, fibre 3.2 g, theobromine 2.4 g, caffeine 0.8 g, polyphenols (catechins, tannins, leuco-cyanidins and cyanidin glycosides) 5.2 g, acids (acetic and lactic) 0.6 g, inorganic salts 2.6 g. The chocolate flavour precursors are formed during fermentation, when the protein and polyphenol compounds react with hydrolytic enzymes. The astringent catechins and other polyphenols are oxidized and become insoluble. The bitter purines are partly lost by exudation during the fermentation process.

Cocoa quality factors including single bean weight (0.6–2.1 g), shell content (11–16%), cotyledon colour (white-purple), butter content (50–65% of dry weight) and butter hardness (harder is more valuable) can be physically measured. However, the most important factors determining cocoa quality are flavour and mouthfeel of the final products, developed during fermenting and after roasting, and these require reliable sensory evaluation. More than 60 aromatic compounds have been found to contribute to cocoa flavour.

Cocoa powder mixed with milk and sugar makes a very nutritious drink and the presence of theobromine and caffeine gives a mildly stimulating action. Plain and milk chocolates have a high calorific value (>2000 kJ/100 g) and provide a concentrated food with excellent keeping quality. A typical bar of milk chocolate may contain 15% cocoa liquor, 20% cocoa butter, 22% milk solids, 40% sugar, small amounts of lecithin emulsifier and vanillin.

The 1000-seed weight (at 30% moisture content) is about 2 kg.

Description Evergreen tree, 4–20 m tall, in cultivation usually 4–6 m. Taproot up to 2 m long with a dense mat of lateral feeder roots up to 6 m long in upper 20 cm of the soil; roots possibly with mycorrhizal associations. Stem growth sympodial, with orthotropic subterminal shoots (chupons) and lateral branching with successive whorls (fan or 'jorquette') of (3–)5(–6) plagiotropic branches. Leaves thin-coriaceous, petiolate, arranged spirally on orthotropic, alternate on plagiotropic branches; petiole 1–10 cm long, characteristically thickened at both ends; blade subobovate-oblong to elliptical-oblong, 15–50 cm × 4–15 cm, rounded at base, subundulate along the margin, apex acuminate, pubescent on the veins; with a prominent main vein and 9–12 pairs of lateral veins. Inflorescences on the trunk and older branches (cauliflorous), usually borne on small tubercles (flower-cushions) in many-flowered fascicles; flower 5-merous, 1–1.5 cm in diameter, regular, bisexual; pedicel 0.5–1.5 cm long; sepals 5, oblong to lanceolate, 5–8 mm × 1.5–2 mm, white to reddish, reflexed; petals 5, smaller than sepals, with obovate base, expanding into concave cup-shaped pouch, upper part spatulate, pale yellow, reflexed; androecium with 5 outer, erect, pointed, ciliate staminodes and 5 inner stamens with reflexed filaments, anthers concealed in pouches of corresponding petals; pistil with 5 very short styles, connate at base. Fruit a berry-like drupe, commonly called pod, very variable in shape, from globose to cylindrical and pointed, 10–32 cm × 6–12 cm, smooth to warty, usually with 5 or 10 furrows, green, yellow, red or purplish, with fruit wall (husk) varying in thickness (up to 2 cm) and in degree of lignification, 20–60-seeded. Seeds (beans) arranged in 5 rows, with central placentation, very variable, globose to ellipsoid, 2–4 cm × 1–2 cm, embedded in mucilageous, whitish, sugary and acid pulp, developed from the outer integument of the ovule, with two convoluted cotyledons and small embryo enclosed in thin membrane (remains of endosperm), with leathery testa. Seedling with epigeal germination.



Theobroma cacao L. – branch with flowers and fruits.

Growth and development Cocoa seed is recalcitrant and there are no effective methods of prolonging seed viability in storage beyond 4–5 weeks without the seed starting to germinate. Seeds in unopened pods may remain viable for 3–4 weeks after harvesting and an inhibitor in the mucilage prevents early germination. Fresh seed placed flat about 1 cm deep in nursery pots will germinate almost immediately, with the closed cotyledons emerging above the ground within a week. A few weeks later the cotyledons open, exposing the plumule, and the first growth phase ends with the hardening-off of the first four leaves that stand out horizontally at the same level. Subsequently, leaves appear at about 6-week intervals, well spaced in a spiral arrangement. Seedlings are ready for planting in the field 4–6 months after sowing, when 40–50 cm tall. Orthotropic growth of the single stem continues until the seedling is 1–1.5 m tall, usually one year after field planting, when the first jorquette is formed. This is the product of five axial subterminal buds that grow out sideways simultaneously, whilst the apical bud ceases to function. The internodes between the side shoots are reduced so much that they grow out at the same level. These plagiotropic shoots are called 'fan' branches. Some years later an orthotropic shoot or 'chupon' may grow out from below the jorquette joint and, after growing a certain length, form another tier of fan branches. This process may be repeated several times. The dimorphic branching in *Theobroma cacao* is not absolute, as is the case in *Coffea* spp., and orthotropic shoots can be induced on mature plagiotropic stems.

First flowering starts 1.5–5 years after field planting, depending on cultivar and ecological conditions. Cocoa is allogamous, with a unique system of gameto-sporophytic self- and cross-incompatibility controlled by a single gene with several dominant and co-dominant alleles. This self-incompatibility gene is operative in all Forastero cocoa germplasm collected from the main centres of genetic diversity (upper Amazon basin), but not always in other types, such as the self-compatible Criollo, Trinitario and Amelonado cocoa. However, even self-incompatible genotypes can be induced to self-fertilize when the pollen mix also contains pollen (called mentor pollen) from a cross-compatible genotype. This phenomenon has important consequences for seed production from biclonal seed gardens. Pollination is effected by insects, the most important being very small midges of the genus *Forcipomyia*, which results in 25–50% cross pollination. Pollination efficiency is low, usually less than 10%, but that is compensated for by the large number of flowers produced. Only one in every 500 flowers may develop into a mature pod, or even fewer in the presence of cross-incompatibility. Initial growth of the young fruits, called 'cherelles', is slow. Cherelle wilt, in which fruits stop growing, blacken and shrivel but remain attached to the stem, is considered to be a physiological mechanism to regulate the crop load on the tree in accordance with available assimilates. It occurs mostly during the first 2–3 months. Full pod size is attained 4–5 months after successful fertilization and another month is required for ripening.

Other botanical information Most natural and cultivated cocoa populations show great variability, due to the allogamous nature of cocoa and a history of frequent inter-population crossing. This complicates attempts of systematic classification, but four main groups of populations within *T. cacao* are generally distinguished:

- Criollo: rather weak-growing tree with relatively low yields, very susceptible to diseases and pests; pods longish and pointed, usually deeply furrowed and warty, thin and soft husk without lignification; green or red immature pods, ripening to yellow or red; 20–40 beans per pod; beans large and almost round in cross-section, requiring 2–3 days fermentation only; white to pale purple cotyledons.
- Forastero of lower Amazon basin (LA): mostly the Amelonado populations; large trees coming into bearing late, but high yielding; immature pods light green ripening to yellow, spherical shape with rounded or very bluntly pointed ends, generally smooth surface with shallow ridges, husk thick and hard with some lignification; beans flat and dark purple, about 40 per pod.
- Forastero of upper Amazon basin (UA): highly variable wild populations from the centres of genetic diversity; sources of plant vigour, productivity and resistance to diseases and pests; pod size and shape variable, but often rather small, pointed, sometimes with a narrow neck, often deeply furrowed and warty surface, but sometimes also smooth; husk comparatively thick and hard, often with distinct layer of sclerenchyma; immature pods always green, ripening to yellow; 30–60 beans per pod; beans small and flat; cotyledons dark purple, but occasionally light red or white.
- Trinitario: natural hybrid between Criollo and Amelonado Forastero; very heterogeneous population but generally much more vigorous and hardy than Criollo; pods variable in shape and husk thickness, smooth to warty surface; immature pods whitish, green, red or purple, ripening to yellow, orange or red; beans plump to flat; cotyledons white to dark purple.

Botanically, *T. cacao* has been subdivided into subsp. *cacao* (with 4 formas) and subsp. *sphaerocarpum* (Chevalier) Cuatr. The former covers the Criollo group, the latter the Forastero and Trinitario groups. For cultivated plants, however, a classification into cultivar groups and cultivars would be more appropriate, but no such classification yet exists. The great cultivars of the older cocoa-growing areas, i.e. the Criollo of Central America and the Caribbean, the Forastero-Amelonados of Brazil and West Africa, the 'Nacional' of Ecuador and Trinitarios of Cameroon and Papua New Guinea, are gradually being replaced by hybrid populations obtained by crossing accessions of UA Forasteros with local selections. These hybrids accounted for 40% of the world cocoa area in the late 1990s, including 5% clonal plantings. The expansion of cocoa in Malaysia (Sabah) during the 1980s and more recently in Indonesia (Sulawesi and Sumatra) is almost entirely based on such hybrids, propagated as seedling populations or selected clones.

T. cacao is the only one of the 22 species within the genus *Theobroma* to be cultivated worldwide for its beans. *T. grandiflorum* (Willd. ex Sprengel) K. Schum. or 'copuaçu' is grown on a small scale in Brazil for the sweetly flavoured mucilage, which is extracted and used to prepare a refreshing sherbet. Fresh cocoa pulp is also used for similar purposes by industrial fruit processors in the state of Bahia. In Indonesia the fresh pulp is used to produce 'nata de cacao'.

Ecology Cocoa is a typical crop of the tropical lowlands which can be grown at higher altitudes if other conditions are favourable.

Annual rainfall of 1500–2500 mm, with no more than three consecutive months with less than 100 mm, and temperatures between 30–32°C mean maximum and 18–21°C mean minimum are optimal (absolute minimum not below 10°C). Light is an important factor affecting the growth and development of cocoa. Wild cocoa grows as an understorey of tropical forests and cocoa is often cultivated under shade. The leaves have a very low light saturation point and a low photosynthetic rate, which declines when leaves are exposed to above-optimal light levels. Large areas of South-East Asia have conditions favourable for optimal cocoa production. In areas without a dry season, cocoa has been shown to develop more quickly than in the major production areas of West Africa where during certain months of the year growth is arrested by drought. Climatic conditions should, however, be considered in relation to soil properties. Soils with a large capacity to store moisture can compensate for periodic lack of rain, while excessive rainfall will cause fewer problems on well-drained soils.

Cocoa requires deep, well-drained, fertile soils and is more demanding than rubber or oil palm. Criteria for appropriate cocoa soils are: at least 1.5 m deep, clay content 30–40%, a topsoil with at least 2% organic carbon, a cation exchange capacity of 120 mmol/kg and a base saturation of 35%.

Soils meeting these requirements are in the orders of well-drained Entisols (alluvial soils), deep and well-drained Inceptisols (volcanic and other origins), red or yellowish Ultisols and Alfisols (mineral-rich soils under forest). In Malaysia (Sabah) and Papua New Guinea (New Britain, Bougainville Island) cocoa thrives on chemically rich Inceptisols of volcanic origin. In Peninsular Malaysia and North Sumatra most cocoa is grown on Ultisols; however, cocoa was successfully established on poorly-drained Inceptisols after water management of the soils was improved. In Sulawesi cocoa is expanding on Entisols and Ultisols.

Propagation and planting Most cocoa is established from seed produced in bi-clonal gardens by open or controlled pollination. Hand pollination is essential to increase and direct seed production and to obtain 100% legitimate hybrid seed, even when the clones are self-incompatible. Vegetative propagation by rooted cuttings, grafting, side-grafting or budding is routinely applied everywhere to multiply selected parents for breeding programmes and elite clones for establishing seed gardens. Green-patch budding in the nursery on the hypocotyl stem of 3-week-old rootstock, and side-grafting in the field to convert mature cocoa plantings are applied in Malaysia for large-scale multiplication of commercial clonal cultivars. Traditionally, vegetative propagation was applied in Indonesia to multiply the Java fine cocoa (DR) clones, but clones of hybrid Forastero cocoa are now also being introduced, along with seed of hybrids from bi-clonal gardens. Advanced techniques of micropropagation through tissue culture or embryogenesis have so far had limited success.

Seedlings and young plants from cuttings or budding are raised in a shaded nursery, usually in polythene bags. Fields are established with 4–6-month-old nursery plants at densities of 1100–1200 trees/ha, or wider spacings when growing conditions are exceptionally favourable (e.g. on East New Britain, Papua New Guinea). In Sabah, experimental high density plantings with semi-dwarf clones have given very high early yields; however, because of high establishment and maintenance costs their commercial advantage is still questionable.

Young trees need shade to reduce irradiance, to buffer the micro-environment and to achieve the right shape and habit of the trees. Once the canopy has closed, the need for shade is reduced. Only under most favourable conditions of soil and nutrient supply can cocoa be grown without shade. It is normally necessary to retain some shade to reduce moisture stress and incidence of insect and fungus damage in order to prolong the economic life of plantations. Shade can be provided either by thinning forest or by planting shade trees. Shade trees are common in South-East Asia, the main ones being seedless *Leucaena leucocephala* (Lamk) de Wit (Indonesia) and *Gliricidia sepium* (Jacq.) Kunth ex Walp. (Malaysia and Indonesia). Often, hedges of leguminous shrubs and banana trees are used for temporary side protection between rows and as a source of mulch. Cocoa is also grown as an intercrop under coconut. The availability of large plantations of old tall coconuts has largely contributed to the rapid expansion of cocoa in South-East Asia.

Husbandry Weeding is needed during establishment, but once the canopy has closed, lack of light will prevent weed growth. Seedling trees need no pruning during the first 2–3 years. Later, low-hanging branches should be pruned to facilitate harvesting and spraying for disease and pest control. A leaf area index of about 4 is needed to ensure optimal light interception and light penetration to the lower layers of the canopy. Vertical growth is usually restricted to the first jorquette. If the first jorquette is formed too low (below a height of 1.5 m), the tree is allowed to make a second one. To retain trees at the desired height, chupons should be removed at regular intervals.

Clonal plantings derived from plagiotropic twigs and branches require intensive pruning within one year after planting to shape the trees and reduce excessive lateral growth to maintain satisfactory yield levels. However, mature clonal trees can be induced to produce chupons allowing conversion into the seedling type of growth with one vertical stem.

Fertilizer requirements depend on yields, which are usually much higher in large estates than in smallholdings. An exception are the high fertilizer rates applied by smallholder cocoa farmers of South Sulawesi, who also achieve record yields. Nutrients removed by 1 t of cured cocoa beans are 20 kg N, 4 kg P and 10 kg K. Rates and types of fertilizer needed depend on soil fertility, age of trees, yields and shade. Lightly shaded and unshaded cocoa requires more fertilizers, especially nitrogen, than shaded cocoa. This is related to the fact that the larger leaf area, greater photosynthetic activity and higher yield of cocoa under high irradiance can only be maintained if trees are well provided with nutrients. As a general guide, per ha mature cocoa needs 50–100 kg N, 25 kg P, 75 kg K and, sometimes, 15 kg Mg per year. The highest nitrogen rate is intended for lightly shaded or unshaded cocoa. Unfortunately, leaf analysis has limited value as a diagnostic aid in cocoa nutrition when it is not combined with soil analysis and fertilizer trials. Detailed fertilizer recommendations are well documented.

Diseases and pests Every year about 40% of the world cocoa crop is lost due to diseases. Black pod caused by *Phytophthora palmivora* is of worldwide significance, but the more aggressive *P. macrokarya* is restricted to West Africa. *P. palmivora* is also the pathogen of bark canker, which is of particular importance in Papua New Guinea. Witches' broom disease (*Crinipellis perniciosa*) and moniliasis or frosty pod rot (*Moniliophthora theobromae*) are two fungal diseases that have co-evolved with the crop in Latin America but have not been observed outside that continent. After large areas of cocoa were established in Africa, the trees became infected by the swollen shoot virus, transmitted by mealybugs from several indigenous tree species. Swollen shoot had a devastating effect on the cocoa industry in Ghana. A fungal disease specific to South-East Asia is vascular streak dieback caused by *Oncobasidium theobromae*. It causes dieback of branches, especially in young trees. The disease was first reported in Papua New Guinea in 1960 but is now also present in Malaysia, the Philippines and Indonesia, where it is particularly severe in areas of high rainfall. A combination of chemical control with fungicides (e.g. triazoles) and sanitation pruning is recommended, but the existence of high levels of host resistance in certain Forastero accessions offers opportunities for a more effective way of combating this disease. In South-East Asia, especially Trinitario type cocoa is also susceptible to anthracnose (*Colletotrichum gloeosporioides*).

Mirids are the most important insect pest of cocoa on a world scale. All regions have their specific mirids, causing severe damage to twigs, branches and young pods. In West Africa the most important pests are mirids of the genera *Distantiella* and *Sahlberghella*. In South-East Asia, mirids of the genus *Helopeltis* are a major pest. Biological control with the ant-mealybug complex has been successfully re-introduced to regulate *Helopeltis*.

The cocoa pod-borer, the larva of a small moth (*Conopomorpha cramerella*), is the most serious insect pest of cocoa in South-East Asia. It bores into the cocoa pod and by feeding on the placental tissues it reduces or prevents normal bean development. During most of its life, the insect is pro-

tected within the pod and so is difficult to control. At the beginning of the 20th Century, the cocoa pod-borer largely destroyed the early cocoa industries of North Sulawesi and Java. The current decline of cocoa production in Malaysia can be partly attributed to this pod-borer. It is increasingly a problem in Indonesian (Java, Sumatra, Moluccas, Sulawesi) and Philippine (Mindanao) cocoa.
A variety of insect pests are important during crop establishment, because they destroy the apical bud and delay or prevent canopy formation. Larvae of the moth *Tirocola plagiata*, the cocoa armyworm, cause extensive damage to young plants, especially in Papua New Guinea. Both rats and squirrels can account for a considerable part of total crop losses in South-East Asia. The only effective control measures are baiting and trapping.

Harvesting The length of the harvesting season depends on genotype and climatic conditions. In many cocoa areas in South-East Asia, where rainfall and its distribution are favourable, the cropping season is extended over the whole year with only 2–3 months having less than 10% of annual yield. The practice of leaving pods to rot on the trees during these months since it is not worthwhile harvesting them should be discouraged because diseases and pests of pods can multiply during this period. Ripe pods, recognizable by the colour change, are harvested at 7–10 day intervals with various types of sharp knives, care being taken not to damage the flower cushions. The time for harvest is not very critical, as the beans remain in good condition in the attached ripe pods for 2–3 weeks. However, overripe beans may germinate in the pods, and unripe beans give poor germination.

Yield Average annual cocoa yields are about 400 kg/ha of cured beans, with national annual average yields per ha ranging from 300 kg (Ghana) and 550 kg (Ivory Coast) to 650–700 kg (Malaysia, Indonesia). Yields of mature cocoa on estates in South-East Asia are usually 1500–2000 kg/ha, but higher yields (3000–4000 kg/ha) are no exception. Cocoa smallholders on the fertile alluvial soils of South Sulawesi are reported to achieve 2000 kg/ha. The seed constitutes about 25% by fresh weight of mature pods.

Handling after harvest Harvested pods are opened and the beans and mucilage removed and transferred to wooden boxes for fermentation during 2–4 days for Criollo and Trinitario, or 4–6 days for Forastero cocoa. In West Africa most of the cocoa is fermented in heaps or in baskets covered with banana leaves. During fermentation the mucilage round the seeds is removed, precursors to the chocolate flavours are developed and most of the astringency disappears. The fermented beans are dried in the sun or in artificial driers to a moisture content of 6–7%. The drying process should not be too rapid in order to allow a gradual curing and further development of the flavour and the brown chocolate colour. Very slow drying may induce mouldiness and off-flavours. Bulk cocoa produced by smallholders in Indonesia (Sulawesi, Sumatra) is often unfermented and rapidly dried on concrete platforms or in artificial driers. This cocoa is of medium quality, but price discount on the world market is insufficient to force farmers to ferment the cocoa properly. In Java, beans are sometimes washed between fermentation and drying, to remove any remnants of pulp adhering to the shell. The resulting clean and attractive appearance and low proportion of shell (8–10%) are a trade mark of the fine-grade Indonesian Trinitario cocoa.
After drying, the beans are bagged and transported to overseas markets in containers. However, the importance of bulk storage and handling is increasing. Beans can safely be stored for 2–3 years. Storage in the tropics requires special precautions to prevent mould, insect damage and deterioration. Further stages of processing include roasting, shelling, liquor grinding, pressing and mixing. At present already 30% of all cocoa is produced into liquor, butter and powder before exportation to consumer countries.

Genetic resources Cocoa germplasm collection in the centres of high genetic diversity started in earnest with the two expeditions in 1937 and 1942 to Peru by F. J. Pound of Trinidad, who was in search of host resistance to the witches' broom disease. These semi-wild UA Forastero accessions were distributed from Trinidad to all major cocoa research centres in the world after 1945 – such as the IMC (Iquitos mixed calabacillo), NA (Nanay), PA (Parinari), SCA (Scavina) and P (Pound) clones or their seedling offspring – and still form the major UA component of modern cocoa hybrids. Some 42 expeditions have been mounted since 1949 to collect wild and other important cocoa germplasm (UA and LA Forastero and Criollo) in primary and secondary centres of genetic diversity in Brazil (19), Ecuador (9), Colombia (4), Venezuela (3), Guyana and French Guiana (2), Peru (2), Guatemala (1) and Belize (1). Large collections are maintained by the International Cocoa Genebank, Trinidad (ICG,T) with 2500 accessions, the 'Comissão Executiva do Plano da Lavoura Cacaueira' (CEPLAC) in Brazil with more than 2000 accessions at Belem, and the 'Centro Agronómico Tropical de Investigación y Enseñanza' (CATIE) in Costa Rica with 700 (Criollo and Trinitario) accessions. There are also smaller collections of original germplasm in Ecuador, French Guiana and Colombia, while most public and private cocoa breeding centres in tropical America, Africa and Asia have their own working collections of wild and improved cocoa germplasm.

The ICGT and CATIE in particular have major projects on detailed taxonomic and agronomic characterization of cocoa germplasm. This information together with data from other cocoa research centres has been assembled in the International Cocoa Germplasm Database (ICGD) coordinated by the University of Reading in the United Kingdom. The ICGD currently holds descriptive data on more than 14 000 genotypes, including 7000 unique wild accessions. The International Plant Genetic Resources Institute (IPGRI) started a global project on cocoa germplasm conservation and utilization in 1997, with financial support from public and private institutions, including the cocoa industry.

International cocoa germplasm exchanges (seed and budwood) require a 2-year period of quarantine to contain inadvertent spread of diseases and pests. Cocoa quarantine facilities are available at the University of Reading (U.K.), at the 'Centre de Coopération Internationale en Recherche Agronomique pour le Développement' (CIRAD) in Montpellier (France) and in Barbados (ICG, T).

Breeding The early 20th Century cocoa breeding programmes in Java and Trinidad achieved progress in plant vigour and yield, in combination with good bean quality, by clonal selection within progeny of Trinitario type hybrids (Djati Roenggo (DR) and Imperial College Selections (ICS) clones in Java and Trinidad respectively). The considerably higher yield potential of hybrids of Amelonado and UA Forastero or even between UA Forastero types, first confirmed in Ghana in the 1960s, eventually led to the reciprocal recurrent selection schemes starting from genetically distinct subpopulations now adopted by most cocoa breeding programmes (e.g. Ivory Coast, Brazil, Malaysia and Indonesia).

Priorities in national cocoa breeding have shifted to host resistance to the globally important black pod and regionally important diseases, such as witches' broom in Brazil, swollen shoot virus in Ghana and vascular-streak dieback in South-East Asia. Disease resistance has to be a component of a fully integrated breeding programme, as resistance is only meaningful to the cocoa grower in combination with acceptable agronomic characteristics. In the case of vascular-streak dieback, high levels of host resistance have been found in some UA Forastero accessions (e.g. SCA and NA) and progress in breeding resistant hybrid cultivars is good. Host resistance to black pod exists in UA Forastero germplasm (e.g. SCA, PA and P) but levels are usually low, making it necessary to accumulate resistance genes in recombination crosses between progenitors prior to integration in the main breeding programme. Recent development of early preselection tests by artificial inoculation of leaf disks (Trinidad, Ivory Coast) should accelerate selection. An ecologically acceptable solution to the serious menace of the pod borer to the South-East Asian cocoa industry may be found in an integrated approach including biological control (e.g. egg parasitoids of the genus *Trichogrammatoidea*) and breeding for partial resistance or for a preventive mechanism, such as the presence of a sclerotic layer in the husk barring penetration of the borer in the pods of certain UA Forastero accessions.

There is evidence that in cocoa the genetic variance for components of all major agronomic characters is mainly due to additive gene effects. This should result in more efficient accumulation of favourable genes within breeding populations, while simultaneous emphasis on maximum gene dispersion between subpopulations will further increase the chances of creating superior hybrids in terms of balanced tree vigour, yield and bean quality.

Selection for low pod index (number of pods required to produce 1 kg of cured beans) results in larger beans (and lower shell ratio) and helps reduce harvesting costs.

Consideration should be given to redesigning the tree architecture to improve photosynthetic efficiency and harvest, but also to increase the effectiveness of available resistance to diseases such as black pod and vascular-streak dieback (e.g. open canopy). This issue should be approached from both angles: genetic (vigour, branch habit, compact growth, tolerance of regular pruning) and agronomic (plant density, pruning).

Prospects Full exploitation of available cocoa genetic resources, by conventional and innovative breeding methods should lead to further improvement in yield and other desirable characteristics. Molecular marker technology is increasingly being applied in cocoa for germplasm management and

to detect genetically divergent subpopulations. Recent experimental evidence also indicates that molecular marker-assisted selection has considerable potential for enhancing selection efficiency in cocoa, particularly with respect to host resistance to important diseases.
Indonesia remains the most competitive cocoa producer in the world because it has the lowest production costs. The only prospects for further expansion in Indonesia are smallholders in eastern Indonesia, but it remains to be seen whether the Sulawesi cocoa boom can be repeated on the other islands, and to what extent the cocoa pod borer will check further expansion. In Malaysia the cocoa pod borer and labour costs make cocoa a less interesting crop than oil palm and rubber, and large-scale conversion of cocoa to oil palm started in the early 1990s. In Papua New Guinea, large areas of suitable soils are available, but whether they will be planted to cocoa will depend on government support. In the Philippines, the main limitation to cocoa expansion is also the pod-borer. Vietnam could become the next country in the region for cocoa production because of the availability of large suitable areas and sufficient labour. The cocoa pod-borer is a very serious threat to the expansion of cocoa cultivation in South-East Asia. Strict quarantine measures must be observed, to prevent the insect from spreading into new areas.
For the long-term survival of the cocoa industry in South-East Asia it will also be essential to emphasize production systems that are sustainable and do not degrade the available natural resources. In that respect, studies on shade and nutritional requirements of cocoa in areas with inherently low soil fertility should have high priority.

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M. Wessel & H. Toxopeus

3 Minor stimulants

Acalypha siamensis Oliv. ex Gage

EUPHORBIACEAE

Synonyms *Acalypha evrardii* Gagnep., *A. sphenophylla* Pax & K. Hoffm.

Vernacular names Wild tea (En). Indonesia: pokok teh (Sumatra), teh-tehan (Javanese). Malaysia: teh hutan, teh kampung, tumput. Cambodia: taè préi. Thailand: cha-khoi (northern), cha-ruesei (central), phakduk (south-western). Vietnam: tr[af] r[uwf]ng, tr[af] h[af]ng r[af]o.

Distribution Native in Peninsular Malaysia, Laos, Cambodia, Vietnam and Thailand and currently cultivated in Thailand, Peninsular Malaysia and Indonesia.

Uses A hot infusion of dried leaves is drunk as a tea by the Thais and Malays. The leaves are also used in traditional medicine to treat fever, bowel complaints and kidney diseases; they are said to have antipyretic properties. The plant is often cultivated as a hedge plant.

Observations A shrub or small scrambling tree to 4 m tall. Leaves rhombic, 2–10 cm × 1–5 cm, glabrous, coriaceous, narrowed into a blunt base, with characteristic serrate blunt tips and 5 slender vein pairs with 1 pair from the leaf base; petiole less than 1 cm long. Inflorescence a slender, puberulous raceme, about 5 cm long, upper part male, with 2 or 3 female flowers at the base; male flowers minute, in small tufts; sepals ovate, acute, ciliate; stamens about 10, filaments hairy, scale-like, lanceolate acuminate; female flowers enclosed in a large herbaceous bract. Fruit a capsule, 2.5 mm long, covered with long protuberances. *A. siamensis* is locally common in dry, evergreen or mixed forest or scrub vegetation, up to about 400 m altitude; often on sandy soils, sometimes on limestone. It can be propagated by seed or stem cuttings. The potential use of *A. siamensis* as a raw material in the herbal and pharmaceutical industry is worth exploring.

Selected sources 1, 15, 50, 55, 59, 69, 75.

Actephila excelsa (Dalzell) Muell. Arg.

EUPHORBIACEAE

Synonyms *Actephila bantamensis* Miquel, *A. dispersa* (Elmer) Merrill, *A. javanica* Miquel.

Vernacular names Philippines: lambonan (Tagbanua), toyokan (Cebu Bisaya), tungkaling (Subanun). Vietnam: da g[af], ch[ef] d[aj]i.

Distribution From India and Assam to Burma (Myanmar), Indo-China, Thailand and throughout the Malesian region except for the Lesser Sunda Islands and the Moluccas.

Uses In the eastern Himalayas the dried leaves are used to make a pleasant tasting tea, but the mucilaginous leaves have no special aroma and contain no alkaloids.

Observations A monoecious, evergreen shrub or small tree up to 11 m tall; bole up to 18 cm in diameter. Leaves arranged spirally, crowded; stipules small; petiole 0.5–7 cm long; blade elliptical-ovate, 9–30 cm × 4–12.5 cm, entire, glabrous, apex acuminate. Flowers in axillary, very short racemes with a few female flowers at base and male ones above; sepals 5, imbricate; petals 5, shorter than the sepals; disk large; male flower on a pedicel up to 2 mm long, sepals about 2.5 mm long, stamens 5, free; female flower long pedicellate, sepals up to 7 mm long, ovary 3-locular with 2 ovules in each cell, styles short, basally connate. Fruit a woody capsule, 1.5 cm × 2.5 cm, seated on the slightly enlarged calyx. *A. excelsa* is generally reported from lowland forest, but is found up to 1000 m altitude in Java. In Peninsular Malaysia and Thailand it is often found on limestone, but elsewhere it has been reported from swamp margins, slopes, ridge forest and scrub forest. Three varieties are distinguished: var. *excelsa* with short-petioled, glossy leaves occurring from India to Burma (Myanmar); var. *acuminata* Airy Shaw with short-petioled, dull leaves occurring in Indo China, Thailand and Peninsular Malaysia; and var. *javanica* (Miquel) Pax & K. Hoffm. with long-petioled leaves occurring in the Malesian region. The latter variety is occasionally distinguished at the species level.

Selected sources 1, 2, 3, 4, 6, 15, 28, 38, 46, 75.

Areca caliso Becc.

PALMAE

Vernacular names Philippines: kaliso (Bagobo), sakolon (Manobo).

Distribution The Philippines (Mindanao to south-eastern Luzon).

Uses The Manobo people of the Philippines use the seeds as a substitute for those of areca palm (*Areca catechu* L.), the Tasaday people use it as their main source for betel chewing. The juice obtained from the inflorescences yields a beverage of inferior quality.

Observations A fairly small, pleonanthic, monoecious palm of 6 m or more tall; stem up to 15 cm in diameter. Leaves about 3 m long; sheaths forming a crownshaft; blade pinnate with linear-lanceolate leaflets, apex falcate, median leaflets 90–95 × cm 6–7 cm. Inflorescence appearing on the trunk below the crown leaves, simply branched (branches spike-like) and adpressed to the main axis; spikes few, 15–20 cm long, slightly unilateral, with (4–)8–14 female flowers in the lower third to half, with many paired male flowers above; male flower sessile, 5–6 mm long, calyx with 3 small, free sepals, corolla with 3 valvate petals, stamens 6; female flower sessile, globose, 8–9 mm in diameter, calyx about as long as the corolla, ovary 1-locular with a single ovary and 3 sessile stigmas. Infructescence about 15 cm long; fruit a drupe, ellipsoid to elongated ovoid, 3–3.5 cm × 2–2.2 cm. Seed with ruminate endosperm. *A. caliso* is found in dense, humid rain forest on mountain slopes at 350–1000 m altitude.

Selected sources 9, 10, 14, 27, 33, 46.

Areca latiloba Ridley

PALMAE

Synonyms *Areca pumila* Blume, non Blume ex Mart.

Vernacular names Indonesia: jambe rende (Sundanese), pinang piji (Palembang).

Distribution Peninsular Malaysia, Sumatra; doubtfully native to Java.

Uses The seeds are used as an inferior substitute for those of areca palm (*Areca catechu* L.) and used to be used by Chinese people for domestic altars. The palms are sometimes planted in graveyards for ornamental purposes.

Observations A small, solitary, pleonanthic, monoecious palm up to 5 m tall; stem up to 5 cm in diameter. Leaves up to 2 m long; sheaths forming a crownshaft; blade pinnate with acuminate, 40–53 cm × 5–9 cm leaflets. Inflorescence appearing below the crown leaves on the trunk, spiciform; spikes few, 4–6 cm long, with 1 female flower at base and male flowers above; male flower sessile, calyx minute, corolla with 3 valvate petals, stamens 3; female flower sessile, much larger than the male one, calyx slightly larger than the imbricate corolla, ovary 1-locular with a single ovary and 3 sessile stigmas. Fruit an ellipsoid to narrow-cylindrical drupe, about 2.5–3 cm long, bright red when ripe. Seed with ruminate endosperm. *A. latiloba* is found in hill forest up to 750 m altitude. It may well prove to be identical to *A. triandra* Roxb.

Selected sources 6, 15, 30, 55, 68, 74.

Areca macrocalyx Zipp. ex Blume

PALMAE

Vernacular names Highland betel nut palm (En). Papua New Guinea: kabibi, kawiwi.

Distribution The Aru Islands, New Guinea and the Bismarck Archipelago.

Uses The seeds are used as an inferior substitute for those of areca palm (*Areca catechu* L.).

Observations A solitary, pleonanthic, monoecious, fairly tall palm; stem 4.5–6 m long. Leaves pinnate; sheaths forming a crownshaft; leaflets narrowly linear-lanceolate, 45–75 cm long, apex long tapering but those of the terminal leaflets praemorse. Inflorescence appearing on the trunk below the crown leaves, spicate; spikes few, bearing few female flowers at base and male ones above; male flowers alternating, in 2 rows, sessile, calyx minute, corolla with 3 valvate petals of about 6 mm long, stamens 6; female flowers sessile, about 9 mm long, calyx about as long as the imbricate petals, ovary 1-locular with a single ovule, stigmas 3, sessile. Infructescence dense; fruit an ellipsoid drupe, about 4 cm long, umbonate, with a persistent perianth. Seed with ruminate endosperm. *A. macrocalyx* is cultivated around villages in the highlands of New Guinea for its fruits.

Selected sources 11, 15, 27, 34.

Areca triandra Roxb.

PALMAE

Synonyms *Areca borneensis* Becc., *A. nagensis* Griffith, *A. polystachya* (Miquel) H. Wendl.

Vernacular names Wild areca palm (En). Indonesia: buring utan (Lampung), pinang yang (Bangka), pinang umbut (western Kalimantan). Malaysia: datea (Punan, Sarawak). Cambodia: sla préi. Thailand: mak-chawaek, mak-nangling (south-eastern), mak-no (northern). Vietnam: cau r[uwf]ng, cau tam h[uf]ng.

Distribution From north-eastern India to Indo-China, Thailand, Peninsular Malaysia, Sumatra, Borneo, Java and the Philippines.

Uses The seeds are sometimes used as an inferior substitute for those of areca palm (*Areca catechu* L.). The palm cabbage is edible, and has been used as a fodder for water buffaloes. In the Andaman and Nicobar Islands the leaves are used for thatching and the stems as posts. The palm is occasionally planted for ornamental purposes.

Observations A clustered or sometimes solitary, small to medium-sized, pleonanthic, monoecious palm up to 7.5 m tall; stem up to 8 cm in diameter, often with suckers at base. Leaves 120–180 cm long; sheaths forming a green crownshaft; blade pinnate with falcate-acuminate, 45–90(–120) cm × 2.5–5 cm leaflets, terminal 2–4 leaflets truncate. Inflorescence appearing on the trunk below the crown leaves, spiciform, with a lemony smell; spikes numerous, 14–17 cm long, with 1 female flower at base and many paired male flowers above; male flower sessile, calyx minute, corolla with 3 valvate petals, stamens 3; female flower sessile, much larger than the male one, calyx slightly larger than the imbricate corolla, ovary 1-locular with a single ovary and 3 sessile stigmas. Fruit an ellipsoid to ovoid drupe, 2–2.5 cm long, orange-red when ripe, beaked. Seed with ruminate endosperm. *A. triandra* flowers almost throughout the year; the fruit takes about 7.5 months to mature. It is found in forest margins and undergrowth of seasonally flooded alluvial forest at low altitudes. It is a highly polymorphic species, within which several varieties have been distinguished. One of these is var. *bancana* Scheff. occurring in Bangka and Borneo (Sarawak) where it is always solitary and has more robust rachillae than var. *triandra*. It may form highly sterile hybrids with *A. catechu*, and may be useful in breeding programmes. *A. triandra* can be propagated by seed, which takes 6–10 months to germinate, or by removing and planting its basal suckers. In the Philippines, *A. hutchinsoniana* Becc. (synonym: *A. mammillata* Becc.) occurs; it is a small palm (3 m tall, stem diameter 3–4 cm), possibly with similar ornamental uses as *A. triandra*, but the cabbage is only used medicinally as a vermifuge.

Selected sources 6, 7, 14, 25, 27, 30, 33, 34, 50, 55, 59, 62, 66, 67, 68, 74.

Areca whitfordii Becc.

PALMAE

Vernacular names Philippines: bungan-gubat (Tagalog).

Distribution The Philippines (Luzon, Mindoro).

Uses The seeds are used as a substitute for those of areca palm (*Areca catechu* L.).

Observations A small to medium-sized, pleonanthic, monoecious palm up to 10 m tall; stem up to 20 cm in diameter. Leaves about 2.5 m long; sheaths forming a prominent, somewhat swollen crownshaft; blade pinnate, with falcate-acuminate leaflets, leaflets with 2–3 prominent ribs, median leaflets about 100 cm × 4.5–5 cm. Inflorescence appearing on the trunk below the crown leaves, 3 times branched, spiciform; spikes numerous, with 1–2 female flowers at base and many male ones above, flowers sessile; male flowers unknown; of the female flowers the sepals ovate, petals longer than the sepals, with a broad triangular point; fruiting perianth cup-shaped, about 15 mm long. Fruit an ellipsoid drupe, 4–5.5 cm × 1.8–2 cm, with a truncate apex, brownish. Seed ovoid-ellipsoid, 2.5–3 cm long, with ruminate endosperm. *A. whitfordii* grows in semi-swampy areas in the lowland; it may be common in river swamps.

Selected sources 8, 10, 34.

Astilbe philippinensis A. Henry

SAXIFRAGACEAE

Vernacular names Philippines: hagman, kauan (Igorot), tugtugi (Bontok).

Distribution The Philippines (northern Luzon).

Uses The leaves, sometimes mixed with a little tobacco, have been used by the Igorot for smoking.

Observations A perennial herb 30–90 cm tall, with indumentum of brown hairs. Leaves alternate, 2–3-ternate but the upper division often 5-foliolate; leaflets leathery, ovate-lanceolate, 8–15 cm × 2–6 cm, double serrate, with scattered bristles, base oblique, apex long acuminate. Inflorescence paniculate, small and lax, broadly pyramidal, glandular hairy; flowers sessile or shortly pedicellate; sepals 5, 1.5 mm long; petals 5, spatulate, 3 mm long, reddish, rounded at apex; stamens 8–10; carpels 2, adhering at base. Fruit a small capsule with a short beak. *A. philippinensis* is a characteristic element of the upper pine region at 1200–2300 m altitude.

Selected sources 14, 29, 37, 46, 47.

Bauhinia winitii Craib

LEGUMINOSAE

Synonyms *Lysiphyllum winitii* (Craib) de Wit.

Vernacular names Thailand: khiunang, oraphim (central).

Distribution Endemic to Thailand.

Uses The very astringent bark is chewed locally together with areca nuts (the endosperm of *Areca catechu* L.).

Observations A tendrilled climber; branches rusty pubescent, glabrescent. Leaves arranged spirally; stipules minute; petiole about 1 cm long; leaflets 2, free, obliquely ovate, 3–4.5 cm × 1.5–2.5 cm with rounded base and apex. Inflorescence a lateral or terminal, mainly unbranched raceme, 6–15 cm long with a rusty pubescent axis; buds velvety pubescent; bracts linear, 5–8 mm long; pedicel 4–8 mm long; bracteoles slightly shorter than bracts; flowers bisexual; receptacle tubular, 4–6 cm long; calyx with 5 free sepals, 2–3.5 cm long; petals 5, lanceolate, up to 9 cm × 4 cm including the 1.5 cm long claw, posterior petal yellowish and slightly larger; stamens 10, all fertile, about 7 cm long, opening by longitudinal slits; ovary superior, stipitate, glabrous, style about 4 cm long with a peltate stigma. Fruit a tardily dehiscent pod, up to 30 cm × 8 cm, glabrous, 6–10(–more)-seeded. Seed compressed, 10–15 mm in diameter. *B. winitii* is found in open, dry or mixed deciduous forest, rarely above 300 m altitude.

Selected sources 15, 24, 60.

Calyptrocalyx spicatus (Lamk) Blume

PALMAE

Vernacular names Indonesia: hena-hena (Ternate), hua alang (Ambon), pinang utan besar (Moluccas).

Distribution Indonesia (Moluccas).

Uses In the Moluccas the seeds are regarded as the best substitute for those of *Areca catechu* L. The wood is hard, easy to split and fairly durable, but is not much used. The palm is occasionally planted for ornamental purposes.

Observations A medium-sized to large, solitary, pleonanthic, monoecious palm; stem slender, 7–12 m long. Leaves drooping, 3–3.5 m long; sheaths with a scarcely developed crownshaft, green; blade pinnate, leaflets many, narrowly lanceolate, pointed. Inflorescence borne among the leaves, up to 2 m long, protandrous, unbranched, spicate, with spirally arranged triads of sessile flowers; male flower with 3 sepals, petals 3, about twice as long as the sepals; female flower more or less globular; ovary 1-locular with a single ovule. Fruit an ovoid drupe, about 3 cm long, bright orange, with vestiges of the stigma at the apex. *C. spicatus* thrives in shaded and wind-protected locations in lowland rain forest, and prefers well-drained soils rich in organic matter. Seeds germinate in 1–2 months after sowing.

Selected sources 15, 30, 33, 34, 62, 68, 71.

Chloranthus spicatus (Thunb.) Makino

CHLORANTHACEAE

Synonyms *Chloranthus inconspicuus* Swartz, *C. obtusifolius* Miquel, *Nigrina spicata* Thunb.

Vernacular names Chulan tree (En). Indonesia: barlen (Sundanese). Thailand: tanmuai (Chiang Mai), foifa (Bangkok), niamom (northern). Vietnam: hoa s[os]i.

Distribution Native to China, but widely cultivated throughout eastern Asia including Japan. In Malesia cultivated in Peninsular Malaysia, Sumatra and Java.

Uses *C. spicatus* is cultivated for its aromatic leaves and flowers which are used to make a tea-like drink or are mixed with tea during drying to increase its fragrance. In Indo-China an infusion is prepared from flowers and leaves and administered to treat cough. In China the bruised root is recommended as a poultice on carbuncles and boils. It is diaphoretic and excitant, reputed to cure malaria, but poisonous in overdose.

Observations A sympodially branched, glabrous shrub up to 1.5 m tall; branches ascending to spreading, with swollen nodes. Leaves decussate; stipules linear, 2–3 mm long, membraneous; petiole 4–12 mm long; blade oblong-ovate to elliptical, 4–13.5 cm × 2–8.5 cm, base cuneate, margin crenate-serrate, apex obtuse to scarcely acuminate. Inflorescence a terminal raceme, consisting of 10–20, opposite spikes, each 2–5 cm long; flowers bisexual, without a perianth; the male part composed of a 3-lobed organ adnate to the ovary; ovary with subsessile stigma. Fruit a green or yellowish drupe, 4 mm × 2 mm. In Malesia *C. spicatus* is cultivated at 700–900 m altitude; flowers have been observed throughout the year. The nematode *Aphelenchoides fragariae* causes a leaf-spot disease and has been located in top buds where it occurs throughout the year. Analysis of the volatiles of the flowers yielded 11 monoterpenes, 11 sesquiterpenes and 7 oxygen-containing compounds. Major constituents are cis-methyl jasmonate, cis-β-ocimene and β-pinene. The wood contains guaiacyl lignin, normally found only in gymnospermous wood.

Selected sources 15, 16, 26, 30, 49, 50, 57, 59, 72, 77.

Clerodendrum villosum Blume

VERBENACEAE

Synonyms *Clerodendrum ferrugineum* Turcz., *C. molle* Jack, *C. velutinum* Wallich ex D. Dietr.

Vernacular names Malaysia: chapaneng, labu-labu, tapak kerbau (Peninsular). Thailand: chumwan (peninsular), nangyaem-paa (south-eastern), phuangphi-daeng (north-eastern).

Distribution From India (Assam) to Burma (Myanmar), Indo-China, Thailand, Peninsular Malaysia, Sumatra, Java, Borneo and the Philippines.

Uses In Peninsular Malaysia the bark has been chewed as a substitute for areca nuts (the endosperm of *Areca catechu* L.).

Observations A tomentose shrub, up to 3(–6.5) m tall, with angular branches. Leaves opposite, exstipulate; petiole 4.5–11 cm long; blade simple, broadly ovate, 7–29 cm × 5–21 cm, base cordate to truncate, margin entire, apex acutely acuminate. Flowers in cymes grouped in a terminal panicle 5–18 cm long; calyx campanulate, 5-lobed, enlarged in fruit; corolla zygomorphic, tube about as long as the calyx, segments 7–10 mm long, white with a green top; stamens 4, long exserted, anthers violet; ovary 4-locular with 1 ovule in each cell, style long exserted. Fruit a white drupe, seated on the widely patent-reflexed, white or greenish-white fruiting calyx. *C. villosum* is fairly common and found in slightly shaded to sunny locations, brushwood, light forest, forest margins and waste places, up to 900 m altitude. It has been reported from Thailand as an endangered plant. In Java it flowers throughout the year.

Selected sources 6, 15, 18, 28, 39, 59, 75.

Coffea congensis Froehner

RUBIACEAE

Distribution *C. congensis* is native to Central Africa along the Congo, Oubangui and Sangha rivers in the northern Democratic Republic of Congo (Zaire), the southern Republic of Central Africa, Congo (Brazzaville) and south-eastern Cameroon. It is generally not planted for coffee production, but is often kept in germplasm collections, for example in Java and the Philippines.

Uses The comparatively small seeds (generally referred to as coffee beans) are rarely used to prepare coffee. *C. congensis* is of importance however in interspecific breeding programmes, especially to introgress improved quality into *C. canephora*.

Observations An evergreen shrub, up to 7 m tall, with richly branched stem. Leaves opposite; stipules interpetiolate, green, triangular to semi-orbicular; petiole 2.5–14 mm long; blade narrowly elliptical to lanceolate or oblanceolate, 4.5–18(–25) cm × 1.2–6.5(–9.5) cm, base cuneate, margin entire, apex acuminate, with hairy domatia below. Inflorescence axillary, composed of 1–3(–5) cymes with comparatively long peduncles, each axil with 1–17 flowers; flowers (4–)5–6(–7)-merous; receptacle urn-shaped to campanulate, often puberulous; calyx minute, truncate or lobed or rarely minutely toothed; corolla white, tube cylindrical, (2–)6–10 (–11) mm long, lobes oblong to ovate-oblong, (6–)8–12(–15) mm long; disk annular, slightly lobed; filaments attached to the lower half of the anther; ovary inferior, 2-locular with a single ovule per cell, style (5–)8–15(–22) mm long, with 2 stigmas. Fruit a drupe, 1–6 per axil, ellipsoid or rarely ovoid or subglobose, 9–17 mm × 5–10 mm, red. Seed ellipsoid, about 12 mm long. *C. congensis* is a lowland coffee that grows in wet primary forest and tolerates waterlogging. It readily hybridises with *C. canephora* Pierre ex Froehner to form the well-known 'Congusta' of Java and the C × R cultivar of India. It is sometimes suggested that *C. congensis* is merely a form of *C. canephora*.

Selected sources 17, 30, 41, 43, 63, 73, 76.

Coffea stenophylla G. Don

RUBIACEAE

Vernacular names Highland coffee, narrow-leaved coffee, stenophylla coffee (En).

Distribution Indigenous to Guinea, Sierra Leone and Ivory Coast, occasionally cultivated in West Africa; introduced into Java (Bogor) in 1896 and to Singapore in 1899. Despite having some favourable attributes, it has never been cultivated or tested in experimental plantings.

Uses A fairly good quality coffee can be prepared from the seeds (generally referred to as coffee beans), although reports on its flavour are contradictory. The species is also used in coffee breeding.

Observations An evergreen, densely branched shrub or small tree up to 6 m tall; branchlets glabrous, swollen at the nodes. Leaves opposite; stipules connate at base, deltoid, acute or acuminate, rarely with an awn; petiole 3–5 mm long; blade narrowly oblong-oblanceolate, (5–)8–14 cm × (0.7–)1.5–4.5 cm, long attenuate at both ends, margin entire, with glabrous domatia below. Inflorescence axillary, each axil with 1(–2) cymes on a peduncle up to 5 mm long and each with 1–2(–4) flowers (1–3(–6) flowers per axil); flower 6–8(–9)-merous; calyx minute, short-toothed; corolla white or slightly pinkish, tube widened towards the throat, 6–8 mm long, lobes ovate to oblong, 12–15 mm long; disk annular; filaments attached at about 1/3 from the base of the anther; ovary inferior, 2-locular with a single ovule per cell, style about 14 mm long, with 2 stigmas. Fruit a drupe, few per axil, globose to broadly ellipsoid or broadly ovoid, 12–13 mm × 8–10 mm, violet-black with a longitudinal groove; fruit stalk 5–8 mm long. Seed ellipsoid, 8–9 mm long. In its native environment *C. stenophylla* grows on hill tops, in gallery forest and in primary rain forest, at 200–700 m altitude. It comprises two well-defined genetic groups. It is immune to the leaf miner *Perileucoptera coffeella*. As *C. stenophylla* does not cross with *C. arabica* L., the hybrid between *C. stenophylla* and *C. liberica* Bull ex Hiern var. *dewevrei* (De Wild. & T. Durand) Lebrun is used as a bridge to transfer leaf miner resistance. Furthermore, *C. stenophylla* is used in coffee breeding because of its drought resistance. The proportion of berries to green coffee is 6–7 to 1.

Selected sources 15, 17, 19, 21, 32, 43, 63, 73.

Desmos dumosus (Roxb.) Safford

ANNONACEAE

Synonyms *Desmos subbiglandulosus* (Miquel) Merrill, *Oxymitra monilifera* Merrill, *Unona dumosa* Roxb.

Vernacular names Malaysia: akar kinching juhu, pisang-pisang padi, pisang-pisang pipit (Peninsular). Thailand: tintang (north-eastern). Vietnam: d[er] b[uj]i.

Distribution India (Assam), Burma (Myanmar), Vietnam, Laos, Thailand, Peninsular Malaysia, Singapore, the Riau Archipelago and Borneo.

Uses Potable water can be obtained from inside the stems.

Observations A scandent, straggling shrub; young twigs tomentose, glabrescent, lenticellate. Leaves alternate, exstipulate, purplish tomentose when young; blade broadly ovate to oblong-ovate, 6–17 cm × 4–7 cm, base subcuneate to emarginate, apex slightly acute or obtuse, venation prominent below. Flowers solitary, leaf-opposed or extra-axillary; pedicel about 2 cm long; sepals 3, valvate, about 1 cm long; petals 6, in 2 rows, obovate-spatulate to broadly ovate-lanceolate, greenish-yellow, densely pubescent when young, the outer ones 5–8 times as long as the sepals; stamens numerous, extrorse. Ripe carpels many, free, 2–3 cm long, constricted between the seeds, glabrous, yellow turning dark purple. Seeds 2–4, 1-seriate, shining, medium brown. *D. dumosus* is found in open country and thickets.

Selected sources 15, 28, 55, 58, 59, 66, 70.

Diplospora DC.

RUBIACEAE

Major species and synonyms

- *Diplospora kunstleri* King & Gamble, synonym: *Urophyllum potatorium* King.
- *Diplospora malaccensis* Hook.f., synonym: *Tricalysia malaccensis* (Hook.f.) Merrill.

Vernacular names

- *D. kunstleri*: Peninsular Malaysia: kahwah hutan.
- *D. malaccensis*: Peninsular Malaysia: gading-gading, kahwah hutan, uloh-uloh. Thailand: yamkhwai (peninsular).

Distribution *Diplospora* comprises some 20 species. *D. kunstleri* is endemic to Peninsular Malaysia. *D. malaccensis* occurs in peninsular Thailand, Peninsular Malaysia, Sumatra and Borneo.

Uses A hot decoction of the leaves of both species used to be drunk in Peninsular Malaysia as a substitute for coffee. The wood of *D. malaccensis* has proved suitable for use in 'guillotine machines' (probably some cutting device), where it lasted three times as long as 'chengal' (*Neobalanocarpus heimii* (King) P. Ashton).

Observations Leaves opposite, entire, coriaceous; stipules triangular. Flowers bisexual or male, small, in short axillary cymes or fascicles, 4-merous; calyx with short tube and triangular lobes; corolla trumpet-shaped, whitish, lobes contorted to the left in bud; disk annular; stamens 4, inserted on the corolla throat, exserted; ovary inferior, 2-locular with 1–3(–6) ovaries in each cell, stigma 2-lobed. Fruit a small, globose or ellipsoid berry, turning orange and red when mature. Seed not embedded in the placenta, angular, hemispherical, spherical or flattened.

- *D. kunstleri*: shrub or small tree up to 4 m tall; leaves oblanceolate or oblong, 15–18 cm × 4.5–6.5 cm, shortly acuminate, with 8–10 pairs of secondary veins; corolla with about 3 mm long tube and very short lobes; fruit ovoid, about 10 mm long.
- *D. malaccensis*: small to medium-sized tree up to 18 m tall with fairly straight bole and smooth to cracked or flaky, white to yellowish-brown, grey or black bark; leaves elliptical, 4–15 cm × 1–6.5 cm, shortly acuminate or acute, with 4–6(–7) pairs of secondary veins; corolla with about 2.5 mm long tube and c. 1.5 mm long lobes; fruit globose, about 17 mm in diameter.

The wood of *D. malaccensis* is apparently very hard. Heartwood pale yellow-brown with a slight pink tinge, not distinct from the sapwood; grain straight; texture fine and even. Growth rings visible to the naked eye; vessels very small to moderately small, mostly solitary but with some radial pairs; parenchyma moderately abundant, apotracheal diffuse, paratracheal confluent; rays very fine, 1–2-seriate; ripple marks absent. The wood does not develop surface checks when carefully seasoned. The genera *Diplospora* and *Discospermum* Dalz. are closely related, but the latter can be distinguished by its larger, drier fruits and the frequently well-developed placental outgrowths around the seeds. *D. malaccensis* most probably does not belong to *Diplospora*, but rather to a genus of the tribe *Hypobathreae*; its proper generic position remains to be determined. *D. kunstleri* is found in montane forest at 1100–1400 m altitude. *D. malaccensis* occurs in lowland and montane forest up to 1500 m altitude.

Selected sources 5, 15, 23, 28, 55, 75.

Discospermum singulare (Korth.) O. Kuntze

RUBIACEAE

Synonyms *Diplospora singularis* Korth., *Discospermum abnorme* (Korth.) Ali & Robbrecht, *Tricalysia singularis* (Korth.) K. Schumann.

Vernacular names Indonesia: kayu begas (Palembang), kayu gading (Bangka), sungkai alas (Kubu). Thailand: dongsian, makhua-pho, sian (northern). Vietnam: ta d[er], song t[uwr] d[ij] di[eej]p.

Distribution From India and the Himalayas to Indo-China, Thailand, Sumatra, Bangka and Borneo.

Uses A hot decoction of the roasted leaves has been drunk by people in Kubu (Sumatra) as a substitute for coffee. This drink is known as 'kopi Kubu'.

Observations A small tree, up to 18 m tall; bole straight; bark fissured, greyish. Leaves opposite; stipules triangular acuminate; petiole 1–1.5 cm long; blade elliptical, 12–18 cm × 4–6.5 cm, coriaceous, rounded at base, obtuse at apex. Flowers small, in short axillary cymes or fascicles, pale green, 4-merous; calyx with a short tube; corolla trumpet-shaped; disk annular; stamens 4, inserted on the corolla throat; ovary inferior, 2-locular with 7–8 ovules in each cell, stigma 2-lobed. Fruit a globose berry, about 2 cm in diameter, purplish-black, on a stalk 10–15 mm long. Seeds embedded in the placentae, imbricate, flattened, about 6 mm 5 mm; testa areolate. *D. singulare* grows in lowland rain forest. In Indo-China it bears fruits in February. *Discospermum javanicum* (Miquel) O. Kuntze has sometimes been incorrectly treated as a synonym of *D. singulare*, from which it is distinguished by its much smaller ellipsoid fruits with few seeds in each locule.

Selected sources 5, 15, 28, 30.

Ficus ribes Reinw. ex Blume

MORACEAE

Synonyms *Ficus merrillii* Elmer, *F. serraria* Miquel, *F. staphylosyce* Ridley.

Vernacular names Indonesia: walen (Sundanese), kopeng (Javanese), ampere (Madurese). Malaysia: ara lumut (Peninsular). Papua New Guinea: pikus. Philippines: tabog, tibig (Tagalog).

Distribution Peninsular Malaysia, Sumatra, Java, Sulawesi and the Philippines.

Uses In Indonesia the bark and leaves used to be chewed with areca nuts (the endosperm of *Areca catechu* L.) as a substitute for gambier (*Uncaria gambir* (Hunter) Roxb.). An extract from the bark, locally called 'gambir utan', used to be applied against malaria, but proved to be ineffective.

Observations A small tree up to 15 m tall; bole up to 30 cm in diameter; outer bark reddish-brown; latex white. Twigs, petioles, lower side of veins, and figs with fine white-brown hairs. Leaves usually subdistichous, occasionally opposite; petiole 2–14 mm long; blade narrowly elliptical to lanceolate or lanceolate-obovate, often asymmetrical, 8–17 cm × 1.5–5 cm (larger in saplings), base cuneate, margin entire to obscurely denticulate, apex acute to acuminate, glabrous to appressed hairy above. Figs mainly on stem and thicker branches, on short leafless twigs set on woody burrs, or becoming panicled racemose in large clusters, or elongated into geocarpic stolons up to 4 m long, with 3 basal bracts, depressed globose to subellipsoid, 7–12(–15) mm wide, ripening yellow-brown; male flowers in 1–2 rings, with 1 stamen; gall flowers with the perianth covering the red ovary; female flowers sessile or short-stalked, covering up to half of the red-brown ovary. Seed 0.7–0.8 mm long. *F. ribes* has been subdivided into 3 varieties, mainly based on the indumentum and shape of the leaves. It occurs in lowland and montane forest, up to 2400 m altitude. In Java it is fertile throughout the year.

Selected sources 6, 15, 20, 30, 75.

Fraxinus griffithii C.B. Clarke

OLEACEAE

Synonyms *Fraxinus eedenii* Boerl. & Koord., *F. philippensis* Merrill, *F. formosana* Hayata.

Vernacular names Formosan ash, Griffith's ash, Philippine ash (En). Indonesia: bedali-gombong, selaton (Javanese), kayu-candu (Madurese). Philippines: asaas, lagili, lagilid (Tagalog).

Distribution Himalaya and north-eastern India, China (Hupai), the Ryukyu Islands, Taiwan, the Philippines (Luzon), Central Sulawesi, East Java and the Lesser Sunda Islands (Flores and Bali).

Uses Leaves of *F. griffithii* used to be used as an opium substitute in Pancur (Besuki, East Java) before 1900; the Madurese name means 'opium tree'. The leaves were dried, crushed and mixed with tobacco to make cigars wrapped in maize bracts ('klobots'). Although smoking these leaves produced the same smell and taste as second grade opium, it did not have the same effect and it did not lessen opium addiction. The wood is used for carving in Luzon, whereas the bark is taken as a laxative in Flores. In Java it can be found as a shade tree in coffee and sometimes as a wayside tree.

Observations Tree, up to 50 m tall, bole up to 90 cm in diameter. Leaves opposite, petiolate, blade imparipinnate, 6–25 cm long, with 2–5(–9) pairs of lanceolate to elliptic-oblong, subcoriaceous, entire leaflets, each 2–14 cm × 1–5 cm. Inflorescence a spreading, many-flowered, terminal and axillary panicle 8–25 cm long; corolla white, divided to the base into 4 narrowly oblong lobes of 2–3 mm 1 mm, recurved at anthesis; stamens 2; ovary superior, ovoid, 2-locular with 2 ovules in each cell, style 1 mm long, stigma 2-lobed. Fruit a samara with a unilateral wing, linear-oblong with a retuse apex, 19–35 mm × 4–6 mm. Seed 1, ovoid-cylindrical with flat cotyledons and fleshy endosperm. Seedling with epigeal germination. In Taiwan *F. griffithii* is recorded as being semi-deciduous; its leafing habit is not recorded for the Malesian region. In Java it has two flowering seasons, one from November to February and a shorter one in April, followed by prolific fruiting in February to July and again in September, respectively. *F. griffithii* penetrates from the subtropics into the tropical zone in areas with a monsoon climate, where it is frequently a pioneer on old lava flows (East Java, the Philippines) or in open rain forest or in *Casuarina junghuhniana* forest. In the Lesser Sunda Islands it grows almost at sea-level, but in Java it is more common at 1100–1700 m altitude. The bark and leaves of *F. griffithii* contain tannin, which causes the bitter taste, and a sweet juice composed mainly of mannitol and found also in the European relative *F. ornus* L. The bark also contains the glucosides ligstrocide, syringin and sinapaldehyde glucoside, but no fraxin or fraxin-like coumarins. The presence of alkaloids has not been demonstrated. The wood is not durable. *F. griffithii* is presumably grown from seed. Although *F. griffithii* is a pioneer species, it does not appear to be common or dominant anywhere in South-East Asia. Because it grows in unstable vegetation types in Malesia, it is likely to be at risk from fire or changing land use.

Selected sources 6, 12, 13, 30, 64, 65.

Garcinia amboinensis Spreng.

GUTTIFERAE

Vernacular names Indonesia: kayu asam besar (Indonesian, Ambon), ai lau asin (Ambon), mayurat (Ternate).

Distribution Indonesia (Moluccas).

Uses Split pieces of the roots, known locally as 'obat saguer', are used to give a more bitter and astringent taste to palm wine. This practice also seems to extend the keeping quality of the wine. The sour leaves can be eaten as a vegetable, for example with fish.

Observations A small tree with stilt roots and a monopodial crown; bark grey; latex yellowish. Leaves opposite, exstipulate; petiole canaliculate; blade ovate-lanceolate, 18–20 cm × 7.5–10 cm, obtuse to emarginate at apex, glabrous, secondary veins many, parallel. Male flowers in umbels; anthers in 4 groups; female flowers axillary; sepals 4, persistent, lanceolate; petals 4, broader than the sepals; ovary superior, many-loculed with 1 ovule per cell, stigma sessile, lobed. Fruit a globose or pear-shaped berry. Seed oblong, compressed. *G. amboinensis* is found in lowland and montane forest.

Selected sources 30, 53, 61.

Garcinia picrorhiza Miquel

GUTTIFERAE

Vernacular names Indonesia: obat sageru lemon, sesoot (Ambon).

Distribution Indonesia (Moluccas, Irian Jaya), Papua New Guinea.

Uses Split pieces of the roots, known locally as 'obat saguer', are used give a more bitter and astringent taste to palm wine. This practice also seems to extend the keeping quality of the wine. The wood is fine, hard and durable; stems have been used locally for house posts.

Observations A large tree with yellowish latex and terete young twigs. Leaves opposite, without stipules; blade oblong to elliptical-oblong or lanceolate, 11–12 cm × 3–3.5 cm, obtuse at apex, with about 60 parallel secondary veins. Female flowers in an axillary raceme of cymes, 5–7 per axil, 4-merous; pedicel 3–4 mm long; sepals orbicular, about 2 mm long; stamens in fascicles; ovary superior, 2-locular with 1 ovule per cell, stigma short, discoid, entire. Fruit a cylindrical berry, 15 mm × 8 mm, 1–2-seeded. *G. picrorhiza* is found in montane forest. *G. picrorhiza* may have been misidentified in the past; reports on its use may actually refer to *G. sizygiifolia* Pierre.

Selected sources 30, 40, 53, 61.

Iguanura geonomiformis (Griffith) Mart.

PALMAE

Synonyms *Iguanura malaccensis* Becc., *I. wallichiana* (Wallich ex Mart.) Hook.f. subsp. *malaccensis* (Becc.) Kiew var. *malaccensis*, *I. wallichiana* (Wallich ex Mart.) Hook.f. subsp. *malaccensis* (Becc.) Kiew var. *elatior* Kiew.

Vernacular names Malaysia: pinang burong, pinang kelasak, pinang tikus (Peninsular). Thailand: pinaeduekong, pinaebong (Malay, peninsular).

Distribution Thailand (peninsular), Peninsular Malaysia, Singapore and Borneo (Sarawak).

Uses The seeds are used as an inferior substitute for those of areca palm (*Areca catechu* L.). The cabbage is edible. The roots and leaves have been taken by women as a contraceptive.

Observations A small, usually clustered pleonanthic, monoecious palm up to 5 m tall; stem up to 2(–3) cm thick. Leaves steeply ascending, entire to lobed or pinnate with up to 20 segment pairs, not abscissing; sheath fibrous; blade (35–)50–85 (–100) cm × (10–)20–30(–40) cm, that of simple leaves smaller. Inflorescence interfoliar, spicate, about 20–90 cm long, sometimes forking into 2–7 branches, protandrous, bearing spirally arranged triads of 2 male and 1 female flowers that are sunken in the rachilla; peduncle 20–50 cm long; flowers sessile, with 3 sepals and 3 petals, all imbricate; male flower 2–2.5 mm long, with 6 stamens; female flower about 3 mm long, petals cream and fleshy, ovary 1-locular with a single ovule, stigmas 3, sessile, projecting beyond the petals. Fruit an ellipsoid drupe, about 1 cm × 0.8 cm, white maturing red. Seed with ruminate endosperm. *I. geonomiformis* is restricted to undergrowth of rain forest along streams, pools and other damp sites, up to 1200 m altitude, and is tolerant of waterlogging.

Selected sources 15, 35, 36, 42, 59, 68.

Licuala pumila Blume

PALMAE

Synonyms *Licuala elegans* Blume.

Vernacular names Indonesia: seredik itam

(Lampung), sadang upul (Palembang), wiru leutik (Sundanese).

Distribution Indonesia (Sumatra, western Java).

Uses The young unfolded leaves used to be used to wrap cigarettes. For this, the young shoots were carefully opened, left hanging up outdoors for 2 nights and then smoothed out. Fine strips of the young leaves were also sometimes mixed with opium, probably to add bulk, but perhaps also to improve combustion. Older leaves are used for thatching roofs and to make hats.

Observations A pleonanthic, small, usually multi-stemmed palm; stems up to 120 cm tall and 15 cm in diameter. Leaves palmate; sheath fibrous; petiole variably spiny in the lower half, usually longer than the blade; blade forming 2/3 of a circle, deeply incised into 8–12(–22), 2–3(–5)-veined segments, larger segments 25–35 cm long. Inflorescence interfoliar, simply branched, spiciform, 40–50 cm long; peduncle with a tubular prophyll and several tubular peduncular bracts; flowers bisexual, sessile; calyx connate, 3-fid, glabrous; corolla deeply 3-fid, slightly longer than the calyx, 4.5–5 mm long; stamens 6, filaments connate to form a 6-lobed tube; pistil 3-carpellate, glabrous, united distally to form a single exserted style. Fruit a globose to broadly ellipsoid drupe, 9–10 mm long, with the remains of the style at the apex. *L. pumila* is found along river banks and in ravines, up to 250 m altitude. It is categorized as a rare species.

Selected sources 6, 30, 48, 68.

Licuala rumphii Blume

PALMAE

Vernacular names Indonesia: koal (Buru), leko wala (Macassarese).

Distribution Indonesia (Sulawesi, Moluccas; probably cultivated in Java).

Uses The young leaves used to be used to wrap cigarettes, for which purpose bundles of leaf segments were soaked in hot water, bleached in the sun, and pounded and smoothed out on a heated pot until they became white. Fine strips of the young leaves were sometimes mixed with opium, probably because of their odour. The broadest central segments are used to wrap fruits and other food.

Observations A pleonanthic, small, usually multi-stemmed palm up to 4 m tall. Leaves palmate; sheath fibrous; blade forming a 3/4 to entire circle, incised almost to the base into 12–15, 4–7-veined, narrowly cuneate segments with emarginate apex, larger segments up to 100 cm × 7–12 cm. Inflorescence interfoliar; lateral axes few, bearing 3–4 digitately arranged thick spikes 12–15 cm long; peduncle with a tubular prophyll and several tubular peduncular bracts; flowers bisexual, sessile; calyx connate, 3-fid, glabrous; corolla deeply 3-fid, 1.5 times as long as the calyx, with distinct grooves and ridges inside; stamens 6, filaments connate to form a 3-lobed tube, each lobe with a bifid apex; pistil 3-carpellate, glabrous, united distally to form a single exserted style. Fruit a glossy red drupe with the remains of the style at the apex.

Selected sources 6, 30, 68, 71.

Microcos paniculata L.

TILIACEAE

Synonyms *Grewia glabra* Jack, *G. microcos* L., *G. ulmifolia* Roxb.

Vernacular names Thailand: kaphla (peninsular), khom (northern), lai (central). Vietnam: bung lai, m[es].

Distribution From Sri Lanka and India to Indo-China, southern China and Thailand. Reports from Peninsular Malaysia and Indonesia (Java and the Lesser Sunda Islands) are questionable, because of the complicated taxonomy.

Uses The leaves are considered eminently suitable for wrapping cigars, e.g. in the Andaman Islands. The light to medium-weight hardwood is used for cabinet work. Rope can be manufactured from the fibrous bark. The fruits are edible. In India *M. paniculata* is reputed to cure indigestion, eczema, itches, typhoid fever, dysentery and syphilitic ulceration of the mouth. In southern China an infusion of the leaves is taken for indigestion and as a cooling drink. In Indo-China a drink prepared from the roasted and boiled leaves is given to children as a vermifuge. Loppings can be used as green manure.

Observations A small to medium-sized, deciduous shrub or tree up to 20 m tall; bole up to 50 cm in diameter; bark dark brown to blackish. Indumentum of stellate and simple hairs. Leaves distichous; petiole 0.5–1 cm long; blade elliptical to oblong, 8–17 cm × 4–8 cm, margin undulate to entire, apex acute, glabrous, tertiary venation scalariform and distinct below. Flowers in terminal and axillary cymes arranged paniculately, 5-merous, pale yellow; sepals free, obovate, about 4 mm long; petals free, glabrous, about half the size of the sepals; stamens many, with dorsifixed anthers; ovary superior, 2–4-locular, glabrous, style subulate. Fruit a globose to obovate drupe, about 1.5 cm × 1 cm, purplish, glabrous, with leathery pericarp. *M. paniculata* is found in mixed deciduous and dry evergreen forest, often along streams, up to 1000 m altitude. In Thailand it flowers and fruits in April-June. Some authors consider *M. tomentosa* Smith (synonym: *Grewia paniculata* Roxb. ex DC.) as a synonym of *M. paniculata*, which sometimes causes confusion in literature.

Selected sources 15, 28, 49, 50, 60, 61, 66.

Piper argyrites Ridley ex C. DC.

PIPERACEAE

Synonyms *Piper nigrantherum* C. DC.

Vernacular names Peninsular Malaysia: sirih rimau puteh.

Distribution Peninsular Malaysia.

Uses The bark, peeled off in strips, has traditionally been used as a substitute for the leaf of *Piper betle* L.

Observations A stout dioecious climber. Leaves arranged spirally, glabrous; petiole sheathing for half its length; blade oblong-ovate, up to 18 cm × 6 cm, with 7 palmate veins, base rounded, slightly unequal, apex acuminate, light green with pale or white spots when young. Flowers sessile in solitary spikes about 8 cm long; bracts obovate, up to 1.5 mm long; rachis hairy; male flower with 2 stamens with kidney-shaped anthers; female plants unknown. *P. argyrites* is found in open vegetation at low altitude.

Selected sources 15, 22, 55.

Piper bantamense Blume

PIPERACEAE

Synonyms *Piper attenuatum* auct., non Miquel.

Vernacular names Indonesia: cabe utan bebau (Ambon), bleng, oyod tepel (Javanese).

Distribution Indonesia (Kalimantan, Java, the Lesser Sunda Islands and the Moluccas).

Uses Potable water runs from the stem when cut. Clothes are soaked in an infusion of the crushed, dried bark to give them a pleasant scent. A poultice of the bark, mixed with ginger, clove and nutmeg can be applied to muscles of arms and legs that are cramped due to cold. Fresh leaves, mixed with some water, have been used to relieve headache.

Observations A dioecious, woody climber up to 15 m long. Leaves arranged spirally; petiole 1–5 cm long; blade oblong-elliptical to ovate-elliptical, 6–14 cm × 2.5–8 cm, base cordate to cuneate, apex acutely acuminate, palmately veined, glabrous or sparsely hairy below. Flowers in solitary spikes 5–20 cm long (up to 26 cm long in fruit); rachis of male spike glabrous, with bracts 1.5–3 mm long; rachis of female spike hairy with bracts 3–4 mm long; male flower with (2–)3(–4) stamens; female flower with 3–4 stigmas. Fruit a broadly ellipsoid to almost globose berry, 4–5 mm long. *P. bantamense* is found in forest and thickets, up to 350 m altitude. Because of a lack of reliable taxonomic information, there is some doubt whether the information given under 'Uses' does indeed refer to *P. bantamense*.

Selected sources 6, 30.

Piper caducibracteum C. DC.

PIPERACEAE

Vernacular names Indonesia: amelaun albar (Ambon), sirih kandati, sirih utan (Moluccas).

Distribution Indonesia (Moluccas).

Uses The fresh or dried bark, the petioles and the young leaves can be used as a substitute for the leaf of *Piper betle* L.

Observations A dioecious, woody, straggling shrub with glabrous stems about 2 cm thick. Leaves arranged spirally; petiole up to 1 cm long, sheathing at base; blade ovate-elliptical, up to 18 cm × 8 cm, palmately 5–9-veined, base slightly unequal, apex acutely acuminate. Flowers sessile in solitary spikes up to 4.5 cm long; peduncle as long as or slightly longer than the petiole; rachis of male and female spikes hirsute, with peltate, deciduous bracts about 1 mm long; male flower with 2 stamens. Fruit a berry, obovoid, about 1.5 mm long, glabrous, dark brown to black. *P. caducibracteum* is locally common, straggling over other shrubs.

Selected sources 30, 45.

Piper siriboa L.

PIPERACEAE

Synonyms *Chavica siriboa* (L.) Miquel, *Piper betle* L. var. *siriboa* (L.) C. DC.

Vernacular names Indonesia: amu malaka (Seram), bido (Halmahera), kau (Leti). Probably also often the same names as for betel pepper (*Piper betle* L.).

Distribution Supposedly a native of Indonesia (Sunda Islands) but probably a species raised in cultivation and nowhere wild.

Uses The fruiting spikes and young leaves are used like betel pepper leaves for chewing. The spikes have to be plucked before they are fully ripe.

Observations A tall dioecious climber with thickened nodes, puberulous when young. Leaves alternate; petiole 2–5.5 cm long; blade ovate, 12–16 cm × 8–12 cm, cordate at base, short-acuminate at apex, with 3 pairs of arcuate veins from the base and one pair from the midrib 1–3 cm above the base, dark green, on drying turning darker than betel pepper. Inflorescence a pendulous spike, opposite a leaf; peduncle 3–7 cm long; spike 8–10 cm long, enlarging to 17 cm × 7 mm in fruit; flowers unisexual. Fruit a berry, concrescent into the fleshy spike. Sometimes *P. siriboa* is considered synonymous with *Piper betle* L.

Selected sources 30, 31.

Pterospermum semisagittatum Buch.-Ham. ex Roxb.

STERCULIACEAE

Vernacular names Cambodia: priĕl praĕhs. Laos: ham 'a:w, ham fa:n. Thailand: hamkhua (northern), kranuan (north-eastern), hamrok (peninsular). Vietnam: l[of]ng mang m[as]c, v[or] m[uw][ow]ng.

Distribution From India and Sri Lanka to Cambodia, Laos and Thailand.

Uses In Vietnam, Cambodia and Laos the bark is used as a masticatory as a substitute for areca nuts (the endosperm of *Areca catechu* L.). The wood is used for axe handles and as fuelwood.

Observations A small to medium-sized tree up to 25 m tall; bole up to 12 m; bark reddish. Leaves alternate, almost distichous, simple; stipules laciniate, about 2 cm long; petiole thick, about 3 mm long; blade lanceolate, 17–20 cm × 4–6 cm, base strongly sagittate, margin entire, apex long acuminate, lower surface woolly. Flowers few together in a leaf axil with laciniate bracts about 1.5 cm long; pedicel 0.5–1 cm long; involucral bracts 3, deeply 5-lobed, 2.0–4.5 cm long; calyx cylindrical, 4–8 cm long, with 5 narrow sepals; petals 5, oblanceolate, c. 5.5 cm × 2.0 cm, white; stamens in 5 bundles of 3, staminodes 5; ovary superior, 5-locular with many ovules in each cell, tomentose, style hairy at base. Fruit a tubular, fusiform to ovoid, woody capsule, up to 8 cm × 6 cm, with persistent calyx. Seed flattened, 4 cm long including the 3 cm long wing on one side. The wood is fairly hard, durable, 640–800 kg/m^3 at 15% moisture content, reddish-grey. *P. semisagittatum* is found in primary and secondary, evergreen forest at 100–900 m altitude. In Thailand it flowers in April–June and fruits in May–September.

Selected sources 15, 28, 51, 61, 66.

Sarcandra glabra (Thunb.) Nakai subsp. brachystachys (Blume) Verdc.

CHLORANTHACEAE

Synonyms *Bladhia glabra* Thunb., *Chloranthus brachystachys* Blume, *Sarcandra hainanensis* (Pei) Swamy & Bailey.

Vernacular names Indonesia: atukan (Javanese), kayu duri-duri (Sumatra), lawi-nata (Flores). Philippines: apot, damoko (Igorot), kari-kari (Bagobo). Vietnam: s[os]i l[as]ng, s[os]i r[uwf]ng.

Distribution North-eastern India, Burma (Myanmar), northern Vietnam, southern China, Thailand and throughout the Malesian region.

Uses The uses of *S. glabra* subsp. *brachystachys* seem similar to those of *Chloranthus erectus* (Buch.-Ham.) Verdc. The roots are used to prepare or flavour tea, but less frequently because the species is much rarer. In the Philippines an infusion is used to treat headache. In China it is occasionally planted for ornamental purposes.

Observations A glabrous shrub or woody herb up to 3 m tall; stem with thickened nodes. Leaves decussate; stipules linear, 1.5 mm long; petiole up to 1.5 cm long; blade elliptical-oblanceolate to lanceolate, 2–20 cm × 1–8 cm, cuneate at base, margin sharply serrate or serrate-dentate, apex long acuminate. Inflorescence a terminal raceme, consisting of opposite spikes each up to 5 cm long with up to 13 flowers; flowers bisexual, without a perianth; the male part reduced to a club-shaped organ with 2 thecae implanted upon the ovary; ovary flask-shaped to subglobose, 1-locular with a single ovule, stigma sessile. Fruit a red or bright orange or rarely black drupe, 9–15 mm × 7–10 mm. *S. glabra* subsp. *brachystachys* is found in evergreen, primary and secondary forest on podzolic soils, shingle banks, eroded limestone and shale slopes, at 100–2550 m altitude. It differs from subsp. *glabra*, which occurs in continental East Asia from India (and Sri Lanka) to Japan, by the thecae being about as long as the whole male structure; in subsp. *glabra* the thecae are much shorter and the non-antheriferous part well-developed. Black-fruited forms from Sumatra have been distinguished as var. *melanocarpa* (Ridley) Verdc. Within Malesia it has been observed flowering in February and April–June. The wood is vesselless and contains guaiacyl lignin, normally found only in gymnospermous wood.

Selected sources 15, 16, 26, 30, 49, 54, 57.

Solanum inaequilaterale Merrill

SOLANACEAE

Distribution The Philippines (Luzon, Mindanao).

Uses The leaves used to be smoked by the Moro-Subanuns.

Observations An unarmed, more or less stellately pubescent shrub up to 3 m tall. Leaves alternate; petiole 2–3 cm long; blade oblong-ovate, unequally sided, subentire to undulate, base obtuse to cuneate, apex acute or acuminate, pubescent below. Flowers in an extra-axillary cyme on a peduncle up to 5 cm long; calyx truncate or obscurely 5-toothed, about 4 mm long; corolla pale purple, tube 2 mm long, lobes 5, oblong to oblong-lanceolate, acute, about 9 mm × 3 mm; stamens 5, anthers adnate; ovary superior, 2-locular, style about 6 mm long. Fruit a globose berry, about 7 mm in diameter, glabrous, shiny. Seed 2–2.5 mm in diameter. *S. inaequilaterale* is found in thickets, chiefly in or near the moss forest, at 1300–2400 m altitude. It may prove to represent just an unarmed form of the closely related *S. torvum* Swartz.

Selected sources 14, 44, 46, 47.

Uncaria homomalla Miquel

RUBIACEAE

Synonyms *Uncaria parviflora* (Ridley) Ridley, *U. quadrangularis* Geddes, *U. tonkinensis* Havil.

Vernacular names Cambodia: sângchoë, voë sângchoë. Thailand: khaokhwaimaiwong, khaokhwaimailup (northern), ngop (south-western). Vietnam: d[aa]y cau m[uws]c, d[aa]y c[aa]u d[awf]ng, d[aa]y d[aws]ng qu[es]o.

Distribution From north-eastern India to Indo-China, southern China, Peninsular Malaysia and Sumatra.

Uses In Indo-China the bark is chewed as a masticatory, as a substitute for areca nuts (endosperm of *Areca catechu* L.). It is also applied as a febrifuge. A gum similar to that of gambier (*Uncaria gambir* (Hunter) Roxb.), which is mainly used for tanning purposes, can be obtained from the bark by careful extraction. In Vietnam the leaves used to be used as a substitute for tea.

Observations A large, woody liana up to 25 m long, climbing with hooks; young branches 4-angular, pubescent. Leaves opposite; stipules linear, distinctly bifid, pubescent, with colleters inside; petiole short; blade elliptical-lanceolate to elliptical, 6–10 cm × 2.5–3.5 cm, rounded at base, long acuminate to caudate at apex, hairy on both sides, with domatia in the axils of secondary veins below. Inflorescence a terminal, globose head, 1–2 cm in diameter; receptacle hairy, with interfloral bracteoles; flowers sessile, 5-merous; calyx with a short tube and short lobes, silky; corolla salver-shaped, green to yellow, tube 5–7.5 mm long, pubescent outside, lobes short; stamens inserted on the corolla throat, filaments very short; ovary inferior, 2-locular, each locule with a thick black placenta and many ovules, style exserted, with a club-shaped stigma. Fruit a dry capsule, splitting loculicidally but remaining intact below the calyx remnants, about 4 mm × 2 mm. Seed with a long wing at both ends, lower wing deeply bifid. *U. homomalla* occurs in thickets, along rivers, at low altitudes. Two types of alkaloids have been extracted from the leaves: pentacyclic oxindoles and pyridino-indolo-quinolizidinones. The latter type is rather rare within *Uncaria* and is also found in *Strychnos angustiflora* Benth. and *Mitragyna parvifolia* (Roxb.) Korth.

Selected sources 15, 28, 50, 52, 55, 56, 59.

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M.S.M. Sosef,
with contributions from:
N.O. Aguilar (*Astilbe philippinensis, Solanum inaequilaterale*)
S. Brotonegoro (*Calyptrocalyx spicatus, Garcinia amboinensis, Garcinia pricrorhiza*)
P.C.M. Jansen (*Piper siriboa*)
R. Kiew (*Fraxinus griffithii*)
Lean Teik Ng & B. Na Songkhla (*Acalypha siamensis*)
Rina R.P. Irwanto, (*Diplospora, Discospermum singulare*)
F.M. Setyowati (*Licuala pumila, Licuala rumphii*)

4 Stimulant plants with other primary use

List of species in other commodity groups (parenthesis), which are used also as a stimulant or in association with stimulants. Synonyms in the indented lines.

Abelmoschus esculentus (L.) Moench (vegetables)
    Hibiscus esculentus L.
Acacia catechu (L.f.) Willd. (dye and tannin-producing plants/timber trees)
    Acacia chundra Willd.
Acacia farnesiana (L.) Willd. (essential-oil plants)
    Acacia smallii Isely
    Mimosa farnesiana L.
    Vachellia farnesiana (L.) Wight & Arnott
Acacia leucophloea (Roxb.) Willd. (dye and tannin-producing plants/timber trees)
    Acacia melanochaetes Zoll.
    Delaportea ferox Gagnep.
    Delaportea microphylla Gagnep.
Acacia nilotica (L.) Willd. ex Del. (dye and tannin-producing plants)
    Acacia arabica (Lamk) Willd.
Acanthus ilicifolius L. (medicinal and poisonous plants)
    Acanthus volubilis Wallich
Achillea millefolium L. (medicinal and poisonous plants)
Acorus calamus L. (medicinal and poisonous plants)
    Acorus asiaticus Nakai
    Acorus terrestris Spreng.
Actinorhytis calapparia (Blume) H.A. Wendland & Drude ex Scheffer (medicinal and poisonous plants)
Allium fistulosum L. (medicinal and poisonous plants)
    Allium bakeri Hoop. non Regel
    Allium bouddhae O. Debeaux
Alpinia galanga (L.) Willd. (spices)
    Amomum galanga (L.) Loureiro
    Languas galanga (L.) Stuntz
    Languas vulgare Koenig
    Maranta galanga L.
Ampelocissus cinnamomea (Wallich) Planchon (medicinal and poisonous plants)
    Vitis cinnamomea Wallich
Andira inermis (W. Wright) DC. (auxiliary plants)
    Andira excelsa Kunth.
    Andira jamaicensis (W. Wright) Urban
Anethum graveolens L. (spices)
    Anethum sowa Roxb. ex Fleming
    Peucedanum graveolens (L.) Hiern
    Peucedanum sowa (Roxb. ex Fleming) Kurz
Areca ipot Becc. (ornamental plants)

Arenga pinnata (Wurmb) Merrill (plants yielding non-seed carbohydrates)
Arenga saccharifera Labill.
Artemisia absinthium L. (medicinal and poisonous plants)
Artemisia dracunculus L. (spices)
Artemisia inodora Willd.
Artemisia redowskyi Ledeb.
Oligosporus condimentarius Cass.
Artemisia maritima L. (medicinal and poisonous plants)
Artocarpus fretessii Teijsm. & Binnend. (timber trees)
Artocarpus dasyphyllus Miquel
Artocarpus leytensis Elmer
Artocarpus paloensis Elmer
Artocarpus gomezianus Wallich ex Trécul (timber trees)
Artocarpus masticatus Gagnep.
Artocarpus petiolaris Miquel
Artocarpus pomiformis Teijsm. & Binnend.
Artocarpus horridus Jarrett (timber trees)
Artocarpus communis J.R. Forster & J.G. Forster var. *pungens* J.J. Smith ex K. Heyne
Artocarpus lakoocha Roxb. (timber trees)
Artocarpus nitidus Trécul subsp. *lingnanensis* (Merrill) (edible fruits and nuts/timber trees)
Artocarpus lingnanensis Merrill
Artocarpus parva Gagnep.
Artocarpus sampor Gagnep.
Asparagus racemosus Willd. (plants yielding non-seed carbohydrates)
Asparagopsis javanica Kunth
Asparagopsis schoberioides Kunth
Asparagus dubius Decaisne
Baeckea frutescens L. (medicinal and poisonous plants)
Bidens bipinnata L. (medicinal and poisonous plants)
Bidens pilosa L. var. *bipinnata* (L.) J.D. Hooker
Bidens pilosa L. (medicinal and poisonous plants)
Bidens leucorrhiza (Loureiro) DC.
Bidens pilosa L. var. *minor* (Blume) Sherff
Bidens sundaica Blume
Blumea balsamifera (L.) DC. (essential-oil plants/medicinal and poisonous plants)
Baccharis salvia Loureiro
Blumea appendiculata (Blume) DC.
Blumea grandis (Wallich) DC.
Blumea zollingeriana C.B. Clarke
Conyza appendiculata Blume
Conyza balsamifera L.
Blumea lacera (Burm.f.) DC. (medicinal and poisonous plants)
Blumea bodinieri Vaniot
Blumea runcinata DC.
Blumea thyrsoidea Sch. Bip.
Borago officinalis L. (spices)

Brackenridgea hookeri (Planch.) A. Gray (timber trees)
Brackenridgea denticulata Furtado
Brackenridgea perakensis v. Tiegh.
Ouratea hookeri (Planch.) Burkill
Brassica nigra (L.) W.D.J. Koch (spices)
Brassica sinapoides Roth
Sinapis nigra L.
Sisymbrum nigrum (L.) Prantl
Bruguiera gymnorhiza (L.) Savigny (dye and tannin-producing plants/timber trees)
Bruguiera conjugata Merrill
Bruguiera cylindrica Hance (non Blume)
Bruguiera rheeddii Blume
Bruguiera sexangula (Loureiro) Poiret (auxiliary plants)
Bruguiera eriopetala Wight & Arnott ex Arnott
Rhizophora sexangula Loureiro
Calamus longispathus Ridley (rattans)
Callicarpa arborea Roxb. (timber trees)
Callicarpa magna Schauer
Callicarpa tomentosa auct., non (L.) Murray
Calycopteris floribunda (Roxb.) Lamk (medicinal and poisonous plants)
Camellia japonica L. (ornamental plants)
Canavalia ensiformis (L.) DC. (forages)
Canavalia gladiata (Jacq.) DC. var. *ensiformis* (L.) Benth.
Dolichos ensiformis L.
Cannabis sativa L. (medicinal and poisonous plants)
Canthium horridum Blume (ornamental plants)
Plectronia horrida Schumann
Carmona retusa (Vahl) Masam. (medicinal and poisonous plants)
Carmona microphylla (Lamk) G. Don
Ehretia buxifolia Roxb.
Ehretia microphylla Lamk
Caryota cumingii Loddiges ex Martius (plants yielding non-seed carbohydrates)
Caryota merrillii Beccari
Caryota mitis Loureiro (plants yielding non-seed carbohydrates)
Cassia auriculata L. (dye and tannin-producing plants)
Cassia densistipulata Taubert
Cassia fistula L. (medicinal and poisonous plants)
Cayratia mollissima (Wallich) Gagnepain (medicinal and poisonous plants)
Vitis mollissima Wallich
Cayratia novemfolia (Wallich) Burkill (medicinal and poisonous plants)
Vitis novemfolia Wallich
Chamaecrista lechenaultiana (DC.) Degener (auxiliary plants)
Cassia lechenaultiana DC.
Cassia mimosoides L. subsp. *lechenaultiana* (DC.) Ohashi
Chrysanthemum coronarium L. (vegetables)
Chrysanthemum spatiosum L.H. Bailey
Matricaria coronaria (L.) Desr.
Pinardia coronaria Lessing

Cichorium intybus L. (vegetables)
Cinnamomum iners Reinw. ex Blume (timber trees)
  Cinnamomum eucalyptoides T. Nees
  Cinnamomum nitidum Blume
  Cinnamomum paraneuron Miquel
Cinnamomum mollissimum J.D. Hooker (timber trees)
Cinnamomum pedatinervum Meissner (essential-oil plants)
Cinnamomum verum J.S. Presl (spices)
  Cinnamomum zeylanicum Blume
  Laurus cinnamomum L.
Cissampelos pareira L. (medicinal and poisonous plants)
Cissus diffusa (Miquel) Amshoff (medicinal and poisonous plants)
  Vitis diffusa Miquel
Citrus aurantium L. cv. group Bouquetier (essential-oil plants)
  Citrus amara Link
  Citrus aurantium L. subsp. *amara* (Link) Engler
  Citrus bigaradia Risso & Poiteau
Cleome viscosa L. (medicinal and poisonous plants)
  Cleome icosandra L.
  Polanisia viscosa DC.
Clerodendrum indicum (L.) Kuntze (medicinal and poisonous plants)
Cocos nucifera L. (vegetable oils and fats)
Coix lacryma-jobi L. (cereals)
  Coix agrestis Loureiro
  Coix arundinacea Lamk
  Coix lacryma L.
Combretum sundaicum Miquel (medicinal and poisonous plants)
Conyza sumatrensis (Retzius) E. Walker (medicinal and poisonous plants)
Cordia subcordata Lamk (timber trees)
  Cordia moluccana Roxb.
  Cordia orientalis R. Br.
  Cordia rumphii Blume
Crotalaria pallida Aiton (auxiliary plants)
  Crotalaria mucronata Desv.
  Crotalaria siamica Williams
  Crotalaria striata DC.
Cumimum cynimum L. (spices)
  Cumimum odorum Salisb.
  Ligusticum cuminum (L.) Crantz
Curcuma zedoaria (Christm.) Roscoe (plants yielding non-seed carbohydrates/ medicinal and poisonous plants)
  Amomum latifolium Lamk
  Amomum zedoaria Christm.
  Curcuma pallida Loureiro
  Curcuma zerumbet Roxb.
Cyathocalyx globosus Merrill (timber trees)
Cyperus esculentus L. (plants yielding non-seed carbohydrates)
Cyperus iria L. (medicinal and poisonous plants)

Cyperus rotundus L. (plants yielding non-seed carbohydrates/medicinal and poisonous plants)
Cyperus curvatus Llanos (non Vahl)
Daemonorops leptopus (Griff.) Mart. (rattans)
Datura metel L. (medicinal and poisonous plants)
Datura fastuosa L.
Derris trifoliata Loureiro (medicinal and poisonous plants)
Derris heterophylla (Willd.) Backer ex K. Heyne
Derris uliginosa (Willd.) Benth.
Dialium cochinchinense Pierre (timber trees)
Dipteryx odorata (Aublet) Willd. (spices)
Dischidia imbricata (Blume) Steudner (medicinal and poisonous plants)
Dodonaea viscosa Jacq. (medicinal and poisonous plants)
Drymophloeus saxatilis Martius (medicinal and poisonous plants)
Ehretia acuminata R. Br. (timber trees)
Ehretia ovalifolia Hassk.
Ehretia polyantha A. DC.
Ehretia serrata Roxb.
Elaeis guineensis N.J. Jacquin (vegetable oils and fats)
Elettaria cardamomum (L.) Maton (spices)
Alpinia cardamomum (L.) Roxb.
Amomum cardamomum L.
Amomum repens Sonnerat
Embelia ribes Burm.f. (medicinal and poisonous plants)
Embelia garciniifolia Wallich ex Miquel
Entada phaseoloides (L.) Merrill (medicinal and poisonous plants)
Entada spiralis Ridley (medicinal and poisonous plants)
Eryngium foetidum L. (spices)
Eryngium antihystericum Rottler
Erythroxylum coca Lamk (medicinal and poisonous plants)
Erythroxylum bolivianum Burck
Erythroxylum peruvianum Prescott
Erythroxylum novogranatense (Morris) Hieron. (medicinal and poisonous plants)
Erythroxylum coca Lamk var. *novogranatense* Morris
Erythroxylum coca Lamk var. *spruceanum* Burck
Erythroxylum truxillense Rusby
Euphorbia thymifolia L. (medicinal and poisonous plants)
Chamaesyce thymifolia (L.) Millsp.
Exocarpus latifolius R. Brown (essential-oil plants)
Exocarpus luzonensis (Presl) A. DC.
Exocarpus ovatus Blume
Xylophyllos latifolius (R. Brown) O. Kuntze
Fagraea bodenii Wernham (timber trees)
Fagraea ampla S. Moore
Fagraea papuana Merrill & Perry
Fagraea suaveolens Cammerl.
Ficus minahassae (Teijsm. & de Vriese) Miquel (fibre plants)
Ficus pungens Reinw. ex Blume (medicinal and poisonous plants)
Ficus kalingaensis Merrill

Ficus myriocarpa Miquel
Ficus ovalifolia Ridley
Ficus septica Burm.f. (medicinal and poisonous plants)
Ficus casearia F. v. Mueller ex Benth.
Ficus hauili Blanco
Ficus kaukauensis Hayata
Ficus variegata Blume (plants producing exudates)
Foeniculum vulgare Miller (spices)
Anethum foeniculum L.
Foeniculum capillaceum Gilib.
Foeniculum officinale Allioni
Galbulimima belgraveana (F. v. Mueller) Sprague (timber trees)
Himantandra belgraveana (F. v. Mueller) F. v. Mueller ex Diels
Gardenia jasminoides Ellis (dye and tannin-producing plants)
Gaultheria leucocarpa Blume (essential-oil plants)
Brossaea leucocarpa (Blume) O. Kuntze
Gaultheria crenulata Kurz
Gaultheria cumingiana Vidal
Gaultheria punctata Blume (essential-oil plants)
Brossaea fragrantissima (auct.) O. Kuntze
Gaultheria fragrantissima auct., non Wallich
Gaultheria fragrantissima Wallich var. *punctata* (Blume) J.J. Smith
Gmelina elliptica J.E. Smith (medicinal and poisonous plants)
Gmelina asiatica L. var. *villosa* Bakh.
Gmelina villosa Roxb.
Gomphia serrata (Gaertner) Kanis (timber trees)
Campylospermum serratum (Gaertner) Bittrich & M.C.E. Amaral
Gomphia sumatrana Jack
Ouratea angustifolia (Vahl) Baillon & Lanessan
Graptophyllum pictum (L.) Griffith (ornamental plants)
Gronophyllum microcarpum R. Scheffer (timber trees)
Heliconia wagneriana Petersen (ornamental plants)
Heliconia aureo-striata Bull
Heliconia bihai (L.) L.
Heliconia indica Lamk
Hemigraphis alternata (Burm.f.) T. Anderson (medicinal and poisonous plants)
Hemigraphis colorata (Blume) H. Hallier
Heterospathe elata Scheffer (ornamental plants)
Hibiscus sabdariffa L. (vegetables)
Hibiscus digitatus Cav.
Hopea odorata Roxb. (timber trees)
Hyptis suaveolens (L.) Poiteau (spices)
Ballota suaveolens L.
Marrubium indicum Thunb., non Burm.f.
Schaueria graveolens Hassk.
Illicium verum J.D. Hooker (spices)
Badianifera officinarum Kuntze
Illicium anisatum Loureiro, non L.
Kaempferia angustifolia Roscoe (medicinal and poisonous plants)

Kaempferia gilbertii W. Bull
Kaempferia roxburghiana Schult.
Kaempferia undulata Teijsm. & Binnend.
Kaempferia galanga L. (medicinal and poisonous plants)
Lactuca sativa L. (vegetables)
Lactuca scariola L. var. *hortensis* Bisch.
Lactuca scariola L. var. *sativa* Boiss.
Lactuca serriola L. var. *sativa* Moris
Lantana camara L. (medicinal and poisonous plants)
Lantana aculeata L.
Lantana trifolia L. (medicinal and poisonous plants)
Laurus nobilis L. (spices)
Laurus undulata Miller
Leonurus sibiricus L. (medicinal and poisonous plants)
Leptospermum javanicum Blume (timber trees)
Leptospermum alpestre Blume
Leptospermum flavescens J.E. Smith var. *javanicum* (Blume) King
Leptospermum floribundum Jungh.
Leucaena leucocephala (Lamk) de Wit (forages/auxiliary plants)
Leucaena glauca (Willd.) Benth.
Leucaena latisiliqua (L.) Gillis
Licuala acutifida Mart. (timber trees)
Licuala paludosa Griffith (timber trees)
Licuala amplifrons Miquel
Licuala paniculata Ridley
Licuala spinosa Wurmb (timber trees)
Lippia alba (Miller) N.E. Brown (spices)
Lippia graveolens Kunth (spices)
Lippia berlandieri J. Schauer
Litsea diversifolia Blume (essential oil plants)
Lophatherum gracile Brongn. (forages)
Loxogramme involuta Bedd. (cryptogams)
Matthaea sancta Blume (medicinal and poisonous plants)
Melissa officinalis L. (spices)
Melissa altissima J.E. Smith
Melissa inodora Bornm., non Hassk.
Mentha arvensis L. (medicinal and poisonous plants)
Micromelum octandrum Turcz. (medicinal and poisonous plants)
Mitragyna speciosa (Korth.) Havil. (medicinal and poisonous plants)
Monodora myristica (Gaertner) Dunal (spices)
Annona myristica Gaertner
Monodora grandiflora Bentham
Xylopia undulata Pal. de Beauv.
Mussaenda frondosa L. (medicinal and poisonous plants)
Mussaenda glabra Vahl
Myristica fragrans Houtt. (spices)
Myristica aromatica Lamk
Myristica moschata Thunb.
Myristica officinalis L.f.

Nelumbo nucifera Gaertner (plants yielding non-seed carbohydrates)
  Nelumbium nelumbo (L.) Druce
  Nelumbium speciosum Willd.
  Nymphaea nelumbo L.
Nephelium lappaceum L. (edible fruits and nuts)
  Nephelium chryseum Blume
  Nephelium glabrum Cambess.
  Nephelium obovatum Ridley
  Nephelium sufferrugineum Radlk.
Nephelium ramboutan-ake (Labill.) Leenh. (edible fruits and nuts)
  Nephelium intermedium Radlk.
  Nephelium mutabile Blume
  Nephelium philippense Monsalud et al.
Nypa fruticans Wurmb (plants yielding non-seed carbohydrates)
  Cocos nypa Loureiro
  Nipa fruticans Thunb.
  Nipa litoralis Blanco
Ocimum basilicum L. (spices)
Ocimum gratissimum L. (essential-oil plants)
  Ocimum suave Willd.
  Ocimum viride Willd.
  Ocimum viridiflorum Roth
Oncosperma tigillarium (Jack) Ridley (timber trees)
  Oncosperma filamentosum Blume
Origanum majorana L. (spices)
  Majorana hortensis Moench
  Origanum dubium Boissier
  Origanum majoranoides Willd.
Origanum vulgare L. (spices)
  Origanum gracile Koch
  Origanum hirtum Link
  Origanum viride (Boissier) Halacsy
Panicum sarmentosum Roxb. (forages)
Papaver somniferum L. (medicinal and poisonous plants)
  Papaver hortense Hussenot
  Papaver officinale C.C. Gmelin
  Papaver setigerum DC.
Pentace burmanica Kurz (timber trees)
Pentadesma butyracea D. Don (vegetable oils and fats)
Pentapetes phoenicea L. (ornamental plants)
Petroselinum crispum (Miller) Nyman ex A.W. Hill (spices)
  Petroselinum hortense Hoffm.
  Petroselinum sativum Hoffm.
  Petroselinum vulgare J. Hill
Phrynium placentarium (Loureiro) Merrill (fibre plants)
  Phrynium capitatum Willd.
Phyla nodiflora (L.) Greene (medicinal and poisonous plants)
  Lippia nodiflora (L.) Richard
Phyllanthus emblica L. (medicinal and poisonous plants)

Emblica arborea Raf.
Emblica grandis Gaertner
Emblica officinalis Gaertner
Phytelephas macrocarpa Ruiz & Pavon (ornamental plants)
Picria fel-terrae Loureiro (medicinal and poisonous plants)
Curanga fel-terrae (Loureiro) Merrill
Pimenta dioica (L.) Merrill (spices)
Myrtus dioica L.
Myrtus pimenta L.
Pimenta officinalis Lindley
Pimenta racemosa (Miller) J.W. Moore (essential-oil plants)
Caryophyllus racemosus Miller
Myrtus acris Swartz
Pimenta acris (Swartz) Kostel.
Pimpinella anisum L. (spices)
Anisum officinarum Moench
Anisum vulgare Gaertner
Apium anisum (L.) Crantz
Pinanga basilanensis Beccari (ornamental plants)
Pinanga batanensis Beccari (ornamental plants)
Pinanga copelandii Beccari (ornamental plants)
Pinanga curranii Beccari (ornamental plants)
Pinanga elmeri Beccari (ornamental plants)
Pinanga geonomiformis Beccari (ornamental plants)
Pinanga heterophylla Beccari (ornamental plants)
Pinanga isabelensis Beccari (ornamental plants)
Pinanga maculata Porte ex Lemaire (ornamental plants)
Pinanga barnesii Beccari
Pinanga modesta Beccari (ornamental plants)
Pinanga negrosensis Beccari (ornamental plants)
Pinanga philippinensis Beccari (ornamental plants)
Pinanga punicea Merrill (timber trees)
Pinanga ternatensis R. Scheffer
Pinanga rigida Beccari (ornamental plants)
Pinanga samarana Beccari (ornamental plants)
Pinanga sclerophylla Beccari (ornamental plants)
Pinanga sibuyanensis Beccari (ornamental plants)
Pinanga speciosa Beccari (ornamental plants)
Pinanga urdanetana Beccari (ornamental plants)
Pinanga urosperma Beccari (ornamental plants)
Pinanga woodiana Beccari (ornamental plants)
Piper aduncum L. (spices)
Artanthe adunca (L.) Miquel
Piper angustifolium Ruiz & Pavón
Piper elongatum Vahl
Piper caninum Blume (spices)
Piper banksii Miquel
Piper lanatum Roxb.
Piper lauterbachii C. DC.

Piper lowong Blume
Piper macrocarpum C. DC.
Pogostemon benghalensis (Burm.f.) Kuntze (essential-oil plants)
Origanum benghalense Burm.f.
Pogostemon parviflorus Benth.
Pogostemon plectranthoides auct., non Desf.
Pouteria sapota (Jacq.) H.E. Moore & Stearn (edible fruits and nuts)
Calocarpum sapota (Jacq.) Merrill
Lucuma mammosa (L.) Gaertner f.
Prosopis juliflora (Swartz) DC. (auxiliary plants)
Mimosa juliflora Swartz
Prosopis vidaliana Naves
Prunus arborea (Blume) Kalkman (timber trees)
Pygeum arboreum (Blume) Blume
Pygeum parviflorum Teijsm. & Binnend.
Pygeum stipulaceum King
Quassia indica (Gaertner) Noot. (medicinal and poisonous plants)
Samadera indica Gaertner
Raphia hookeri G. Mann & H.A. Wendland (fibre plants)
Raphia vinifera Palisot de Beauvois (fibre plants)
Rheum officinale Baillon (medicinal and poisonous plants)
Rorippa nasturtium-aquaticum (L.) Hayek (vegetables)
Nasturtium officinalis (R. Br.) P. Royen
Rorippa officinale R. Br.
Sisymbrium nasturtium-aquaticum L.
Rosmarinus officinalis L. (spices)
Rosmarinus angustifolius Miller
Rosmarinus latifolius Miller
Salvia rosmarinus Schleiden
Scaevola sericea Vahl (medicinal and poisonous plants)
Scaevola frutescens Krause
Scleria levis Retzius (medicinal and poisonous plants)
Scoparia dulcis L. (medicinal and poisonous plants)
Senna alata (L.) Roxb. (medicinal and poisonous plants)
Cassia alata L.
Senna hirsuta (L.) Irwin & Barneby (auxiliary plants)
Cassia hirsuta L.
Cassia leptocarpa Benth.
Senna septemtrionalis (Viv.) Irwin & Barneby (auxiliary plants)
Cassia floribunda auct., non Cavanilles
Cassia laevigata Willd.
Senna tora (L.) Roxb. (medicinal and poisonous plants)
Cassia borneensis Miquel
Cassia tora L.
Shorea roxburghii G. Don (timber trees)
Shorea cochinchinensis Pierre
Shorea floribunda (Wallich) Kurz
Shorea talura Roxb.
Sinapis alba L. (spices)

Brassica alba (L.) Rabenhorst
Brassica hirta Moench
Sindora siamensis Teijsm. ex Miquel (timber trees)
Sindora cochinchinensis Baillon
Smilax corbularia Kunth (medicinal and poisonous plants)
Staurogyne malaccensis C.B. Clarke (medicinal and poisonous plants)
Staurogyne setigera (Nees) O. Kuntze (medicinal and poisonous plants)
Streblus asper (Retzius) Loureiro (medicinal and poisonous plants)
Styrax benzoides Craib (plants producing exudates)
Styrax benzoin Dryander (plants producing exudates)
Styrax paralleloneurum Perkins (plants producing exudates)
Styrax sumatrana J.J. Smith
Styrax serratulum Roxb. var. *mollissimum* Steen. (plants producing exudates)
Styrax subpaniculatum Jungh. & de Vriese
Styrax siamensis Rordorf (plants producing exudates)
Syzygium aromaticum (L.) Merrill & Perry (spices)
Caryophyllus aromaticus L.
Eugenia aromatica (L.) Baill.
Eugenia caryophyllus (Sprengel) Bullock & Harrison
Syzygium nervosum DC. (timber trees)
Cleistocalyx operculatus (Roxb.) Merrill & Perry
Eugenia operculata Roxb.
Syzygium operculatum (Roxb.) Niedenzu
Taraxacum officinale Weber ex F.H. Wigg. (vegetables/medicinal and poisonous plants)
Tephrosia purpurea (L.) Pers. (auxiliary plants)
Cracca purpurea L.
Tephrosia diffusa (Roxb.) Wight & Arnott
Tephrosia wallichii Grah. ex Fawc. & Rendle
Terminalia triptera Stapf (timber trees)
Terminalia nigrovenulosa Pierre ex Gagnep.
Terminalia obliqua Craib
Terminalia tripteroides Craib
Thevetia peruviana (Pers.) K. Schum. (ornamental plants)
Thevetia neriifolia Jussieu
Thottea parviflora Ridley (medicinal and poisonous plants)
Trachyspermum roxburghianum (DC.) H. Wolff (spices)
Carum roxburghianum (DC.) Benth.
Ptychotis roxburghiana DC.
Trachyspermum involucratum (Royle) H. Wolff
Trigonella foenum-graecum L. (spices)
Trigonopleura malayana J.D. Hooker (dye and tannin-producing plants)
Uncaria callophylla Blume ex Korth. (dye and tannin-producing plants)
Uncaria jasminiflora J.D. Hooker
Uncaria gambir (Hunter) Roxb. (dye and tannin-producing plants)
Uncaria lanosa Wallich (medicinal and poisonous plants)
Uncaria longiflora Merrill (medicinal and poisonous plants)
Vanilla planifolia H.C. Andrews (spices)
Vanilla fragrans (Salisb.) Ames

Vanilla mexicana P. Miller p.p.
Vanilla viridiflora Blume
Veitchia merrillii (Beccari) H.E. Moore (ornamental plants)
Adonidia merrillii Beccari
Vetiveria zizanioides (L.) Nash (essential-oil plants)
Andropogon muricatus Retzius
Andropogon zizanioides (L.) Urban
Phalaris zizanioides L.
Vigna angularis (Willd.) Ohwi & Ohashi (pulses)
Phaseolus angularis (Willd.) W.F. Wright
Vitex glabrata R. Br. (medicinal and poisonous plants)
Vitex helogiton K. Schumann
Vitex minahassae Koord.
Vitex pentaphylla Merrill
Xanthophyllum lanceatum (Miquel) J.J. Smith (vegetable oils and fats)
Xanthophyllum glaucum Wallich
Xylopia pierrei Hance (essential-oil plants)

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Acronyms of organizations

- ASIC: Association Scientifique Internationale du Café (Paris, France).
- CATIE: Centro Agronómico Tropical de Investigación y Enseñanza (Turrialba, Costa Rica).
- CEPLAC: Comissão Executiva do Plano da Lavoura Cacaueira (Itabuna, Brazil).
- CIRAD: Centre de Coopération Internationale en Recherche Agronomique pour le Développement (Paris, France).
- CRU: Cocoa Research Unit, The University of the West Indies (St. Augustine, Trinidad and Tobago).
- DGIS: Directorate-General for International Cooperation of the Netherlands Ministry of Foreign Affairs (Den Haag, the Netherlands).
- EMBRAPA: Empresa Brasileira de Pesquisa Agropecuária (Brasilia, Brazil).
- FAO: Food and Agriculture Organization of the United Nations (Rome, Italy).
- FRIM: Forest Research Institute Malaysia (Kepong, Malaysia).
- ICCO: International Cocoa Organization (London, United Kingdom).
- ICCRI: Indonesian Coffee and Cocoa Research Institute (Jember, Indonesia).
- ICG,T: International Cocoa Genebank, Trinidad (St. Augustine, Trinidad and Tobago).
- ICO: International Coffee Organization (London, United Kingdom).
- ICRA: International Centre for development-oriented Research in Agriculture (Wageningen, the Netherlands).
- ICRAF: International Centre for Research in Agroforestry (Nairobi, Kenya).
- IEBR: Institute of Ecology and Biological Resources (Hanoi, Vietnam).
- INGENIC: International Group for Genetic Improvement of Cocoa (Reading, United Kingdom).
- INRA: Institut National de la Recherche Agronomique (Paris, France).
- INTA: Instituto Nacional de Tecnología Agropecuaria (Buenos Aires, Argentina).
- IPGRI: International Plant Genetic Resources Institute (Rome, Italy).
- IRD (formerly ORSTOM): Institut de recherche pour le développement (Montpellier, France)
- ITC: International Tea Committee (London, United Kingdom).
- LIPI: Indonesian Institute of Sciences (Jakarta, Indonesia).
- MARDI: Malaysian Agricultural Research and Development Institute (Serdang, Malaysia).
- PCCARD: Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (Los Baños, the Philippines).
- PROSEA: Plant Resources of South-East Asia (Bogor, Indonesia).
- TISTR: Thailand Institute of Scientific and Technological Research (Bangkok, Thailand).

- TMA: Tobacco Merchants Association (Princeton, New Jersey, United States).
- UNITECH: Papua New Guinea University of Technology (Lae, Papua New Guinea).
- USDA: United States Department of Agriculture (Washington D.C., United States).
- WHO: World Health Organization (Geneva, Switzerland).
- WU (formerly WAU): Wageningen University (Wageningen, the Netherlands).

Glossary

abaxial: on the side facing away from the axis or stem (dorsal)
abdominalgia: painful abdomen
abortifacient: causing abortion; an agent that causes abortion
absolute: a highly concentrated, alcohol-soluble liquid, normally obtained by alcoholic extraction of concretes or pomades and considered to reflect most accurately the taste and odour of the original material
accession: in germplasm collections: plant material of a particular collection, usually indicated with a number
accessory buds: those additional to the axillary and normal buds; more than one bud in an axil
accrescent: increasing in size with age
achene: a small dry indehiscent one-seeded fruit
acicular: needle-shaped; with a sharp point
acid value: a measure of the content of free acid present in an aromatic material, which tends to increase with increasing age of products such as essential oils and esters, particularly esters of lower and terpene alcohols
actinomorphic: radially symmetrical; applied to flowers which can be bisected in more than one vertical plane
aculeate: furnished with prickles; prickly
acumen: the point of an acuminate leaf; the drip-tip
acuminate: ending in a narrowed, tapering point with concave sides
acute: in botany: sharp; ending in a point with straight or slightly convex sides; in medicine: with a short and relatively severe course
adaxial: on the side facing the axis (ventral)
adherent: the union of parts usually separate
adnate: united with another part; with unlike parts fused, e.g. ovary and calyx tube
adpressed (appressed): lying flat for the whole length of the organ
adulterate: falsify by admixture of ingredients
adventitious: not in the usual place, e.g. roots on stems, or buds produced in other than terminal or axillary positions on stems
agarbatti, joss stick: incense stick consisting of a blend of aromatic plant matter wrapped around a thin length of bamboo, impregnated with a perfume compound. In high-quality agarbattis the base material is sufficiently fragrant not to require perfuming
agroforestry: land-use systems in which trees or shrubs are grown in association with crops (agricultural crops or pastures) in a spatial arrangement or a rotation and in which there are both ecological and economic interactions between the trees and the other components of the system
air layering: a form of layering in which soil (rooting medium) is brought to the branch to be layered; the ball of soil in a polyethene cover is wrapped around the girdled branch; after adventitious roots grow out above the girdle, the layer can be separated
albumen: the nutritive material stored within the seed, and in many cases surrounding the embryo (endosperm)
-algia: a word termination denoting a painful condition
aliphatic compounds: acyclic organic compounds; the chain of C-atoms in these compounds may be straight or branched and some of the bonds between C-atoms may be unsaturated
alkaloid: large group of organic bases containing nitrogen and usually oxygen that occur for the most part in the form of salts with acids; usually optically and biologically active
allogamous: from allogamy, cross-fertilization
allopathic: pertaining to or characteristic of allopathy (a system of therapeutics in which diseases are treated by producing a condition incompatible with or antagonistic to the condition to be cured or alleviated; also called heteropathy)
allotetraploid: an allopolyploid produced when a hybrid between two species doubles its chromosome number (also mentioned: amphidiploid)
alternate: leaves, etc., inserted at different levels along the stem, as distinct from opposite or whorled

alveolate: marked as though honeycombed

Alzheimer's disease: dementia of insidious onset and gradually progressive course, usually occurring after the age of 50

amphidiploid: an allopolyploid produced when a hybrid between two species doubles its chromosome number (also mentioned: allotetraploid)

amplexicaul: stem-clasping, when the base of a sessile leaf or a stipule is dilated at the base, and embraces the stem

anastomosis: cross connection of branches or roots; union of one vein or parenchyma band with another, the connection forming a reticulation

androecium: the male element; the stamens as a unit of the flower

androgynophore: a column on which stamens and carpels are borne

androphore: a stalk or column on which the stamens are borne

annual: a plant which completes its life cycle in one year

annular: used of any organs disposed in a circle

anterior: of time, previous; of place, position in front, or turned away from the axis

anthelmintic: destructive to worms: a drug or agent that destroys worms

anther: the part of the stamen containing the pollen

antheriferous: bearing anthers

anthesis: the time the flower is expanded, or, more strictly, the time when pollination may take place

anthracnose: a disease characterized by distinctive limited lesions on stem, leaf or fruit, often accompanied by dieback and usually caused by a *Gloeosporium* or a *Colletotrichum*, imperfect fungi; the perfect state of the fungus, when known, is *Gnomonia* or *Glomerella*

antidote: anything counteracting the effects of a poison

antioxidant: a substance that opposes oxidation or inhibits reactions promoted by oxygen or peroxides; many of these substances are used as preservatives in various products

antipyretic: relieving or reducing fever

antiseptic: pertaining to asepsis (prevention of contact with micro-organisms); preventing decay or putrefaction; a substance inhibiting the growth and development of micro-organisms without necessarily killing them

antispasmodic: relieving spasm; an agent that relieves spasm

apetalous: without petals

apex (plural: apices): the tip or summit of an organ

aphrodisiac: stimulating sexual desire; a drug arousing the sexual instinct

apical: at the apex of any structure

apiculate: ending abruptly in a short point

apocarpous: with the carpels free from each other

apomixis: reproduction by seed formed without sexual fusion (apomictic)

apotracheal: not associated or contiguous with vessels or vascular tracheids

appendage: a part added to another; attached secondary or subsidiary part, sometimes projecting or hanging

appendix (botany): a name given to appendages of any kind, e.g. in *Araceae* the sterile top part of the spadix

appressed (adpressed): lying flat for the whole length of the organ

arbuscular: shrubby, and branched like a tree

architectural model: model describing the branching habit of a tree as determined by the pattern of activity of axes, the pattern including timing, positioning and fate (e.g. terminating in an inflorescence) of active axes

arcuate: curved

areolate: with irregular squares or angular spaces marked out on a surface, e.g. of a fruit; with small cells or cavities

areole: an irregular square or angular space marked out on a surface, e.g. of a fruit; a small cell or cavity

aril: an expansion of the funicle enveloping the seed, arising from the placenta; sometimes occurring as a pulpy cover (arillus)

arillate: possessing an aril

aristate: awned

armed: bearing some form of spines

aromatherapy: the treatment of disorders in humans by the use of essential oils; essential oil are usually used in diluted form as massage oils or preparations for the bath, or in products acting as odour carriers for the purported psychological benefits of essential oils when smelled

aromatic compounds: see benzene derivatives

arthritis: inflammation of a joint or joints

articulate: jointed, or with places where separation takes place naturally

ascendent, ascending: curving or sloping upwards

astringent: an agent or substane causing constriction of the skin, mucous membranes or raw or exposed tissues; as such, ethanol is used in skin-toning lotions and aluminium chlorohydrate in anti-perspirants

attar: liquid perfume traditional in India. It car-

ries the scent of an aromatic plant in a base of sandalwood or sesame oil
attenuate: gradually tapering
auct.: auctorum (Latin); of authors
auct., non: auctorum, non (Latin); of authors, not ... (author name); used after a scientific name when this name is erroneously applied by several authors to material actually belonging to a different species than the species described by the author mentioned
auricle: a small lobe or ear
auriculate: eared, having auricles
awn: a bristle-like appendage, especially occurring on the glumes of grasses
axial: in the direction of the axis; in longitudinal direction
axil: the upper angle between the leaf and the stem
axillary: arising from the axil
axis: the main or central line of development of a plant or organ
bark: the tissue external to the vascular cambium collectively, being the secondary phloem, cortex and periderm
basifixed: attached or fixed by the base
basionym: the synonym of a scientific name that supplies the epithet for the correct name
batteuse: industrial equipment for washing concretes with alcohol to produce absolutes
beak: a long, prominent and substantial point, applied particularly to prolongations of fruits
bechic: a remedy or treatment of cough
bearded: awned; having tufts of hairs
benzene derivatives (benzenoids): chemical compounds containing a characteristic benzene ring often represented as a C_6 ring with 3 double bonds alternating with single bonds between the C-atoms
berry: a juicy indehiscent fruit with the seeds immersed in pulp; usually several-seeded without a stony layer surrounding the seeds
biennial: a plant which flowers, fruits and dies in its second year or season
bifid: forked, divided in two but not to the base
bilabiate: two-lipped
bipinnate: when the primary divisions (pinnae) of a pinnate leaf are themselves pinnate
biseriate: arranged in two rows
bisexual: having both sexes present and functional in the same flower
blade: the expanded part, e.g. of a leaf or petal
blennorrhoea: an excessive discharge of mucus; former name for gonorrhoea
body note: the note or combination of notes by which the odour of an essential oil is characterized; on a smelling strip body notes appear after evaporation of monoterpenes and other highly volatile compounds
bole: the main trunk of a tree, generally from the base up to the first main branch
brachyblast: a short reproductive branch
bract: a reduced leaf subtending a flower, flower stalk or the whole or part of an inflorescence
bracteole: a secondary bract on the pedicel or close under the flower
bristle: a stiff hair or a hair-like stiff slender body
bronchitis: inflammation of the bronchial tubes
bud: the nascent state of a flower or branch; often applied to those primordial vegetative or reproductive branches that are enclosed in a prophyllum and have a resting stage
bullate: surface much blistered or puckered
bunch: cluster, growing together
bush: a low thick shrub without a distinct trunk
buttress: the enlargement of the base of trunks of tropical trees that ranges from a small spur or swelling to massive structures, partly root, partly stem, reaching as high as 10 m up the stem, thin and flat to thick, twisted or anastomose
caducous: falling off
callus: in plants, small hard outgrowth at the base of spikelets in some grasses, or tissue that forms over cut or damaged plant surface
calorific value: the heat produced by the combustion of a unit weight of a fuel
cabbage (of palms): a terminal bud of a palm tree that resembles a head of a cabbage and is eaten as a vegetable
calyx: the outer envelope of the flower, consisting of sepals, free or united
cambium (plural: cambia): a layer of nascent tissue between the wood and bark, adding elements to both
campanulate: bell-shaped
canaliculate: channelled, with a longitudinal groove
canopy: the uppermost leafy layer of a tree, forest or crop
capitate: headed, like the head of a pin in some stigmas, or collected into compact headlike clusters as in some inflorescences
capsule: in botany: a dry dehiscent fruit composed of two or more carpels and either splitting when ripe into valves, or opening by slits or pores
carminative: relieving flatulence; an agent relieving flatulence and assuaging pain
carpel: one of the foliar units of a compound pistil or ovary; a simple pistil has only one carpel

carpophore: the part of the receptacle which is prolonged between the carpels as a central axis
cartilaginous: hard and tough
caryopsis: the fruit of a grass, in which the outer layer (testa) of the seed proper is fused to the ovary wall
cataphyll: reduced or scale-like leaf present in certain seedlings on the lower stem nodes and sometimes elsewhere on the seedling stem
cathartic: purgative
caudate: with a tail-like appendage
cauliflorous: with the flowers borne on the trunk
cauline: belonging to the stem or arising from it
chartaceous: papery
chemotype: taxon which is morphologically similar to another one but with different chemical content
chromosome: a structural unit in the nucleus which carries the genes in a linear constant order; the number is typically constant in any species
ciliate: with a fringe of hairs along the edge
ciliolate: fringed with small hairs
cincinnus: a monochasial cymose inflorescence with branches alternating from one side of the vertical axis to the other and normally curved to one side
circinate (circinnate): coiled into a ring or partially so
clavate: club-shaped or thickened towards the end
claw: the basal, narrow part of a petal or sepal
cleistogamous: pollination and fertilization taking place within the unopened flower
clone: a group of plants originating by vegetative propagation from a single plant and therefore of the same genotype
cohobation: re-use of distillation waters for the purpose of recovering dissolved essential oil
colleter: a multicellular glandular hair
column (botany): a cylindrical body, e.g. a tube of connate stamen filaments or the central axis of a fruit
coma: in botany: the hairs at the end of some seeds; a tuft of leafy bracts or leaves at the top of an inflorescence (e.g. pineapple)
commissural: of the face by which two carpels adhere, as in *Umbelliferae*
compatibility: in floral biology: capable of cross- or self-fertilization; in plant propagation: stock-scion combinations resulting in a lasting union
compound: in botany, of two or more similar parts in one organ, as in a compound leaf or compound fruit; in chemistry, a substance consisting of 2 or more elements combined chemically in fixed proportions; in perfumery, a perfume concentrate in which the ingredients of a perfume formula are mixed together
concave: hollow
concolorous: similarly coloured on both sides or throughout; of the same colour as a specified structure
concrescent: growing together
concrete: a fatty or waxy aromatic product obtained from a natural source by extraction with a pure, volatile hydrocarbon solvent, a mixture of solvents or carbondioxide; they are mainly used as raw material for production of absolutes
condenser: in distillation that part of a still in which the hot vapours from a distillation vessel are condensed to liquid by cooling, usually by cold water circulating round a coiled part of the vapour pipe known as 'worm'
cone: the fruit of a pine or fir tree (gymnosperms), largely made up of imbricated scales
conical: having the shape of a cone (cone-shaped)
connate: united or joined
connective (botany): tissue between the pollen sacs of an anther
conspecific: belonging to the same species
contorted: twisted or bent
convex: having a more or less rounded surface
convolute: rolled, the margins overlapping (e.g. floral envelopes in the bud)
coppice: a small wood which is regularly cut at stated intervals; the new growth arising from the stools
cordate: heart-shaped, as seen at the base of a leaf, etc., which is deeply notched
cordiform: heart-shaped
core: central part; the seeds and integuments of a pome, such as an apple; pith in dicotyledonous plants
coriaceous: of leathery texture
corolla: the inner envelope of the flower consisting of free or united petals
corona: any appendage or extrusion that stands between the corolla and stamens; crown; the remains of the calyx limb on e.g. apples or pears
cortex: the bark or rind
corymb: a flat-topped indeterminate inflorescence in which the branches or pedicels sprout from different points, but attain approximately the same level, with the outer flowers opening first
corymbose: flowers arranged to resemble a corymb
cotyledon: seed-leaf, the primary leaf; dicotylous embryos have two cotyledons and monocotylous embryos have one
cover crop: a close-growing crop primarily grown

for the purpose of protecting and improving soil between periods of regular crop production or between trees or vines in orchards and plantations

crenate: the margin notched with blunt or rounded teeth

crenulate: slightly crenate, with small teeth

crest: an elevation or ridge upon the summit of an organ

cross-pollination: the transfer of pollen from one flower to the stigma of a flower of another plant which is not of the same clone

crown: the aerial expanse of a tree, not including the trunk; corona; a short rootstock with leaves; the base of a tufted, herbaceous, perennial grass

crownshaft: a conspicuous cylinder formed by tubular leaf sheaths at the top of the stem (e.g. in some palms)

culm: the stem of grasses and sedges

cultigen: a plant species or race that has arisen or is known only in cultivation

cultivar (cv., plural: cvs): an agricultural or horticultural variety that has originated and persisted under cultivation, as distinct from a botanical variety; a cultivar name should be written with an initial capital letter and given single quotation marks (e.g. banana 'Gros Michel') unless preceded bij 'cv.' (e.g. cv. Gros Michel)

cuneate: wedge-shaped; triangular, with the narrow end at the point of attachment, as the bases of leaves or petals

cupular: furnished with or subtended by a cupule

cupule: a small cup-like structure; the cup of such fruits as the acorn, consisting of an involucre composed of adherent bracts

cusp: a sharp, rigid but small point

cuspidate: abruptly tipped with a sharp rigid point

cuticle: the outermost skin of plants, consisting of a thin continuous fatty film

cutting: a portion of a plant, used for vegetative propagation

cyme: a determinate inflorescence, often flat-topped, in which each growing point ends in a flower and the central flowers open first

cymose: bearing cymes or inflorescences related to cymes

cystolith (botany): mineral concretions, usually of calcium carbonate on a cellulose stalk

damping-off: a disease of seeds or seedlings caused by fungi which cause various effects, from failure to germinate to the dying off of the seedling

deciduous: shedding, applied to leaves, petals, etc.

declinate: bent or curved downward or forward

decoction: a medicinal preparation or other substance made by boiling, especially in water

decompound: several times divided or compounded

decumbent: reclining or lying on the ground, but with the summit ascending

decurrent: extending down and adnate to the petiole or stem, as occurs in some leaves

decussate: of leaves, arranged in opposite pairs on the stem, with each pair perpendicular to the preceding pair

deflexed (reflexed): abruptly recurved; bent downwards or backwards

dehiscent: opening spontaneously when ripe, e.g. of capsules, anthers

deltoid: shaped like an equilateral triangle

density: the ratio of mass to volume of a substance at a given moisture content (see also: specific gravity)

dentate: margin prominently toothed with the pointed teeth directed outwards

denticulate: minutely toothed

depressed: sunk down, as if flattened from above

depurative: tending to purify or cleanse

determinate: of inflorescences, when the terminal or central flower of an inflorescence opens first and the prolongation of the axis is arrested; of shoot growth, when extension growth takes the form of a flush, i.e. only the previously formed leaf primordia unfold; for pulses also used to indicate bush-shaped plants with short duration flowering in one plane

dextrorse: twining to the right (clockwise)

diaphoretic: pertaining to, characterized by, or promoting (profuse) perspiration; an agent inducing sweating, having the power to increase perspiration

dichasium (plural: dichasia): a cymose inflorescence with 2 equal or nearly equal lateral branches arising below the terminal flower, this pattern being repeated or not (compound and simple dichasium respectively)

dichotomous: forked, parted by pairs

dicotyledon: angiosperm with two cotyledons or seed-leaves

didynamous: with the stamens in two pairs, two long and two short ones

dieback: the dying off of parts of the aboveground structure of the plant, generally from the top downward

digestibility: the percentage of a foodstuff taken into the digestive tract that is absorbed into the body

digitate: a compound leaf whose leaflets diverge from the same point like the fingers of a hand

dilated: expanded into a flat structure
dimorphic: of two forms, as may occur with branches, etc.
dioecious: with unisexual flowers and with the staminate and pistillate flowers on different plants (dioecy)
diploid: with two sets (genomes) of chromosomes, as occurs in somatic or body cells; usually written $2n$, having twice the basic chromosome number of the haploid germ cells
discolorous: dissimilarly coloured on both sides or throughout; of a different colour as a specified structure
disjunct: separated
disk: a fleshy or elevated development of the receptacle within the calyx, corolla or stamens, often lobed and nectariferous
dispersal: the various ways by which seeds are scattered, e.g. by wind, water or animals
distal: situated farthest from the place of attachment
distichous: regularly arranged in two opposite rows on either side of an axis
distillation: the process of transforming (fractions of) a liquid or solid into the vapour state, and condensing the vapour back to liquid or solid, named the distillate
diuretic: tending to increase the flow of urine; an agent that promotes the excretion of urine
domatium (plural: domatia): a modified projection that provides shelter for other organisms
dormancy: a term used to denote the inability of a resting plant or plant part (e.g. the seed, bulb, tuber, or in tree crops usually the buds) to grow or to leaf out, even under favourable environmental conditions
dorsal: back; referring to the back or outer surface of a part or organ (abaxial)
dorsifixed: attached by the back, as in the case of the attachment of a filament to an anther
double-flowered: petals monstrously increased at the expense of other organs, especially the stamens
downy: covered with very short and weak soft hairs
dropsy: oedema
drupaceous: resembling a drupe, whether actually a drupe or not
drupe: a fleshy one-seeded indehiscent fruit with the seed enclosed in a strong endocarp
dryout: the final notes perceptible from an aromatic material or perfume after the body notes have evaporated
dysmenorrhoea: painful menstruation
dyspepsia: a condition of disturbed digestion
ecotype: a biotype resulting from selection in a particular habitat
edema: the presence of abnormally large amounts of fluid in the intercellular tissue spaces of the body
eglandular: without glands
ellipsoidal: a solid which is elliptical in outline
elliptical: oval in outline but widest about the middle
emarginate: notched at the extremity
emetic: tending to induce or cause vomiting; an agent that induces or causes vomiting
emmenagogue: a substance or measure that induces menstruation
endemic: exclusively native to a specified or comparatively small region; also used as a noun for a taxon thus distributed
endo-: prefix, referring to the inside or the inner surface or part
endocarp: the innermost layer of the pericarp or fruit wall
endosperm: the starchy or oily nutritive material stored within some seeds, sometimes referred to as albumen; it is triploid, having arisen from the triple fusion of a sperm nucleus and the two polar nuclei of the embryo sac
energy value: the heat produced by the combustion of a unit weight of a fuel or food (= calorific value)
enfleurage: the process of transferring the volatile compounds responsible for the scent of picked flowers to a fixed oil or fat spread out on a glass plate; enfleurage is successful only with flowers that continue to produce aroma compounds for several hours after picking, such as jasmine and tuberose
enteritis: inflammation of the small intestine
entire (botany): with an even margin without teeth, lobes, etc.
epicalyx: an involucre of bracts below the flower, resembling an extra calyx
epidermis: in plants, the true cellular skin or covering of a plant below the cuticle; in humans, the outermost and nonvascular layer of the skin
epigeal: above the ground; in epigeal germination the cotyledons are raised above the ground
epigynous: on the pistil, apparently above the ovary
epipetalous: borne upon or placed before the petals
epiphyte: a plant that grows on another plant but without deriving nourishment from it
epithet: the second part of the scientific name of a species, the first part denoting the genus to which the species belongs

erect: directed towards summit, not decumbent
erecto-patent: between spreading and erect
essential oil: a volatile product, obtained from a natural source, which agrees with that source in odour and name; in a narrow sense, only volatile products obtained by steam or water distillation are called essential oils
evapotranspiration: loss of water from the soil by evaporation from the surface and by transpiration from the plants growing thereon
evergreen: bearing foliage all year long; a plant that changes its leaves gradually
ex situ: in an artificial environment or unnatural habitat
excitant: any agent that produces excitation of the vital functions, or of those of the brain
exocarp: the outer layer of the pericarp or fruit wall
expectorant: promoting the ejection of mucus or other fluids from the respiratory tract; an agent tending to promote discharge of mucus or other fluids from the respiratory tract
expression: any process for the removal of essential oil from the outer rind of a citrus fruit, involving scarification and compression of the peel
exsert, exserted: protrude beyond, as stamens beyond the tube of the corolla
exstipulate: without stipules
extra-axillary: beyond or outside the axil
extraction: any process for separating aroma compounds from animal or plant matter using a volatile solvent; the product is called a concrete; the composition, and hence odour quality, of an aromatic extract depends strongly on the nature of the solvent used
extrastaminal: outside the stamens
extrorse: directed outward, as the dehiscence of an anther
F_1, F_2, *etc.*: symbols used to designate the first generation, second generation, etc., after a cross
falcate: sickle-shaped
fallow: land resting from cropping, often covered by natural vegetation or planted with fast growing herbs, shrubs or trees (fallow crop)
fascicle: a cluster of flowers, leaves, etc., arising from the same point
fasciculate: connected or drawn into a fascicle
febrifuge: an agent serving to reduce fever
fermentation: a chemical change accompanied by effervescence and suggestive of changes produced in organic materials by yeasts
ferrugineous (ferruginous): rust-coloured
fertile (botany): capable of completing fertilization and producing seed; producing seed capable of germination; having functional sexual organs
fertilization (biology): union of the gametes (egg and sperm) to form a zygote
fibre (botany): any long, narrow cell of wood or bark other than vessel or parenchyma elements
fibrosis: the formation of fibrous tissue
fibrous: composed of or containing fibres
filament: thread; the stalk supporting the anther
filiform: slender; threadlike
fimbriate: fringed
fissured: provided with fissures (cracks of considerable length and depth), e.g. in the bark of some trees
fixed oil: a non-volatile oil, chemically a triglyceride of fatty acids; many fixed oils from plants have faint odours, even when purified, showing that they contain traces of volatile compounds
flavonoid: water-soluble phenolic compound, consisting of 2 aromatic rings joint together with a 3-carbon unit
fleshy: succulent
floret: a small flower, one of a cluster as in grasses or *Compositae*; a grass floret typically consists of a lemma, palea, 2 lodicules, 3 stamens and a pistil with 2 plumose stigmas
flowering branch: a leafy or leafless segmented axis that bears one or more inflorescences
flush: a brief period of rapid shoot growth, with unfolding of the leaf primordia which had accumulated during the previous quiescent period
fluted: of a bole, with rounded grooves and folds
fodder: something fed to domesticated animals, especially coarse, dried food from plants (hay, straw, leaves)
foliaceous: leaf-like
foliolate (2-, 3-, 4- etc.): with 2-, 3-, 4- leaflets
follicetum: a whorl of follicles
follicle: in plants: a dry, unicarpellate fruit, dehiscing by the ventral suture to which the seeds are attached
forage: grassland and fodder plants suitable as feed for herbivores, usually with lower nutrient concentration and digestibility than concentrates such as grain
fougère: a French word meaning fern; fougère-type perfumes are based on coumarin in combination with oak-moss, and with lavender accentuated in the topnote; their odour has no relation with that of ferns
fractionation, fractional distillation: a distillation process in which a fractionating column is interposed between the distillation vessel and the condenser. During fractionation of a homogeneous mixture of volatile components of differ-

ent boiling point, components with a lower boiling point move up the column faster than components with a higher boiling point and the components distil over in sequence
free: neither adhering nor united
fringed: fimbriate; with hair-like appendages along the margin
fruit: the ripened ovary with adnate parts
fugaceous: withering or falling off rapidly or early
fungicide: an agent that destroys fungi or inhibits their growth
funicle: the cord or thread which sometimes connects the ovule or seed to the placenta
funicle (funiculus): the little cord which attaches the ovule or seed to the placenta
fusiform: spindle-shaped; tapering towards each end from a swollen centre
galenical: herbal medicine, after the famous physician Galenius
gall flowers: atrofied female flowers of the fig, within whose ovaries the eggs of an insect undergo evolution
gamete: either of two mature reproductive cells, an ovum or sperm, which in uniting produce a zygote
gamopetalous: with united petals either throughout their length or at the base
gamosepalous: with united sepals either throughout their length or at the base
gas-liquid chromatography (GLC): a technique for the separation of the constituents of liquid or gaseous mixtures; in combination with mass spectroscopy it is a powerful tool for the qualitative and quantitative analysis of complex mixtures of chemical compounds such as essential oils or perfumery products
gastralgia: gastric colic
gastrodynia: stomach pain
geitonogamy: the fertilization of a pistil by pollen from another flower of the same plant
gene: the unit of inheritance located on the chromosome
geniculate: abruptly bent so as to resemble the knee-joint
genome: a set of chromosomes as contained within the gamete and corresponding to the haploid chromosome number of the species
genotype: the genetic makeup of an organism comprising the sum total of its genes, both dominant and recessive; a group of organisms with the same genetic makeup
genus (plural: genera): the smallest natural group containing distinct species
geocarpy: the subterraneous ripening of fruits, which have developed from a flower above ground
geometrical isomerism (cis-trans isomerism): a from of stereoisomerism in which the orientation of structural elements on each side of a double bond in the molecule of one isomer is at a 180° angle to that of the other isomer
germplasm: the genetic material that provides the physical basis of heredity
girth: a measure around a body
glabrate: devoid of pubescence and of any roughness
glabrescent: becoming glabrous or nearly so
glabrous: devoid of hairs
glandular: having or bearing secreting organs or glands
glaucous: pale bluish-green, or with a whitish bloom which rubs off
globose: spherical or nearly so
glomerule: a condensed head of almost sessile flowers; a cluster of heads in a common involucre
glucoside: compound that is an acetal derivative of sugars and that on hydrolysis yields glucose
glume (plural: glumes): the chaffy or membranous two-ranked members of the inflorescence of grasses and similar plants; lower glume and upper glume, two sterile bracts at the base of a grass spikelet
glycoside: compound that is an acetal derivative of sugars and that on hydrolysis yields one or more molecules of a sugar and often a noncarbohydrate
gonorrhoea: a venereal disease characterized by inflammation of the mucous membrane of the genitourinary tract and a discharge of mucus and pus
graft: a union of different individuals by apposition, the rooted plant being termed the stock, the portion inserted the scion
grafting: the process of inserting a scion, which consists of a piece of stem and two or more buds of the plant to be propagated, into another plant (rootstock) with the intention that it will unite and grow
grain (botany): a general term for cereals, those grasses cultivated for food; the caryopsis or the fruit of cereals
grain (wood anatomy): the general direction or arrangement of the fibres; texture
granular: divided into or bearing little knots or tubercles (also granulate)
granulose (granular): composed of or covered with grain-like minute particles

green manure: green leafy material applied to and mostly worked into the soil to enrich the soil with nutrients and organic matter

gregarious: growing in associated groups or clusters but not matted; at the same time

guaiacyl lignin: a type of lignin, occurring mainly in coniferous wood (softwood), in which a majority of the monomers have one methoxyl group added to position 3 of the basic phenyl propane ring.

gynoecium: the female part or pistil of a flower, consisting, when complete, of one or more ovaries with their styles and stigmas

gynophore: a stalk supporting the gynoecium formed by elongation of the receptacle

habit (botany): external appearance or way of growth of a plant

habitat: the kind of locality in which a plant grows

haematuria: the presence of blood in the urine

halophyte: a plant that grows naturally in soils having a high content of salts

hapaxanthic: pertaining to plants in which individual stems flower once only and then die (cf. pleonanthic)

haploid: having a single set (genome) of chromosomes in a cell or an individual, corresponding to the chromosome number (n) in a gamete

harvest-index: the total harvestable produce as a fraction of the total biomass produced by the crop in a given year

hastate: with more or less triangular basal lobes diverging laterally

head: a dense inflorescence of small crowded often stalkless flowers (a capitulum)

headspace: the space in a container between the contents and the closure; in perfumery, the volatile compounds evaporated by flowers, representing their true odour

hemi-: prefix, meaning half

herb: any vascular plant which is not woody

herbaceous: with the texture, colour and properties of a herb; not woody

hermaphrodite: bisexual; in flowers, with stamens and pistil in the same flower

hesperidium: a superior, polycarpellary, syncarpous berry, pulpy within, and externally covered with a tough rind, e.g. citrus fruits

heterogamous: with two or more kinds or forms of flowers

heterogeneous: lacking in uniformity; exhibiting variability

heteromorphic: varying in number or form

heterostylous: having styles of two or more distinct forms or of different lengths

hexaploid: having six sets of chromosomes ($6n$)

hilum: the scar left on a seed indicating its point of attachment

hirsute: with rather coarse stiff hairs

hispid: covered with long rigid hairs or bristles

hoarseness: a rough or noisy quality of voice

homogeneous: uniform as to kind; showing no variability

homologous: of one type

husk: the outer covering of certain fruits or seeds

hyaline: almost transparent

hybrid: the first generation offspring of a cross between two individuals of different species or taxa

hybridization: the crossing of individuals of different species or taxa

hypanthium: a cup-like receptacle usually derived from the fusion of the floral envelopes and androecium on which are seemingly borne the calyx, corolla and stamens

hyperaemia: an excess of blood in a part of the body

hypocotyl: the young stem below the cotyledons

hypogeal: below ground; in hypogeal germination the cotyledons remain below ground within the testa

hypoglycemia: abnormal decrease of sugar in the blood

idioblast: a cell differing markedly in form and contents from other constituents of the same tissue, like crystalliferous cells, oil and mucilage cells

imbricate: overlapping like tiles; in a flower bud when one sepal or petal is wholly external and one wholly internal and the others overlapping at the edges only

imparipinnate: of leaves, pinnate with an unpaired terminal leaflet

impressed: marked with slight depressions

in situ: in the natural environment; in medicine: in the natural or normal place

in vitro: outside the living body and in an artificial environment

incised: cut deeply

incompatibility: in floral biology: not capable of cross- or self-fertilization; in plant propagation: not capable of making stock–scion combinations resulting in a lasting union

indehiscent: not opening when ripe

indented: forced inward to form a depression

indeterminate: of inflorescences: a sequence in which the terminal flowers are the last to open, so that the floral axis may be prolonged indefinitely by the terminal meristem; of shoot

growth: when the shoot apex forms and unfolds leaves during extension growth, so that shoot growth can continue indefinitely
indigenous: native to a particular area or region
indumentum: a covering, as of hairs, scales, etc.
inferior: beneath, lower, below; an inferior ovary is one which is situated below the sepals, petals and stamens
inflexed: bent or curved inward toward the centre
inflorescence: the arrangement and mode of development of the flowers on the floral axis; the branch that bears the flowers, including all its bracts and branches
infrafoliar: borne below the leaves
infructescence: a ripened inflorescence in the fruiting stage
inner bark: the secondary phloem; the living part of the tissue outside the cambium
insecticidal: destroying or controlling insects
insecticide: an agent that destroys insects
integument: the envelope of an ovule
intercropping: the growing of two or more crops in different but proximate rows
interfoliar: borne among the leaves
internode: the portion of the stem (culm) between two nodes
interpetiolar: of stipules placed between the petioles of opposite leaves
intrapetiolar: of stipules, positioned within the petiole axil
introrse: turned inward, towards the axis, as the dehiscence of an anther
involucel: a secondary partial involucre
involucral: belonging to an involucre
involucre: a ring of bracts (involucral bracts) surrounding several flowers or their supports, as in the heads of *Compositae* or the umbels in *Umbelliferae*
involute: having the edges of the leaves rolled inwards
irregular flower: in which parts of the calyx or corolla are dissimilar in size and shape; asymmetrical or zygomorphic
isozymes: multiple distinct molecular forms of an enzyme that differ in net electrical charge; important to the investigation of the molecular basis for cellular differentiation and morphogenesis, and increasingly used to clarify genotypic relationships
joint; jointed: an articulation, like a node in plants and a place of union of two bones in the human body; articulated
jorquette: branching system in cocoa whereby 3–5 lateral plagiotropic branches grow almost horizontally and at the same level, looking like a fan
joss stick: see agarbatti
jugate: connected or yoked together; e.g. in leaves 1–n-jugate: with 1–n pairs of leaflets
juvenile phase (stage): the period between germination and the first signs of flowering, during which vegetative processes preclude flower initiation even under the most favourable conditions
keel (carina): a ridge like the keel of a boat; the two anterior and united petals of a papilionaceous corolla; the principal vein of a sepal or glume
kernel: the nucellus of an ovule or of a seed, that is, the whole body within the coats
labellum: lip; the lowest petal of an orchid; petaloid anterior staminode in *Zingiberaceae*
lacerate: torn; irregularly cleft or cut
laciniate: slashed, cut into narrow lobes
lamellate: made up of thin plates
lamina: see blade
lanate: with woolly hairs
lanceolate: lance-shaped; much longer than broad, being widest at the base and tapering to the apex
landrace: a locally developed kind of cultivar, without formal recognition, and usually much more variable than an official registered cultivar and from which usually several cultivars can be selected
lanose: woolly
lateral: on or at the side
latex: a juice, usually white and sometimes sticky, exuding from broken surfaces of some plants
lax: loose, distant
leaflet: one part of a compound leaf
lemma: the lower of the two glumes which surround each floret in the spikelet of grasses
lenticel: lenticular masses of loose cells protruding through fissures in the periderm on stems, fruits and roots, usually arising beneath individual stomata; their main function is gaseous exchange
lenticular: shaped like a double-convex lens
leucoplakia: a white patch on a mucous membrane that will not rub off
leucorrhoea: a whitish, viscid discharge from the female genitals
liana: a woody climbing vine
ligulate: possessing an elongated flattened strap-shaped structure or ligule
ligule: an elongated flattened strap-shaped structure; a membranous outgrowth on the upper surface of a grass leaf at the junction of the sheath and the blade which may be presented

by a ridge or by a line of hairs; in palms it is a distal projection of the leaf sheath, often coriaceous
limb (botany): the expanded part of a tubular corolla, as distinct from the tube or throat; the lamina of a leaf or of a petal; the branch of a tree
linear: long and narrow with parallel sides
lingulate: tongue-shaped
lobe: any division of an organ or specially rounded division
lobed: divided, but not to the base
locellate: dividing into locelli
locellus: small locule (loculus in Latin)
locular: divided by internal partitions into compartments as in anthers and ovaries
locule: the cavity of an ovary or anther
loculicidal: the cavity of a pericarp dehiscent by the back, the dorsal suture
lodge: (in agronomy): to beat (as a crop) flat to the ground
lodicule: one of the small, usually thin, delicate and transparent structures inserted usually in a single whorl of 3, immediately below the stamens in the grass and bamboo flower
longitudinal: lengthwise
lumbago: pain in the lumbar region of the back (loins); lumbar rheumatism
maceration: a process of softening plant matter by soaking; in perfumery it denotes the extraction of odorous plant material by soaking it in hot melted fat
macronutrients: chemical elements of which relatively large quantities are essential for the growth of a plant (such as N, P, Ca, Mg)
Malesia: the biogeographical region including Malaysia, Indonesia, the Philippines, Singapore, Brunei and Papua New Guinea
mangrove: a brackish-water coastal swamp of tropical and subtropical areas that is partly inundated by tidal flow
marcotting: air layering, a form of layering in which soil (rooting medium) is brought to the branch to be layered; the ball of soil in a polyethene cover is wrapped around the girdled branch; after adventitious roots grow out above the girdle, the layer can be separated
mass spectroscopy: a technique of analysis in which the molecules of a pure compound are subjected to bombardment with high energy electrons; the molecules of the sample are fragmented and separated according to their masses, producing a graphical 'fragmentation pattern'; the molecular structure of the compound can be derived from this pattern
membranaceous (membranous): thin and semi-transparant, like a fine membrane
membranous: thin and semi-transparent, like a fine membrane
mericarp: one of the separate halves or parts of a fruit, as in *Umbelliferae*
meristem: undifferentiated tissue of the growing point whose cells are capable of dividing and developing into various organs and tissues
merous (4-, 5- etc.): with 4, 5 etc. parts or numbers of sepals, petals etc.
mesocarp: the middle layer of the pericarp or fruit wall which is often fleshy or succulent
mesophyll: the interior parenchyma of a leaf
midrib: the main vein of a leaf which is a continuation of the petiole
miscibility: the capability of liquids of being mixed to form a homogeneous substance (see also: solubility)
mixed cropping: the growing of two or more crops simultaneously in the same field at the same time
monadelphous: of stamens, united into one group by their filaments
monocarp: a plant that flowers and fruits only once during its lifetime; the single carpel of an apocarpous fruit
monochasium: a cymose inflorescence where a pattern of a single lateral branch arising below the terminal flower is repeated
monocotyledon: angiosperm having a single cotyledon or seed-leaf
monoculture: the cultivation during an extended period of time of a single product to the exclusion of other possible uses of the land
monoecious: with unisexual flowers, but male and female flowers borne on the same plant
monoterpene: a terpene of molecular formula $C_{10}H_{16}$, e.g. limonene, myrcene and phellandrene; most monoterpenes are readily oxidized to coarse-smelling products, so essential oils containing them must be carefully preserved to minimize this tendency
monotypic: consisting of a single element, e.g. of a genus consisting of only one species
mucilage: a gelatinous substance that is similar to gum but that swells in water without dissolving and forms a slimy mass
mucilaginous: slimy
mucro: a sharp terminal point
mucronate: ending abruptly in a short stiff point
mulch: plant or non-living materials used to cover the soil surface with the object of protecting it from the impact of rainfall, controlling weeds,

temperature and evaporation

muricate: rough, with short and hard tubercular excrescences

mycorrhiza: a symbiotic association of roots with a fungal mycelium which may form a layer outside the root (ectotrophic) or within the outer root tissue (endotrophic)

narcotic: pertaining to or producing narcosis or stupor; an agent that in moderate doses dulls the senses, relieves pain and induces sleep, but in excessive doses may cause stupor, coma, convulsions and death

naturalized: introduced into a new area and established there, giving the impression of wild growth

nectar: a sweet fluid exuded from various parts of the plant (e.g. by the flower to attract pollinators)

nectary: a group of modified subepidermal cells in flowers or leaves (extrafloral) secreting nectar

nematode: small elongated cylindrical worm-like micro-organism, free-living in soil or water, or parasitic in animals or plants

nerve: in botany: a strand of strengthening and/or conducting tissue running through a leaf, which starts from the midrib and diverges or branches throughout the blade

neuralgia: pain radiating along the course of one or more nerves

neuter: sexless, neither male or female; having neither functional stamens nor pistils

node: the point on the stem or branch at which a leaf or lateral shoot is borne

nucellar: belonging to the body of the ovule or macrosporangium containing the embryo sac or macrospore

nucellus: the nutritive tissue in an ovule

nut: a one- to many-seeded indehiscent fruit with a hard dry pericarp or shell

nutlet: a little nut

ob-: prefix, indication inverse or opposite condition (obtriangular, obcordate, etc.)

oblanceolate: reverse of lanceolate

oblique: slanting; of unequal sides

oblong: longer than broad, with the sides parallel or almost so

oblongoid: a solid object which is oblong in section

obovate: reverse of ovate

obovoid: a solid object which is obovate in section

obtuse: blunt or rounded at the end

offset (offshoot, rhizome cutting): a lateral shoot used for propagation

oil cell (anatomy): a parenchymatous idioblast filled with oil

oil gland: a glandular cell which secretes oil

oleoresin: a natural plant product consisting of a viscous mixture of mainly essential oil and non-volatile odourless solids

olfaction: the process of smelling

operculum: a lid or cover which separates by a transverse line of division

opposite: of leaves and branches when two are borne at the same node on opposite sides of the stem

optical activity: in organic chemistry, the property of a compound, containing an asymmetrical carbon atom, of rotating the plane of polarized light, clockwise in the case of dextrorotatory (abbreviated d-) compounds, and counterclockwise in the case of laevorotatory (abbreviated l-) compounds; in perfumery d- and l-compounds may have different odours, e.g. d- and l-limonene

optical isomerism: isomerism in which the molecular structures of the molecules are mirror-images of one another; optical isomers have the same structural formula, but their molecules cannot be superimposed

optical rotation: see optical activity

orbicular: flat with a more or less circular outline

oriental: in perfumery, a heavy and long-lasting perfume; ambergris-like and/or spicy notes combined with woody and balsamic tonalities are typical of this perfume family; middle notes are generally floral, topnotes tend to be contrastingly fresh and light

orifice: an opening by which spores, etc., escape; ostiole

orthotropic: having a more or less vertical direction of growth

outer bark: the periderm or rhytidome; the non-living layer of fibrous or corky tissue outside the cambium in woody plants which may be shed or retained

ovary: in plants, that part of the pistil, usually the enlarged base, which contains the ovules and eventually becomes the fruit

ovate: egg-shaped in outline or in section; a flat surface which is scarcely twice as long as broad with the widest portion below the middle

ovoid: a solid object which is egg-shaped (ovate in section)

ovule (botany): the immature seed (egg) in the ovary before fertilization

palea: the upper of two membranous bracts enclosing the flower in grasses

palisade cells: perpendicular elongated parenchyma cells on the surface of most leaves

palmate: of leaflets, leaf-lobes or veins, with the different elements arising from the same point
palmatifid: cut about half way down in a palmate manner = palmately lobed
palmatilobed: lobed in palmate manner
panacea: a universal remedy; a herb credited with remarkable healing properties
panduriform: fiddle-shaped, drawn in at the middle
panicle: an indeterminate branched racemose inflorescence
paniculate: resembling a panicle
pantropical: distributed throughout the tropics
papillate: having minute nipple-like protuberances
papillose: covered with minute nipple-like protuberances
pappus: the various tufts of hairs on achenes or fruits; the limb of the calyx of *Compositae* florets
papyraceous: papery, like paper
parasitic: deriving nourishment from some other organism
paratracheal: applied to wood-elements arranged about the vessels
parenchyma: in plants: ground tissue composed of thin-walled, relatively undifferentiated cells, e.g. the pith and mesophyll
paripinnate: a pinnate leaf with all leaflets in pairs
partite (parted): cleft, but not quite to the base
patent (botany): spreading out widely
pedicel: the stalk of an individual flower
pedicellate: furnished with a pedicel
peduncle: the stalk of an inflorescence or partial inflorescence
pedunculate: furnished with a peduncle
pellucid: translucent
peltate: of a leaf, with the stalk attached to the lower surface, not at the edge
pendent, pendulous: drooping; hanging down from its support
penninerved: pinnately veined, parallel veins arise at an angle from a midvein (as in *Musa*)
pentamerous: having five parts in a flower-whorl
perennial: a plant living for many years and usually flowering each year
perfect flower: a flower possessing both male and female organs
perfume: a harmonious composition prepared from natural and/or synthetic aromatic materials having aesthetic appeal alone, or after incorporation in an end-product
perianth: the floral leaves as a whole, including both sepals and petals if both are present
pericarp: the wall of the ripened ovary or fruit whose layers may be fused into one, or may be more or less divisible into exocarp, mesocarp and endocarp
persistent: remaining attached; not falling off, not deciduous; applies to organs that remain in place after they have fulfilled their natural functions
petal: a member of the inner series of perianth segments (corolla) which are often brightly coloured
petaloid: petal-like
petiolate: having a petiole
petiole: the stalk of a leaf
petiolule: the stalk of a leaflet
phenology: the complex annual course of flushing, quiescence, flowering, fruiting and leaf fall in a given environment
phenotype: the physical or external appearance of an organism as distinguished from its genetic constitution (genotype); a group of organisms with similar physical or external make-up
phloem: the principal food-conducting tissue of vascular plants; the bast element of a vascular bundle and basically composed of sieve elements, parenchyma cells, fibres and sclereids
photoperiod: the relative duration of illumination in a cycle of light and darkness, whether occurring naturally (day and night) or imposed in an artificial way
photosensitive: sensitive to the action of radiant energy such as light
phyllotaxy: the arrangement of leaves or floral parts on their axis
phylogenetic: based on natural evolutionary and genealogical relationships
phytosanitary: of or relating to health or health measures of plants
pilose: hairy with rather long soft hairs
pilosellous: hairy with short soft hairs
pinna (plural: pinnae): a primary division or leaflet of a pinnate leaf
pinnate: arranged in pairs along each side of a common axis
pinnatifid: pinnately divided about halfway to the midrib
pinnatisect: pinnately divided down to the midrib
pistil: the female part of a flower (gynoecium) of one or more carpels, consisting, when complete, of one or more ovaries, styles and stigmas
pistillate: a unisexual flower with pistil, but no stamens
pistillode: a sterile, often reduced pistil
placenta: in plants, the part of the ovary to which the ovules are attached

placentation: the way in which the placentae are arranged in the ovary

plagiotropic: having an oblique or horizontal direction of growth

plano-convex: flat on one side and convex on the other

pleonanthic: of plants (e.g. some palms) flowering continuously, not dying after flowering (cf. hapaxanthic)

ploidy: degree or repetition of the basic number of chromosomes

plumose: featherlike with fine hairs

plumule: the primary bud of an embryo or germinating seed

pod: a dry fruit composed of a single carpel and dehiscing by sutures, as in legumes; a general term for a dry dehiscent fruit

pollarding: cutting a tree back to the trunk to promote the growth of a dense head of foliage

pollen: spores or grains borne by the anthers containing the male element (gametophyte)

pollination: the transfer of pollen from the dehiscing anther to the receptive stigma

polyembryonic: with more than a single embryo in an ovule

polygamous: with unisexual and bisexual flowers in the same plant

polymorphic, polymorphous: with several or various forms; variable as to habit

polyploid: with more than two sets (genomes) of chromosomes in the somatic cells

pomade (pommade): the highly fragrant, essential-oil-soaked fat resulting from enfleurage, usually used for absolute production

posterior: next to or towards the main axis

poultice: a soft, moist, usually heated and sometimes medicated mass spread on cloth and applied to sores or other lesions to create moist local heat or counterirritation

praemorse: as though the end were bitten off

prickle: a sharp, relatively stout outgrowth from the outer layers

primary vegetation: the original, undisturbed plant cover

procumbent: lying along the ground; in wood anatomy also of ray parenchyma cells with their longest dimension in radial direction

propagule: a part of a plant that becomes detached and grows into a new plant

prophyll: the bracteole at the base of an individual flower; the first bract borne on the inflorescence

prostrate: lying flat on the ground

protandrous: of flowers, shedding pollen before the stigma is receptive

protogynous: of flowers, the stigma is receptive before the pollen is shed; of inflorescences, the female flowers mature before the male ones

protuberance: projection, an extension beyond the normal surface

proximal: in botany: the part nearest the axis (as opposed to distal)

pruinose: having a waxy powdery secretion on the surface, a bloom

pruning: cutting off the superfluous branches or shoots of a plant for better shape or more fruitful growth

puberulent: covered with down or fine hairs

puberulous: minutely pubescent

pubescent: covered with soft short hairs

pulp: the soft fleshy part of the fruit; mechanically ground or chemically digested wood used in manufacturing paper and allied products

pulvinus (plural: pulvinae): a minute gland or swollen petiole base.

punctate: marked with dots or translucent glands

punctiform: in the form of a point or dot

pungent: bearing a sharp point; causing a sharp or irritating sensation

pyrene: a nutlet or kernel; the stone of a drupe or similar fruit

pyriform: resembling a pear in shape

quadrangular: four-cornered or four-edged

qualitative short-day plant: plant requiring short days to flower (often with quantitative response); if the daylength surpasses a certain value (the critical daylength) the plant does not flower

quantitative short-day plant: plant flowering sooner under short-day conditions, but short days are not absolutely necessary to flower

raceme: an unbranched elongated indeterminate inflorescence with stalked flowers opening from the base upwards

racemose: raceme-like

rachilla: a diminutive or secondary axis, e.g. the branch that bears a flower or the stalk of the spikelet in grasses

rachis (plural: rachides): the principal axis of an inflorescence or a compound leaf beyond the peduncle or petiole

radical: arising from the root, or its crown

radicle: the first root of an embryo or germinating seed

rain forest: a tropical forest receiving an annual rainfall of at least 1800 mm, characterized by lofty evergreen trees forming a continuous canopy below which terrestrial herbs and shrubs are poorly developed *ray*: the radiating branch of an umbel; the outer floret of an inflorescence of the *Compositae* with straplike perianth which differs from those in the centre or disk

receptacle (botany): the flat, concave or convex part of the axis from which the parts of the flower arise

reconstitution: the reproduction of an aromatic material of natural origin; it involves identification of the components of the natural product, followed by close matching of the results of the analysis using mainly cheaper synthetic aroma chemicals to produce an essentially convincing representation of costly natural products; some products, e.g. bergamot oil, have been reconstituted with astonishing success, while other odours, e.g. those of cassie oil and ylang-ylang oil are more difficult to reproduce

rectification: a second distillation of an essential oil with the purpose of removing non-volatile matter

recurved: bent or curved downward or backward

reflexed: abruptly bent or turned downward or backward

reforestation: the planting of a formerly forested area with forest trees

refractive index: the ratio of the sine of the angle of incidence to the sine of the angle of refraction when a beam of light passes from a vacuum (or the atmosphere) into the medium studied; this ratio is equivalent to the ratio of the velocity of light in free space to that in the medium

refrigerant: in medicine: an agent that relieves fever and thirst

regular: of a radially symmetrical flower; actinomorphic

reniform: kidney-shaped

resin: solid to soft semisolid amorphous fusible flammable substance obtained as exudate or as an extract of plants

resinoid: prepared by solvent extracting exudates, highly lignified plant material, or animal substances; incorrectly but commonly used when describing the physical condition of absolutes

reticulate: netted, as when the smallest veins of a leaf are connected together like the meshes of a net

retrorse: turned or directed backward or downward (opposed to antrorse)

revolute: of leaves with the margins, rolled downwards towards the midrib

rhizome: an underground stem which is distinguished from a root by the presence of nodes, buds, and leaves or scales

rhombic: shaped like a rhomb, an equilateral oblique-angled figure

rind: the tough outer layer of the fruit

ripple marks: fine horizontal striations visible on tangential longitudinal surfaces of wood, due to the storied arrangement of rays or of axial elements or both

root sucker: a shoot originating from adventitious buds on the roots

rootstock: see rhizome; a stock for grafting consisting of a root and part of the main axis

rosette: a cluster of leaves or other organs in a circular form

rostrum: a beak-like extension

rotate: circular and flat, applied to a gamopetalous corolla with a short tube

rotund: rounded in outline, somewhat orbicular, but a little inclined towards oblong

rudimentary: of organs, imperfectly developed and non-functional

rugose: wrinkled

rugulose: somewhat wrinkled

ruminate: of endosperm, mottled in appearance, due to the infolding of a dark inner layer of the seed-coat into the paler coloured endosperm

saccate: pouched

sagittate: shaped like an arrowhead; of a leaf base with two acute straight lobes directed downwards

salver-shaped: tubular with a spreading limb, e.g. the corolla of the primrose (also called hypocrateriform)

saponin: a glycoside with soap properties

saprophyte: a plant which derives its food from dead organic matter

sapwood: the outer layers of wood adjacent to the bark which in the living tree contain living cells and reserve materials

sarcotesta: the fleshy outer seed-coat

scabrid, scabrous: rough to the touch

scalariform: ladder-like, having markings or perforations suggestive of a ladder

scale: a thin scarious body, often a degenerate leaf or a trichome of epidermal origin

scandent: climbing

scarification: scratching or making incisions, e.g. to harvest latex from Papaver somniferum; of seed, the cutting or softening of the wall of a hard seed to hasten germination

schizocarp: a dry fruit formed from a syncarpous ovary which splits into one-seeded portions, mericarps or 'split fruits'

sciophyte: shade-loving plant

sclerenchyma cells: all thick-walled cells which retain their propoplasm

scorpioid: circinate; coiled as to resemble a scorpion
scrub: vegetation whose growth is stunted because of lack of water coupled with strong transpiration
secondary vegetation: a plant cover that has been disturbed by natural causes or by man
secondary venation: the collection of veins of a leaf blade branching off from midrib in pinnately veined leaves, or from the main veins in palmately veined ones
section (botany): a taxonomic rank between the genus and the species accommodating a single or several related species
seed: the reproductive unit formed from a fertilized ovule, consisting of embryo and seed-coat, and, in some cases, also endosperm
seedling: a plant produced from seed; a juvenile plant, grown from a seed
segment: one of the divisions into which a plant organ, as a leaf or a calyx, may be cleft; the division of a palmate or costapalmate leaf
self-compatible: capable of fertilization and setting seed after self-pollination
self-fertile: capable of fertilization and setting seed after self-pollination
self-pollination: pollination with pollen from the same plant or from other flowers of plants of the same clone
self-sterile: failure to complete fertilization and obtain seed after self-pollination
semi-: prefix, meaning half or incompletely, e.g. semi-inferior
sepal: a member of the outer series of perianth segments
sepaloid: sepal-like
septate: divided by one or more partitions
septum (plural: septa): a partition or cross-wall
sericeous: silky
serrate: toothed like a saw, with regular pointed teeth pointing forwards
serrulate: serrate with minute teeth
sesquiterpene: a terpene of molecular formula $C_{15}H_{24}$, e.g. caryophyllene and farnesene
sessile: without a stalk
seta (plural: setae): a bristle-like body
setose: set with bristles or bristle-like elements
shaggy: villous
sheath: a tubular structure surrounding an organ or part, as the lower part of the leaf clasping the stem in grasses
shell: the hard envelop of a nut
shoot: the ascending axis, when segmented into dissimilar members it becomes a stem; a young growing branch or twig
shrub: a woody plant which branches from the base, all branches being equivalent (see also tree)
sialagogue: an agent promoting the flow of saliva
simple (botany): not compound, as in leaves with a single blade
sinuate: with a deep wavy margin
sinuous: wavy
sinusitis: inflammation of a sinus (cavity)
slash: a cut or stroke along the stem of a tree to reveal exudates and colours of bark and sapwood
sole crop: one crop grown alone in pure stands (also called single crop)
solubility: the weight of a solute required to saturate 100 g of a solvent at a given temperature
solvent extraction: see extraction
spadix: a flower spike with a fleshy or thickened axis, as in aroids and some palms
spasm: a sudden, violent, involuntary contraction of muscles
spasmolytic: checking spasms; antispasmodic
spatulate (also: spathulate): spoon-shaped
spathe: a large bract enclosing a spadix, or two or more bracts enclosing a flower cluster
spatheole: small spathe
specific gravity: ratio of the weight of a volume of material to the weight of an equal volume of water of 4°C
spherical: globular
spicate: spike-like
spiciform: with the form of a spike
spicule: a fine, fleshy or brittle, needlelike spine
spike: a simple indeterminate inflorescence with sessile flowers along a single axis
spikelet: a secondary spike, one of the units of which the inflorescence is made in grasses, consisting of one or more florets on a thin axis, subtended by a common pair of glumes
spine (botany): a short, stiff, straight, sharp-pointed, hard structure usually arising from the wood of a stem
spinescent: ending in a spine or sharp point
spinose, spinous: having spines
spiral: as though wound round an axis
spur: in botany: a hollow and slender extension of some part of the flower, usually nectariferous; a small reproductive shoot; in forestry: a buttress-like projection of a tree trunk
squamose: scaly
squamous cell carcinoma: carcinoma developed from squamous epithelium, having cuboid cells and characterized by keratinization and often by preservation of intercellular bridges

stamen: one of the male reproductive organs of a flower; a unit of the androecium
staminate: a flower bearing stamens but no pistil
staminode: an abortive or rudimentary stamen without or with an imperfect anther
steam distillation: distillation using steam injected under pressure into a distillation vessel
stellate: star-shaped, as of hairs with radiating branches, or of petals arranged in the form of a star
stem: the main ascending axis of a plant; in bamboos usually named culm, in other plant groups occasionally
stereoisomerism: isomerism in which 2 or more compounds have the same molecular and structural formula, but differ in the spatial arrangement of the atoms in their molecules (see also: geometrical or cis-trans isomerism and optical isomerism)
sterile: unable to produce offspring; in plants: failing to complete fertilization and produce seed as a result of defective pollen or ovules; not producing seed capable of germination; lacking functional sexual organs (sterility)
stigma: the portion of the pistil which receives the pollen
still: an apparatus for distillation
stipe: the stalk supporting a carpel or gynoecium
stipitate: borne on a stipe or short stalk
stipule: a scale-like or leaf-like appendage at the base of a petiole
stolon: a trailing stem usually above the ground which is capable of producing roots and shoots at its nodes
stoloniferous: bearing a stolon or stolons
stoma (plural: stomata): a breathing pore or aperture in the epidermis
stomachic: pertaining to the stomach; a medicine stimulating the action of the stomach
stone: the hard endocarp of a drupe containing the seed or seeds
strain: a group of individuals of a common origin, usually a more narrowly defined group than a cultivar
striate: marked with fine longitudinal parallel lines, as grooves or ridges
strigose: with short stiff hairs lying close along the surface
stump: seedling with trimmed roots and shoot and used as planting stock; the part of anything that remains after the main part has been removed, e.g. the part of a tree remaining attached to the root after the trunk is cut
style: the part of the pistil connecting the ovary with the stigma
sub-: prefix, meaning somewhat or slightly (e.g. subacute), or below (e.g. subterranean) or less than, imperfectly
subfamily: a taxonomic rank between the family and the tribe denoting a part of a family
subglobose: nearly globular
subspecies: a subdivision of a species, in rank between a variety and a species
subulate: awl-shaped, sharply pointed
succulent: juicy, fleshy
sucker: a shoot, usually originating from adventitious buds on the roots or basal stem parts, which does not fit in the architectural model, but is capable of repeating the model
sudorific: causing or promoting the flow of sweat; an agent causing sweating
sulcate: grooved or furrowed
superior: of an ovary, with the perianth inserted below or around its base, the ovary being attached at its base only
supra-axillary: growing above an axil
sympetalous: with united petals
sympodial: of a stem in which the growing point either terminates in an inflorescence or dies, growth being continued by a new lateral growing point
syncarp: a multiple or fleshy aggregate fruit, including fruit produced from a more or less entire inflorescence (as in *Artocarpus*, *Ananas*, *Morus*)
syncarpous: of an ovary composed of two or more united carpels
tail (botany): any long and slender prolongation
tangential: lengthwise, in a plane at right angles to the radius but not passing through the pith (cf. radial)
taproot: the primary descending root, forming a direct continuation of the radicle
taxon (plural: taxa): a term applied to any taxonomic unit irrespective of its classification level, e.g. variety, species, genus, etc.
taxonomy: the study of principles and practice of classifying living organisms (systematics)
tendril: a thread-like climbing organ formed from the whole or part of a stem, leaf or petiole
tepal: a segment of a perianth, applied when no distinction between sepals and petals can be made
terete: cylindrical; circular in transverse section
terminal: placed at the end or apex; a termination, end or extremity
terpene: an unsaturated hydrocarbon of molecular formula $(C_5H_8)_n$. In monoterpenes n=2, in sesquiterpenes n=3. The term terpene is often used to refer to a terpenoid

terpenoid: a chemical compound derived from a terpene
terrestrial: on or in the ground
tertiary venation: generally the collection of the smallest veins of a leaf blade
testa: the outer coat of the seed
tetradynamous: of a flower, having four long stamens and two short ones, as in *Cruciferae*
tetraploid: having four times ($4n$) the basic number of chromosomes or twice the diploid number ($2n$)
texture (wood anatomy): the general direction or arrangement of the fibres; grain
thorn: a woody sharp-pointed structure formed from a modified branch
throat (botany): of a corolla, the orifice of a gamopetalous corolla
thyrse (thyrsus): a compound inflorescence composed of a panicle (indeterminate axis) with the secondary and ultimate axes cymose (determinate)
tiller: a shoot from the axils of the lower leaves, e.g. in some grasses and palms (making such shoots: tillering)
timber: any wood other than fuelwood
tissue culture: a body of tissue growing in a culture medium outside the organism
tomentellous: minutely tomentose
tomentose: densely covered with short soft hairs
tomentum: pubescence
tonic: restoring or producing the normal tone (degree of vigour and tension) of tissue or organs; characterized by continuous tension (e.g. tonic spasm); medicinal preparation believed to have the power of restoring normal tone to tissue or organs
top note: the first odour impression given by an aromatic material when smelled
tree: a perennial woody plant with a single evident trunk (see also shrub)
triad: a group composed of 3 elements; a special group of 2 lateral staminate and a central pistillate flower, structurally a short cincinnus
tribe: a taxonomic rank between the family and the genus
trichome: any hair, bristle or scale-like outgrowth of the epidermis
trifid: cleft in three parts
trifoliate: three-leaved
trifoliolate: with three leaflets
trigonous: three-angled, with plane faces
truncate: cut off more or less squarely at the end
trunk: the main stem of a tree apart from its limbs and roots
tuber: the swollen portion of an underground stem or root which acts as a storage organ and propagule; it is usually of one year's duration, those of successive years not arising directly from the old ones nor bearing any constant relation to them
tuberculate: covered with warty protuberances
tuberous: producing tubers or resembling a tuber
tufted: growing in tufts (caespitose)
turgid: swollen, but not with air
umbel: an indeterminate, often flat-topped inflorescence whose divergent peduncles (rays) and pedicels arise from a common point; in a compound umbel each ray itself bears an umbellule (small umbel)
umbellet (umbellule): diminutive of umbel
umbonate: bearing an umbo (a convex elevation) or boss in the centre
unarmed: devoid of thorns, spines or prickles
uncinate: hooked
undershrub: any low shrub; partially herbaceous shrub, the ends of the branches perishing during the winter
undulate: wavy, said for instance of a leaf margin if the waves run in a plane at right angles to the plane of the leaf blade
unifoliolate: with one leaflet only, but in origin a compound leaf
uniseriate: in one horizontal row or series
unisexual: of one sex, having stamens or pistils only
urceolate: urn-shaped
vacuum distillation: distillation in equipment from which most air has been removed; this reduces the pressure acting on the material to be distilled, with the result that it will boil and distil at a lower temperature; it is used to distil liquids containing compounds that decompose at high temperature
valvate: meeting exactly without overlapping (e.g. parts of some flower-buds)
valve: one of the parts produced by a dehiscing capsule
variegated: irregularly coloured in patches, blotched
variety: a botanical variety which is a subdivision of a species; an agricultural or horticultural variety is referred to as a cultivar
vein (botany): a strand of vascular tissue in a flat organ, such as a leaf
velutinous: see velvety
velvety: with a coating of fine soft hairs; the same as tomentose but denser so that the surface resembles (and feels like) velvet

venation (botany): the arrangement of the veins in a leaf
ventral: in botany: facing the central axis (adaxial), opposed to dorsal (abaxial)
vermifuge: an agent expelling worms or intestinal animal parasites; an anthelminthic
verrucose: warty
versatile (botany): turning freely on its support, as anthers on their filaments
verticil: whorl
verticillaster: a false whorl, composed of a pair of opposed cymes, as in *Labiatae*
verticillate: in a whorl with several elements arising at the same node
vesicular: bladder-like
vestigial: small and imperfectly developed
viability: ability to live, grow and develop
villose: with long weak hairs
villous: bearing long weak hairs
vine: a plant having a stem that is too slender to hold itself erect and therefore supports itself by climbing over an object
viscid: sticky
viscous: glutinous, or very sticky
vitta (plural: vittae): an aromatic oil duct of the pericarp of most *Umbelliferae*
volatile: a volatile substance is one that evaporates at room temperature. It is an essential property of odorous materials
warty: covered with firm roundish excrescences
water distillation: a form of distillation in which an aromatic plant material is treated with boiling water to release, vaporize and subsequently condense the essential oil it contains; neroli oil is water distilled from citrus flowers to prevent clumping of the petals, which would occur under steam distillation
waterlogged: flooded with water, generally for a period of at least a few weeks
wax: waxes are mixtures of esters of higher alcohols and higher fatty acids. Waxes are used as stiffening agents in the manufacture of cosmetics. Natural plant waxes are removed from concretes to produce absolutes
whorl: arrangement with more than two organs of the same kind arising at the same level
wind-break: one to several rows of closely spaced, preferably low branching trees planted to protect adjacent areas from strong winds
wing: any membraneous expansion attached to an organ; a lateral petal of a papilionaceous corolla
wood: the hard, compact, fibrous substance between pith and bark
woolly: clothed with long and tortuous or matted hairs
xylem: the main water-conducting tissue in vascular plants which extends throughout the body of the plant and is also involved in transport of minerals, food storage and support; primary xylem is derived from the procambium, secondary xylem (e.g. the wood of trees and shrubs) from the vascular cambium; xylem is composed of tracheary elements: tracheids and (in angiosperms) vessel elements; both are elongated hollow cells, with thickened, usually heavily lignified walls, and lacking protoplasts when mature; they are joined end to end to form a continuous conducting tube
zygomorphic: irregular and divisible into equal halves in one plane only

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Index of scientific plant names

Page numbers printed in bold refer to main treatment.

Index of vernacular plant names

Page numbers printed in bold refer to main treatment. For transcriptions of Vietnamese names, see at the end of the index.

Transcriptions of Vietnamese characters

[aa] = â	[ar] = ả	[ax] = ã	[ej] = ẹ	[oo] = ô	[ow] = ơ	[uj] = ụ	[uwx] = ữ
[aaf] = ầ	[as] = á	[ee] = ê	[er] = ẻ	[oof] = ồ	[owf] = ờ	[ur] = ủ	[ux] = ũ
[aaj] = ậ	[aw] = ă	[eef] = ề	[es] = é	[ooj] = ộ	[owj] = ợ	[us] = ú	
[aar] = ẩ	[awf] = ằ	[eej] = ệ	[ex] = ẽ	[oor] = ổ	[owr] = ở	[uw] = ư	
[aas] = ấ	[awj] = ặ	[eer] = ể	[if] = ì	[oos] = ố	[ows] = ớ	[uwf] = ừ	
[aax] = ẫ	[awr] = ẳ	[ees] = ế	[is] = í	[oox] = ỗ	[owx] = ỡ	[uwj] = ự	
[af] = à	[aws] = ắ	[eex] = ễ	[of] = ò	[or] = ỏ	[ox] = õ	[uwr] = ử	
[aj] = ạ	[awx] = ẵ	[ef] = è	[oj] = ọ	[os] = ó	[uf] = ù	[uws] = ứ	

The Prosea Foundation
(Plant Resources of South-East Asia)

Name, location, legal status and structure

- Prosea is a Foundation under Indonesian law, with an international charter, domiciled in Bogor. It is an autonomous, non-profit, international agency, governed by a Board of Trustees. It seeks linkage with existing regional and international organizations;
- Prosea is an international programme focusing on the documentation of information on plant resources of South-East Asia;
- Prosea consists of a Network Office in Bogor (Indonesia) coordinating 6 Country Offices in South-East Asia, and a Publication Office in Wageningen (the Netherlands).

Participating institutions

- Forest Research Institute of Malaysia (FRIM), Karung Berkunci 201, Jalan FRIM, Kepong, 52109 Kuala Lumpur, Malaysia;
- Indonesian Institute of Sciences (LIPI), Sasana Widya Sarwono, Jalan Gatot Subroto 10, Jakarta 12710, Indonesia;
- Institute of Ecology and Biological Resources (IEBR), Nghia Do, Cau Giay, Hanoi, Vietnam;
- Papua New Guinea University of Technology (UNITECH), Private Mail Bag, Lae 411, Papua New Guinea;
- Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD), Los Baños, Laguna, the Philippines;
- Thailand Institute of Scientific and Technological Research (TISTR), 196 Phahonyothin Road, Chatuchak, Bangkok 10900, Thailand;
- Wageningen University (WU), Costerweg 50, 6701 BH Wageningen, the Netherlands.

Objectives

- to document and make available the existing wealth of information on the plant resources of South-East Asia for education, extension work, research and industry;
- to make operational a computerized data bank on the plant resources of South-East Asia;
- to publish the results in the form of an illustrated, multi-volume handbook in English;
- to promote the dissemination of the information gathered.

Target groups

- those professionally concerned with plant resources in South-East Asia and working in education, extension work, research and commercial production (direct users);
- those in South-East Asia depending directly on plant resources, obtaining relevant information through extension (indirect users).

Activities

- the establishment and operation of data bases;
- the publication of books;
- the sponsorship, support and organization of training courses;
- research into topics relevant to Prosea's purpose;
- the publication and dissemination of reports and the research results.

Implementation

The programme period has been tentatively divided into 3 phases:
- preliminary phase (1985–1986): publication of 'Plant Resources of South-East Asia, Proposal for a Handbook' (1986);
- preparatory phase (1987–1990): establishing cooperation with South-East Asia through internationalization, documentation, consultation and publication; reaching agreement on the scientific, organizational and financial structure of Prosea;
- implementation phase (1991–2000): compiling, editing and publishing of the handbook; making operational the computerized data bank with the texts and additional information; promoting the dissemination of the information obtained.

Documentation

A documentation system has been developed for information storage and retrieval called Prosea Data Bank. It consists of 7 data bases:
- BASELIST: primarily a checklist of more than 6200 plant species;
- CATALOG: references to secondary literature;
- PREPHASE: references to literature from South-East Asia;
- ORGANYM: references to institutions and their research activities;
- PERSONYM: references to specialists;
- TEXTFILE: all Prosea publications and additional information;
- PHOTFILE: photographs of useful plants of South-East Asia.

Publication

The handbook in blue cover (hardbound) is distributed by Backhuys Publishers, Leiden, the Netherlands (formerly by Pudoc, Wageningen, the Netherlands). The handbook in green cover (paperback) is distributed in two price-classes: a low-price paperback, distributed by Prosea South-East Asia for all developing countries; a medium-price paperback, distributed by Backhuys

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In brief, Prosea is

- an international programme, focused on plant resources of South-East Asia;
- interdisciplinary, covering the fields of agriculture, forestry, horticulture and botany;
- a research programme, making knowledge available for education and extension;
- ecologically focused on promoting plant resources for sustainable tropical land-use systems;
- committed to conservation of biodiversity;
- committed to rural development through diversification of resources and application of farmers' knowledge.

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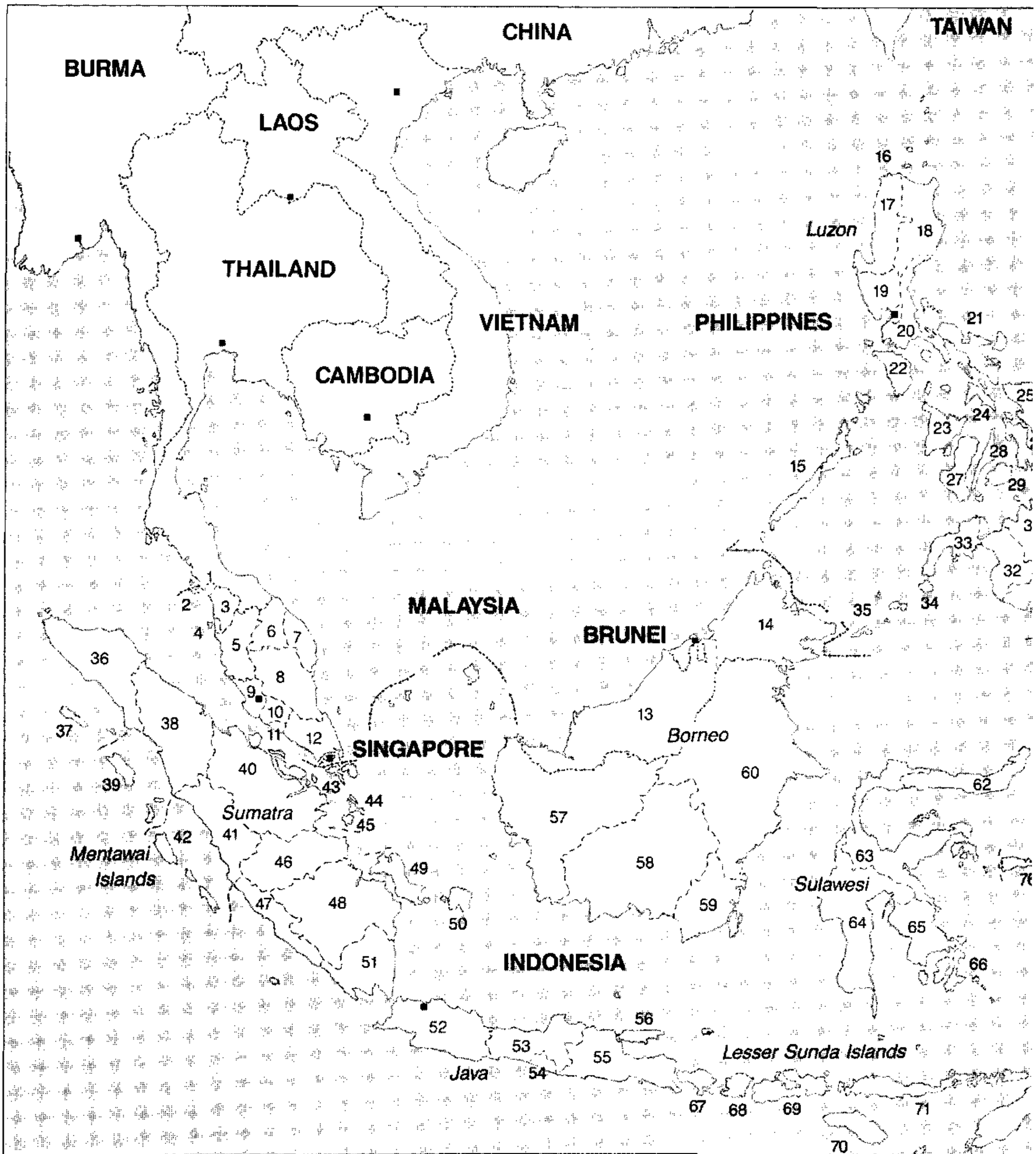

MAP OF SOUTH-EAST ASIA FOR PROSEA

Names of countries in capital letters and islands in lower case; numbers refer to the key.

Key of islands (*i*), states (*s*), regions (*r*) and provinces (*p*).

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Kedah *s* 3
Kelantan *s* 6
Langkawi *i* 2
Melaka *s* 11
Negeri Sembilan *s* 10
Pahang *s* 8
Peninsular Malaysia (West Malaysia) *r* 1-12
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Perlis *s* 1
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Selangor *s* 9
Terengganu *s* 7

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Palawan *i* 15
Panay *i* 23
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