Plant Resources of South-East Asia

No 14

Vegetable oils and fats

H.A.M. van der Vossen and B.E. Umali (Editors)

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Foreword

Oil crops have been cultivated for several thousands of years and the oils of plants such as olive, rapeseed and sesame already gained prominence in the economies and trade of early civilizations. Over the past 100 years there has been a 14-fold increase in world demand for vegetable oils and fats. The 95 million t produced in 2000 from 12 major oil crops represents about 80% of all non-mineral oils; the remaining 20% are made up of oils and fats of animal origin. Soya bean is still the largest producer, accounting for almost 28% of the world supply of vegetable oils, but is closely followed by oil palm with 27% (palm and kernel oils), rapeseed with 15%, sunflower with 10% and the remaining 8 crops including coconut accounting for 20%.

Vegetable oils and fats are essential components in the diet of people in the tropics and subtropics. Nutritionally, oils and fats are two times more efficient as a source of energy than cereals, and they have important functions in food preparation and processing. For a balanced diet of energy, essential fatty acids, and important vitamins, the World Health Organization (WHO) recommends a minimum annual consumption of 25 kg per adult person. In South-East Asia, however, the consumption of vegetable oils and fats often falls below this requirement.

Increasing the availability of inexpensive vegetable oils would be an efficient way of alleviating malnutrition worldwide. In the next two decades, world demand for vegetable oils and fats is expected to grow by 60% as a result of population growth and per capita increase in consumption. Of the major oil crops, oil palm has the largest potential for growth, particularly in South-East Asia, and may soon surpass soya bean as the number one source of vegetable oils in the world.

By carefully reviewing published and less-accessible literature, Prosea volume 14 on vegetable oils and fats presents a synthesis of the oil crops' botanical descriptions, growth and development patterns, ecological requirements, production management, diseases and pests and their control, and harvesting and post-harvest handling techniques. All relevant properties pertaining to the main uses and secondary uses of the crops are also discussed. It also provides updates on the crops' production statistics and international trade status.

Being the result of collective efforts of many specialists, we are confident that this publication, will prove beneficial to researchers, students, teachers, commercial growers, and other stakeholders in their search for relevant and up to date information on vegetable oils and fats. We are also hopeful that the knowledge presented in this volume will contribute to research and development of oil crops in South-East Asia and support the growth and expansion of the region's oil crop-based industries.

Los Baños, Laguna, Philippines, August 2001

Dr. Patricio S. Faylon
Executive Director, PCARRD and Member PROSEA Board Of Trustees

1 Introduction

1.1 Definition and species diversity

1.1.1 Choice of species

Oils and fats are water-insoluble substances, called lipids, consisting of a mixture of triglycerides and containing also small amounts of other lipid and lipid-soluble compounds. Oils are liquid and fats are (semi-)solid at temperatures of 18–24°C. Oils and fats are of vital importance in human nutrition, but have also several technical applications. About 80% of the present world supply is of vegetable and the remainder of animal origin. This Prosea volume reviews plant resources for edible and nonfood oils and fats, collectively called vegetable oils in the introductory chapter.

The 14 major oil crops (17 species) that produce most of the world vegetable oils are presented in Table 1. Only 9 of these will be included in Chapter 2, because 5 have been treated already in other Prosea volumes on account of their primary use. This applies to the pulses (Prosea 1) groundnut (*Arachis hypogaea* L.) and soya bean (*Glycine max* (L.) Merr.), the cereal (Prosea 10) maize (*Zea mays* L.) and the fibre plants (Prosea 17) cotton (*Gossypium* spp.) and flax/linseed (*Linum usitatissimum* L.). The dominant oil crops in South-East Asia are coconut (*Cocos nucifera* L.) and oil palm (*Elaeis guineensis* Jacq.). The remaining major oil crops included in Chapter 2 are rapeseed (*Brassica juncea* (L.) Czern., *B. napus* L., *B. rapa* L.), safflower (*Carthamus tinctorius* L.), sunflower (*Helianthus annuus* L.), olive (*Olea europaea* L.), sesame (*Sesamum orientale* L.) castor (*Ricinus communis* L.) and tung-oil tree and wood-oil tree (*Vernicia fordii* Hemsl. and *V. montana* Lour., respectively). Rapeseed may have little potential as a crop for South-East Asia, but the high degree of interchangeability of major oils makes it a likely component of edible oils available in local markets. Outside of the Mediterranean region, olive oil and table olives are speciality or gourmet items consumed world-wide by more affluent people.

Another 8 oil crops including 11 species (Table 2), which are of local importance only or have potential for future cultivation in South-East Asia, are dealt with in Chapter 2. Rice (*Oryza sativa* L.), from which rice bran oil is derived as a by-product, appeared earlier in the volume on cereals (Prosea 10). Niger seed (*Guizotia abyssinica* (L.f.) Cass.) and jojoba (*Simmondsia chinensis* (Link) C.K. Schneider) would have potential for low-rainfall regions in South-East Asia because of their considerable drought resistance. Jojoba produces a liquid wax of high technical value.

Brief descriptions of 34 minor oil-producing plant species are given in Chapter 3. Other plant species with vegetable oil or fat as a secondary product besides their primary use are listed in Chapter 4.

1.1.2 Origin and geographic distribution

Of all the major oil crops, only the coconut has a South-East Asian – Pacific origin. Since its first domestication some 3000 years ago by Malesian peoples, the coconut has become the 'tree of life' for all coastal tropical regions, on account of the many useful products derived from the palm. Coconut was the most important world source of vegetable oil until overtaken by soya bean in the early 1960s.

Coconut oil is generally preferred for cooking purposes in South-East Asia, but the oil palm is now by far the most important oil crop in the region. The oil palm was taken to South-East Asia from its West-African origin more than 150 years ago and a plantation industry started to develop gradually in the 1920s. The oil palm gained prominence as the dominant oil crop in Malaysia and Indonesia in the 1980s and a decade later also in Papua New Guinea and Thailand. The oil palm continues to be a major oil crop in West Africa and a few countries in tropical America. The American oil palm (*Elaeis oleifera* (Kunth) Cortes) is of no economic importance in South-East Asia, but germplasm has been introduced for experimental plantings. Early European travellers to the Guinean coast of West Africa compared palm oil favourably to olive oil and this may have inspired the botanist Jacquin in 1763 to name the palm *Elaeis guineensis*. Olive oil is extracted from the fruits of the Mediterranean olive tree, which is one of the oldest (4000 BC) cultivated oil crops in the world. Despite its superb quality, olive oil production continues to be mostly restricted to the Mediterranean region due to the specific ecological requirements of the tree. There are some pockets of olive cultivation in North and South America, Australia, South Africa and even in China and Japan.

Soya bean cultivation gradually spread all over Asia from its region of origin in north-east China during the first millennium AD and was introduced into North America in the 18th Century. Groundnut has a South American origin and was taken to Africa and Asia by Portuguese, Spanish and Dutch seafarers in the 16th Century. Soya bean and groundnut occupy 1st and 5th place respectively in the world production of vegetable oils, but in South-East Asia they are mostly cultivated as pulses. The seeds are used for the preparation of fresh, roasted, fermented and dried food products and only a minor portion is crushed for oil extraction.

Brassica rapa and *B. juncea* are two ancient (2000 BC) oil crops of West and South Asia, while *B. napus* has a fairly recent West European origin. The three species together are important producers of vegetable oils in temperate climates, but a recently developed day-length neutral *B. napus* may provide opportunities for rapeseed cultivation in the highlands of South-East Asia. Ethiopian mustard (*B. carinata* A. Braun) is an oil crop restricted to East Africa. Safflower is also an old crop of West Asian origin (2000 BC), cultivated initially for the orange dye obtained from the florets in the Mediterranean and Asian regions, and reaching China and Japan in 200–400 AD. Safflower is now a source of high quality edible oil with considerable areas of cultivation in India, the Americas and Australia. It is grown on a small scale in South-East Asia, particularly in Thailand.

Sunflower was domesticated by North American people more than 5000 years ago and was taken to Europe in the 16th Century. It became an important oil

Table 1. Origin and geographic distribution of 14 major oil crops.

Scientific name	Common name	Region of origin and first cultivation	Region of distribution
Crops producing edible oils			
Arachis hypogaea	groundnut	South America (2000 BC)	Asia, Americas, Africa
Brassica spp.			
B. juncea	Indian mustard	Central Asia (2000 BC)	South Asia
B. napus	rapeseed	Western Europe (1600 AD)	Europe
B. rapa	rapeseed	West Asia (2000 BC)	worldwide
Carthamus tinctorius	safflower	Eastern Mediterranean, West Asia (2000 BC)	Asia, Europe, Americas
Cocos nucifera	coconut	Tropical Asia, Pacific (1000 BC)	pantropical
Elaeis guineensis	oil palm	West Africa (500 AD)	pantropical
Glycine max	soya bean	North-eastern China (1100 BC)	Asia, Americas, Africa
Gossypium spp.	cotton	Asia, Africa & Americas (4000 BC)	Asia, Americas, Africa
Helianthus annuus	sunflower	South-western United States (3000 BC)	worldwide
Olea europaea	olive	Mediterranean (4000 BC)	Mediterranean, Americas, South Africa
Sesamum orientale	sesame	East Africa, South Asia (2000 BC)	Asia, Africa, Americas
Zea mays	maize	Mexico, Central America (1000 BC)	worldwide
Crops producing nonfood oils			
Linum usitatissimum	linseed	India, West Asia (1000 BC)	worldwide
Ricinus communis	castor	East Africa (4000 BC)	worldwide
Vernicia spp.			
V. fordii	tung-oil tree	Central China (100 AD)	Asia, Americas, Africa
V. montana	wood-oil tree	Southern China (100 AD)	

crop in the 19th Century in Russia and subsequently in Central Europe, the Balkan Peninsula, North and South America, West Europe, China and India. In South-East Asia sunflower is grown in Burma (Myanmar) and to a small extent also in Thailand. Sesame has been cultivated for its seeds and edible oil for at least 4000 years in South and West Asia, but its region of origin may have been Ethiopia. It is now produced in many countries in Africa, tropical America and Asia, including Burma (Myanmar), Thailand and Vietnam.

Cotton was domesticated for its seed fibre more than 6000 years ago in South Asia (*Gossypium arboreum* L. and *G. herbaceum* L.) and in South and Central America (*G. barbadense* L. and *G. hirsutum* L.). The American (tetraploid) cotton species dominate present cotton cultivation in all major production areas. In addition to being the most important fibre plant, cotton is also the 4th world oil crop. In South-East Asia, Burma (Myanmar) is the largest producer of cottonseed and oil, followed by Thailand, Indonesia, the Philippines, Vietnam and Laos. Linseed has a West or South Indian origin and was first cultivated for its fibre at about 1000 BC. This is another oil-producing fibre plant with specialized fibre (flax) and seed (linseed) cultivars, the former being grown in temperate and the latter in subtropical regions. However, linseed has no potential for cultivation in the South-East Asia.

Of the two major cereals yielding a vegetable oil as secondary product, maize is a major oil crop worldwide but of little significance in South-East Asia. Rice bran oil is only a minor commodity due to predominantly traditional methods of processing of most rice in Asia, where more than 60% of the rice is grown. China, Japan, Burma (Myanmar), India and Vietnam produce sizable quantities of rice bran oil in nonfood and edible grades.

The two remaining major oil crops mentioned in Table 1 both produce oils for industrial applications. Castor originated in Ethiopia and was cultivated already 6000 years ago in Egypt for lamp oil and medicinal purposes. It spread throughout the Mediterranean basin, to West and South Asia, reached China in the 9th and Europe in the 15th Centuries and is now grown world-wide in warmer climates. The tung-oil tree and wood-oil tree originate in China, where the drying oil has been used for the past 2000 years as wood preservative, for oiling of paper and waterproofing of fabrics. Outside China the tung-oil tree is grown commercially in a few countries including Argentina, Paraguay and Malawi. Efforts to introduce the wood-oil tree in Indonesia around 1930 did not lead to large plantings.

An overview of origin and distribution of 8 other oil crops, including the earlier mentioned rice, is presented in Table 2. Only tengkawang (*Shorea* spp.) and Philippine tung (*Reutealis trisperma* (Blanco) Airy Shaw) are of South-East Asian origin. Jojoba and chia (*Salvia hispanica* L.) are indigenous to South or Central America; rice and kokam butter tree (*Garcinia indica* (Thouars) Choisy) are from South Asia; Chinese tallow tree (*Triadica sebiferum* (L.) Small) is from China; niger seed has its origin in Ethiopia.

The majority of the 35 minor oil-bearing species treated in Chapter 3 have an Asian origin (24 species); 10 species are from South America and 1 from West Africa.

1.2 Role of oil crops

1.2.1 Edible uses of vegetable oils

Vegetable oils are essential components of the daily diet as a source of energy, essential fatty acids and some vitamins. They have also several important functions in food preparation and processing, such as tenderizing, lubricating and adding flavour during cooking and frying and providing structure in bakery products (Stauffer, 1996).

Table 2. Oil crops of local importance or with promising economic value.

Scientific name	Common name	Region of origin	Region of distribution
Garcinia spp.			
G. indica	kokam butter tree	India	Coastal regions of India
G. morella	tamal	India, Sri Lanka	Southern and north-eastern India, Sri Lanka, Bangladesh, south-eastern Tibet, South-East Asia
Guizotia abyssinica	niger seed	Ethiopia	India, Ethiopia
Oryza sativa	rice	foothills of the Himalayas	China, Japan, India, South-East Asia
Reutealis trisperma	Philippine tung	Philippines	Philippines, Indonesia
Salvia hispanica	chia	Mexico, Guatemala	United States, Central America, Argentina
Shorea spp. (3)	tengkawang	Indonesia	South Asia, South-East Asia
Simmondsia chinensis	jojoba	southern United States, Mexico	United States, Mexico, South America, Australia, southern Africa
Triadica sebiferum	Chinese tallow tree	China	China, Taiwan, south-eastern United States, Japan

In many rural areas of developing countries large quantities of unrefined vegetable oils are still used directly for cooking and frying purposes, e.g. palm oil in West Africa, coconut oil in South-East Asia and various seed oils (rapeseed, sesame, niger seed) in South Asia and East Africa. Much of the olive oil consumed as salad and cooking oil in the Mediterranean region is also virtually unrefined apart from some filtration.

Otherwise, all vegetable oils are subjected to various processes following extraction to adapt them to a large diversity of uses. These include salad oils and dressings, margarines, vanaspati, mayonnaises, cooking and frying oils for home consumption. Large quantities of commercial grade frying oils, shortenings, fats and emulsifiers are applied in the food industry for potato crisp, pastry, bakery, biscuit, confectionery, ice-cream, coffee creamer and other products. Vegetable oils are also used in the fish and canning industry (Hatje, 1989).

1.2.2 Technical uses of vegetable oils

Soap and lamp oil are two of the traditional nonfood applications of vegetable oils, notably coconut, oil palm, rapeseed and olive, since time immemorial.

About 15% of present day vegetable oils are converted into soaps and oleochemicals, such as fatty acids, methyl esters, fatty alcohols, fatty acid amides, fatty amines and epoxidized oils (Helme et al., 1995; Pryde & Rothfus, 1989;

Pantzaris, 1997). These are intermediate materials for the manufacture of a wide range of industrial and technical products including toilet soaps, shampoos, cosmetics, candles, waxes and polishes, detergents, surfactants, paints and varnishes, waterproofing of textiles, printing inks, lubricating greases, corrosion inhibitors, plasticizers and stabilizers in (PVC) plastics and even diesel fuels. Refined vegetable oils, particularly palm oil, find application as non-toxic lubricants of food-processing machinery, in the sheet steel and tinning industries to prevent oxidation and also as lubricating oil of textile fibres during spinning and weaving. Castor oil has many technical and pharmaceutical applications.

1.2.3 Seeds, fruits and meals for food and feed

Direct consumption of seed and fruits

A considerable proportion of the seeds or fruits harvested from some oil crops is not used for oil extraction, but consumed directly as a snack or processed food products.

Oilseeds

About 85% of the world soya bean crop undergoes extraction for oil and protein, but in Asia much of it is used in preparing fresh, fermented and dried food products such as sprouted beans, roasted seeds, soya milk, tofu, tempeh and soya sauce. More than 40% of the world groundnut crop and about 80% in South-East Asia is consumed as roasted whole seeds or peanut butter for various food preparations. Non-oilseed sunflower cultivars (10% of the total crop) produce seeds for direct consumption as (roasted) snacks, in confectionery and baking and also as birdseed. Large quantities of whole sesame seeds are used to prepare sweets and in baking or as roasted snacks in South Asia. A paste from ground hulled sesame seeds forms a favourite food in North Africa and the Middle East.

Fruits

It is estimated that 45% of all coconuts produced worldwide are used for edible purposes other than oil extraction: coconut water from immature coconuts, coconut milk from freshly grated endosperm, shredded and desiccated fresh coconut as a side-dish and as an ingredient of bakery and confectionery products and ball copra, an Indian speciality. In West Africa, the mesocarp pulp of freshly harvested oil-palm fruits, after boiling and removal of fibres, forms the basis of a nutritious soup. About 8% of the olive crop is processed into green and black table olives.

Meals

The residual cake after oil extraction is ground into a meal, which is a valuable source of protein to supplement livestock feeds and sometimes also human food (Bell, 1989). More than half of the total meal production is from soya bean.

While in most oilseeds the meal is a by-product of oil extraction, it is in fact the main product of the soya bean crop, being much larger in quantity and value than the oil. Other important producers of meals are canola rapeseed, cottonseed, sunflower and groundnut, while sesame, safflower and linseed also produce high-protein meals. Maize (corn germ), copra and palm-kernel meals have a lower protein and higher fibre content than soya bean and other meals. About 10% of the meals of soya bean, sunflower and groundnut in particular, are processed into flour and protein concentrates for use in bakery and other food products, such as bread and pies, fortified breakfast cereals, meat and milk extenders, meat-like products and infant food formulations.

Low-grade oil cakes and meals or those containing anti-nutritional and toxic substances (e.g. from traditional rapeseed and castor) are used as organic fertilizers. The fibre mass of extracted oil-palm fruits provides fuel for the mill boilers.

1.2.4 Production and international trade

Table 3 gives an overview of world area and mean annual production during the last four years (1997–2000) for each of 14 major edible and nonfood oil crops, in decreasing order of importance based on oil output. Production figures include amounts of 'seed' (kernels for the oil palm and copra for the coconut), meal and oil. Export percentages for meals and oils show the relative magnitude of international trade and local consumption for each commodity. The degree of global cultivation and regional concentration of these oil crops are reflected in the total number of countries and in the five most important ones, which together account for a large proportion of total production (indicated in brackets).

Soya bean is by far the largest oil crop, producing 62% of the world's oilseed meals (169 million t) and 28% of all vegetable oils (86 million t). The United States, Brazil and Argentina together account for at least 60% of world soya bean oil production. About one-third of soya bean meal and oil is traded internationally. The oil palm is a close second with its palm and palm-kernel oils forming 25% of world oil production. However, palm oil is by far the largest vegetable oil in the international market, mainly as a result of the high proportion of export from Malaysia and Indonesia, which together produce about 81% of world palm oil. Rapeseed is, with 13% of total meal and 15% of world oil the third most important oil crop. Sunflower, groundnut, cottonseed and coconut (copra) are 4th to 7th in the ranking order, producing together another 21% of all meals and 25% of the world vegetable oils. The remaining 7 crops produce only 7% of the world vegetable oils, 1.5% of it of nonfood type. But olive and sesame oils are highly appreciated for their quality and maize (germs and bran) is a substantial contributor of meals for livestock feeds.

World average productivity of each oil crop can be estimated from the annual production divided by the area of cultivation in Table 3. It is between 0.3 and 0.5 t oil per ha for soya bean, rapeseed, sunflower, groundnut, coconut, olive and castor, while still lower for cottonseed, sesame, safflower and linseed. With 3.2 t palm oil per ha, the oil palm is 6–10 times more productive than any of the other oil crops and to this 0.4 t palm-kernel oil should be added as well. Maximum oil yields vary from 1.0 t/ha for soya bean and 1.6 t/ha for rapeseed to 2.7

Table 3. World production and export of major oil crops and products (average for 1997–2000).

Crop	Producing countries (number)	Cultivation (10^6 ha)	Annual production (10^6 t)			Exports (% of production)		Major producing countries[2]
			seed	meal	oil	meal	oil	
Edible								
Soya bean	73	72.0	160.1	105.4	24.3	34	31	United States, Brazil, European Union, Argentina, China (73%)
Oil palm (palm oil)	40	6.0	–	–	19.1		68	Malaysia, Indonesia, Nigeria, Colombia, Thailand (90%)
Oil palm (kernel)	40		6.1	3.0	2.4	83	50	Malaysia, Indonesia, Nigeria, Colombia, Thailand (90%)
Rapeseed	53	26.0	39.2	20.4	13.1	13	15	China, European Union, India, Canada, Australia (81%)
Sunflower	58	22.0	26.6	10.9	9.2	25	33	Argentina, Russian Federation, Ukraine, United States, France (70%)
Groundnut	92	22.1	20.1	6.6	4.6	5	7	China, India, Nigeria, Sudan, United States (81%)
Cottonseed	80	32.6	33.1	15.5	3.9	4	5	China, India, United States, Pakistan, Uzbekistan (70%)
Coconut (copra)	52	9.7	4.9	1.7	3.0	47	55	Philippines, Indonesia, India, Mexico, Vietnam (78%)
Olive	21	7.7	–	–	2.4		22	Spain, Italy, Greece, Tunisia, Syria (85%)
Maize (germ)				3.2	2.0	37	37	United States, European Union, Brazil, Japan, South Africa (79%)
Sesame	49	6.7	2.7	0.9	0.7	2	3	China, India, Burma (Myanmar), Sudan, Japan (70%)
Safflower	12	1.0	0.9	0.3	0.3	10	20	India, United States, Mexico, Argentina, Australia (92%)
Nonfood								
Linseed	38	3.5	2.8	1.4	0.7	7	24	European Union, China, United States, India, Canada (80%)
Castor	23	1.3	1.1		0.4		55	India, China, Brazil, Paraguay, Ethiopia (90%)
Tung-oil tree	6	0.2	0.5		0.1		25	China, Paraguay, Argentina, United States, Malawi (95%)
Total		210.8	287.1	169.3[1]	86.2	28	36	

[1] excluding 14.1 million t meals prepared from maize bran (called gluten in statistical overviews).
[2] in brackets share of 5 countries in total oil production.
Source: Mielke & Mielke, 2001.

Table 4. World production of oils and fats between 1910 and 2000.

Commodity	**Production (10^6 t)**						
	1910	**1935**	**1960**	**1975**	**1985**	**1995**	**2000**
Vegetable oils & fats							
Soya bean	0.3	0.9	3.3	8.5	14.2	21.0	26.4
Oil palm (palm oil)	0.3	1.0	1.3	2.8	7.7	17.5	21.8
Oil palm (kernel oil)	0.2	0.4	0.4	0.5	1.1	2.2	2.8
Rapeseed	1.1	1.2	1.2	2.5	6.4	11.5	14.5
Sunflower	0.1	0.6	1.9	2.7	6.9	9.2	9.4
Groundnut	0.7	1.4	2.5	2.7	3.5	4.6	4.8
Cottonseed	1.0	1.2	2.3	2.9	3.6	3.8	4.0
Coconut	0.8	1.9	1.9	2.6	3.3	3.2	3.4
Olive	0.6	0.9	1.3	1.6	1.6	2.8	2.6
Maize (germ)	0.3	0.4	0.3	0.6	1.1	1.9	2.1
Sesame	0.2	0.3	0.2	0.3	0.5	0.7	0.7
Linseed	0.9	1.0	0.9	0.7	0.7	0.7	0.8
Castor	0.1	0.2	0.2	0.3	0.4	0.5	0.5
subtotal	**6.6**	**11.4**	**17.7**	**28.7**	**51.0**	**79.6**	**93.8**
Animal oils & fats							
Marine	0.2	0.9	0.9	1.0	1.5	1.3	1.2
Tallow	1.3	1.4	3.4	5.5	6.5	7.4	8.2
Butter	2.5	3.8	4.2	5.4	6.5	5.7	6.0
Lard	2.5	2.4	3.3	4.2	5.5	6.0	6.8
subtotal	**6.5**	**8.5**	**11.8**	**16.1**	**20.0**	**20.4**	**22.2**
Total vegetable and animal oils & fats	**13.1**	**20.3**	**29.5**	**44.8**	**70.0**	**100.0**	**116.0**

Sources: Hatje, 1989; Mielke & Mielke, 2001.

t/ha for sunflower and 3.6 t/ha for coconut. However, for the oil palm 7 t/ha has been achieved already with advanced planting material and under optimum ecological conditions. Clearly, oil palm is by far the most efficient producer among all oil crops.

Total world production of oils and fats, of both animal and vegetable origin, has increased approximately by a factor of 9 since the beginning of the 20th Century, with the share of vegetable oils going up from 49% in 1910 to 81% in 2000 (Table 4). Exponential growth in production has taken place over the last 25 years in oil palm, soya bean, rapeseed and sunflower.

The total value of the annual production of all oil crops (Table 5) is estimated at US$ 40–62 billion for vegetable oils and another US$ 42–63 billion for the meals and unprocessed seeds. On average about one-third is exported, which means that vegetable oils and meals collectively represent some of the most important commodities in world trade. Total value of soya bean oil and palm oil are comparable, but soya bean also produces an enormous quantity of meal with a total value more than double of that of the oil. Olive and groundnut oils

Table 5. Value of world's major vegetable oils and meals (1995–2000).

Commodity	Value in 10^9 US$	
	Oil[1]	Meal (+ seeds)[2]
Soya bean	8.7 – 15.2	23.7 – 37.1
Palm oil	6.4 – 12.4	
Palm kernel	1.5 – 1.8	0.2 – 0.4
Rapeseed	4.8 – 8.3	3.1 – 5.2
Sunflower	3.4 – 5.8	1.9 – 3.3
Groundnut	3.6 – 4.6	7.6 – 10.1
Cottonseed	1.9 – 2.6	0.8 – 1.5
Coconut (copra)	1.9 – 2.2	0.2 – 0.3
Olive	1.4 – 2.3	0.1 – 0.2
Maize	1.0 – 1.2	1.6 – 2.2
Sesame	0.4 – 0.6	0.1 – 0.3
Safflower	0.2 – 0.3	0.0 – 0.1
Total[3]	40.0 – 62.0	42.0 – 63.0
World trade	10.6 – 17.2	14.1 – 21.9

[1] Ranges estimated by multiplying world production (Table 3) with the lowest and highest annual prices per t during 1995–2000.
[2] Considerable fraction is sold for consumption without oil extraction as seeds (e.g. soya bean, groundnut, sunflower, sesame), or as fruits (olive).
[3] Total, including other oil crops.
Source: Mielke & Mielke, 2001.

in particular, but also coconut and palm-kernel oils, usually fetch premium prices of 50–100% more than those paid for the main vegetable oils.
South-East Asia produces more than 66% of all coconut and 81% of all palm oils in the world, but otherwise plays only a minor role in oil crops at global level (Table 6). Burma (Myanmar) has hardly any oil palm or coconut production, but data show a great diversity in other oil crops including soya bean, sunflower, groundnut, cottonseed and sesame. Indonesia has, in addition to oil palm and coconut, significant areas of soya bean and groundnut in cultivation. Malaysia and Papua New Guinea depend almost entirely on oil palm and coconut, while in addition to these, Thailand has also groundnut, sesame and sunflower. Vietnam production data include soya bean, groundnut, coconut and sesame.

1.3 Properties of vegetable oils and meals

1.3.1 Oil content

The oil content in the harvested and dried seeds of annual oil crops, such as rapeseed, sunflower, groundnut, sesame, safflower and linseed, usually varies between 40% and 50% of seed weight. However, the seeds of soya bean and cotton only contain about 20% oil. The mesocarp of ripe oil-palm fruits has

Table 6. Annual production of major oil crops in South-East Asia (average for 1997–2000).

Crop		Burma	Indonesia	Malaysia	Papua N.G.	Philippines	Thailand	Vietnam	S.-E. Asia	% of world
Soya bean	10^3 ha	74	1112			5	265	129	1581	2
	10^3 t seed	69	1338			2	375	145	1929	1
	10^3 t oil	11				1	171	11	193	1
Oil palm	10^3 ha		2014	2726	68	15	156		4979	83
	10^3 t palm oil		5860	9690	256	48	397		16251	85
	10^3 t kernel oil		614	1264	29	6	38		1951	81
Sunflower	10^3 ha	171					40		211	1
	10^3 t seed	132					20		152	1
	10^3 t oil	39					5		44	
Groundnut	10^3 ha	465	670			46	105	272	1558	7
	10^3 t seed	387	688			25	108	260	1478	7
	10^3 t oil	116	11					35	162	3
Cottonseed	10^3 ha	279	20			20	45		364	1
	10^3 t seed	91	23			17	43		174	
	10^3 t oil	13	3				6		21	
Coconut	10^3 ha		2650	255	211	2270	367	208	5961	62
	10^3 t copra		1008	80	150	1950	90	125	3374	69
	10^3 t oil		600	47	51	1200	53	74	1976	66
Sesame	10^3 ha	766					61	29	856	13
	10^3 t seed	275					34	11	320	12
	10^3 t oil	85						3	88	12

No data available for Cambodia and Laos.
Source: Mielke & Mielke, 2001.

45–50% oil, but it is common to express palm oil content on a fresh fruit-bunch basis, which is 20–25% for modern cultivars. The kernel of the oil palm and copra of the coconut have similar water content (6%) and oil composition, but oil content is considerably higher in copra (60–65%) than in palm kernels (50%). In olive, 5–6 kg ripe fruits will produce about 1 kg oil (16–20% oil to fresh fruit).

1.3.2 Chemical aspects of vegetable oils

Triglycerides

Vegetable oils consist for more than 95% of triglycerides (triacylglycerols), which are esters of glycerol and fatty acids. The basic chemical structure of a triglyceride is given in Figure 1b. The fatty acids have a carboxylic acid group (COOH) on one end of an aliphatic chain of 6 to 24 hydrocarbons, almost always in even numbers (Stauffer, 1996). The fatty acids are called saturated, mono-unsaturated or polyunsaturated according to the number of double bonds present in the carbon chain. There are several fatty acids, but in the major edible vegetable oils only few fatty acids predominate, mainly palmitic (C16:0), oleic (C18:1) and linoleic (C18:2) acids. The chemical structure of these three fatty acids with the position of double bonds is given in Figure 1a. Most naturally occurring unsaturated fatty acids are in the cis configuration, which means that the two hydrogen atoms at the double bonds are on the same side. Isomers in the trans configuration are rare in natural vegetable oils, but are formed during the hardening process by hydrogenation.

The fatty acid composition of major edible vegetable oils is presented in Table 7. These data averages are only for demonstrative purposes, as fatty acid composition may vary considerably under the influence of climate and cultivar. The following categories can be distinguished:

- lauric oils from coconut and palm kernel (and also the babassu and cohune palm) with high contents of short-chain lauric acid (C12:0);

Table 7. Fatty acid composition (%)[1] of major edible vegetable oils.

Commodity	**Saturated**[2]								**Unsaturated**[2]						**IV**[3]
	C6:0 - C10:0	C12:0	C14:0	C16:0	C18:0	C20:0	C22:0	C24:0	C16:1	C18:1	C20:1	C22:1	C18:2	C18:3	
Soya bean				14	4					23			**54**	8	130
Palm oil, crude				**43**	5					**40**			11		55
Palm olein				**34**	4					**47**			14		65
Palm kernel	7	**48**	16	8	3					15			2		15
Rapeseed				4	1	1				19	7	**41**	15	11	105
Canola				4	2	1				**61**	1	< 1	21	9	105
Sunflower				7	5	1				19			**68**	1	130
Sunflower (high oleic)				4	5		1			**82**			9		130
Groundnut				11	3	3	1	2		**47**	1	1	**32**		90
Cottonseed			1	22	3				1	19			**55**	1	100
Coconut (copra)	13	**47**	19	9	3					7			2		10
Olive				9	3				1	**80**			6	1	80
Maize				11	2					26			**60**	1	120
Sesame				10	5					**40**			**40**		110
Safflower				7	3					12			**78**		145

[1] Data averaged and adjusted to nearest whole figure; less than 1% not indicated.

[2] Symbols and common names of fatty acids:

C6:0	caproic	C18:0	stearic	C18:2	linoleic
C8:0	caprylic	C20:0	arachidic	C18:3	linolenic
C10:0	capric	C22:0	behenic	C20:1	eicosenoic
C12:0	lauric	C24:0	lignoceric	C22:1	erucic
C14:0	myristic	C16:1	palmitoleic		
C16:0	palmitic	C18:1	oleic		

[3] IV = iodine value: g of iodine absorbed by 100 g of oil; used to measure oil unsaturation.

Sources: Gunstone et al., 1986; Salunkhe et al., 1992; Stauffer, 1996.

- palm oil with a mixture of palmitic and oleic acids; in palm olein the oleic oil content is raised by fractionation during processing;
- oleic oils from the olive, canola, high-oleic sunflower (and also the pataua palm);
- linoleic oils from soya bean, sunflower, cottonseed, maize and safflower;
- oleic-linoleic oils from groundnut and sesame (and also niger seed);
- traditional rapeseed oils with a high content of erucic acid (C22:1).

Simple triglycerides have three identical fatty acids, such as tripalmitin (glycerol with 3 molecules of palmitic acid) and triolein (glycerol with 3 oleic acid molecules), the latter being a major triglyceride in olive oil. Mixed triglycerides have saturated and unsaturated fatty acids. In most natural vegetable oils the unsaturated fatty acids are placed on the central 2-position and the saturated fatty acids on the outer 1- and 3-positions of the glycerol molecule. The overall composition of fatty acids and their arrangement on the three positions of the triglycerides determine to a large extent the chemical and physical characteristics of an oil (Åppelqvist, 1989).

Unsaturated oils are subject to autoxidation at the site of double bonds initiated by (hydro)peroxides and leading to oxidative rancidity. This may cause a characteristic 'cardboard' flavour. The relative rate of oxidation of linolenic (C18:3) and linoleic (C18:2) fatty-acid chains is 25 and 12 times higher respectively than that of oleic (C18:1) acid. Oxidation is slowed down by anti-oxidants (e.g. tocopherols), which occur naturally in many vegetable oils, or by adding such organic compounds in low concentrations during manufacturing. Processing and storage under oxygen-free and dark conditions are important measures to prevent oil rancidity.

Rapeseed and soya bean oils contain some α-linolenic acid, but this should not affect the quality as an edible oil when properly processed and stored. However, linseed oil is unsuitable for consumption, as it contains more than 50% linolenic acid. When exposed to air, the oil polymerizes into a flexible film as a result of rapid oxidation at the double bonds. It finds wide application as drying oil in paints and industrial coatings. Edible linseed oil with only a few percent linolenic acid and a much higher linoleic acid content is now being produced from recently developed 'Linola' linseed cultivars (Dribnenki et al., 1999).

The fatty acid composition of the castor and tung oils deviates from that of the edible oils (Åppelqvist, 1989). Ricinoleic acid, which predominates in castor oil, has an aliphatic chain of 20 carbons with a single double bond and a hydroxyl group. The α-eleostearic acid (C18:3) of tung oil has one double bond in the cis and two in the trans configuration. Both oils have many applications in the chemical industry.

There are a number of other chemical reactions, in addition to oxidation, with important consequences for the properties of vegetable oils (Stauffer, 1996). One that occurs naturally is the cleaving of the triglyceride esters into glycerol and free fatty acids (FFA) by hydrolysis causing hydrolytic rancidity. The reaction is catalyzed in the presence of water by metals or by the action of the enzyme lipase. The fat-splitting lipase is found in oil-palm fruits (Hartley, 1988) and is also produced by fungi and other micro-organisms contaminating vegetable oils. Low content in free fatty acids is an important quality requirement of crude and refined vegetable oils. Hydrolysis with the base potassium (or sodium) hydroxide is called saponification, as it neutralizes the fatty acids to soap. The esters can also be split reductively, with sodium and potassium metals, into glycerol and fatty alcohols, which are used to manufacture detergents and lubricants. Glycerolysis is a reaction of glycerol and fatty acids, with potassium carbonate as basic catalyst, to form monoglyceride emulsifiers. Hydrogenation, by adding hydrogen gas to unsaturated oils in the presence of a nickel catalyst, converts double bonds into single bonds in the carbon chains. This improves the oxidative stability of oils and may also change liquid oils into solid fats. The properties of the fats can be improved further by inter-esterification, which involves heating in the presence of sodium methoxide or metallic sodium. It produces a more plastic fat as a result of changes in the position of fatty acids in the triglycerides (Stauffer, 1996; Young et al., 1986).

The chemical properties of oils are determined by a number of analytical tests (Gunstone et al., 1986). One is the iodine value (IV) to measure oil unsaturation (number of double bonds) and is expressed as grams of iodine absorbed by 100 g of oil. Examples of IV are presented in Table 7. The saponification value (number of mg potassium hydroxide to saponify 1 g oil) indicates carbon-chain length of the fatty acids, the higher the value the shorter the chain lengths, e.g. 260 for coconut and 190 for soya bean oil. Several tests have been developed to measure oxidative stability (e.g. the active oxygen method and oil stability index), oxidative degradation (e.g. peroxide value, anisidine value and total oxidation number) and free fatty acid content of vegetable oils (Gunstone et al., 1986; Stauffer, 1996).

Other components

Unrefined vegetable oils contain 0.1–3% lecithins, including phospholipids, and small amounts of waxes, sterols, and other hydrocarbons such as carotenoids (pro-vitamin A), tocopherols (vitamin E) and tocotrienols (Åppelqvist, 1989; Stauffer, 1996).

Phospholipids are triglycerides with one of the three apolar fatty acid chains replaced by a polar head consisting of an alcohol group (e.g. choline, ethanolamine, serine) linked to the glycerol group by phosphate (Figure 1c). This amphiphilic characteristic makes them very useful as emulsifiers. Phospholipids also form the main component of cell membranes in animals. Waxes are apolar lipids of long chain fatty acids linked to fatty alcohols. Sterols are lipid compounds with ring structures including cholesterol (rare in vegetable oils) and phytosterols. The waxes, sterols and other hydrocarbons form part of the so-called unsaponifiable matter content, up to 2% in crude oils but usually less than 0.5% in refined oils (Stauffer, 1996).

The oil extracted from jojoba seeds consists almost entirely of unique liquid waxes composed of mono-unsaturated fatty acids (20–24 carbons) esterified to long chain alcohols. Sulphurized jojoba oil is an excellent replacement for sulphurized oil of the sperm whale, which has traditionally been the extreme-pressure lubricant (Pryde & Rothfus, 1989).

1.3.3 Physical aspects of vegetable oils

Solubility

Triglycerides are soluble in the solvents hexane, benzene or acetone. The small amounts of hydrophilic substances present in vegetable oils, such as the phospholipids, monoglycerides, free fatty acids and oxidation products, are removed during refining by washing with water (Stauffer, 1996).

Melting and solidification

Pure triglycerides have a fairly exact melting point, i.e. the temperature at which they change from a solid into a liquid substance when slowly heated. The melting point becomes higher with increasing carbon chain length and degree of saturation of the fatty acids and also by a change from the cis to trans isomer (e.g. during hydrogenation). Examples of melting points are: trilaurin 47°C, tripalmitin 66°C, palmitoleopalmitin 37°C, triolein 5°C and trilinolein –13°C (Gunstone et al., 1986; Stauffer, 1996).

These are melting points of triglycerides having the stable β-crystal structure in the solid form, which occurs under conditions of slow cooling. Unstable α-crystals are formed under rapid and β-crystals under intermediate cooling rates. Melting points vary according to crystal structure, e.g. for tripalmitin in the α-form the melting point is 45°C and 64°C in the β-form. Triglycerides solidified in the α-crystal structure have a waxy appearance, in the β-form they are grainy and hard, while in the β'-form they have a smooth and creamy texture. The β'-form, which reverts to the β-form fairly quickly for a single triglyceride, is maintained much longer in complex mixtures such as shortenings and margarines.

Natural vegetable oils are a mixture of several triglycerides, with the result that they melt gradually over a range of temperatures. Various analytical methods have been developed to specify melting and solidification characteristics of natural and manufactured oils and fats. Melting point (mp) tests include the complete mp, Wiley mp, dropping mp and slip point. The latter is measured by slowly warming a sample of solid fat in a capillary tube and observing the temperature at which it moves. For instance, the slip point of crude palm oil from Malaysia was 31–38°C, of palm olein 19–23°C and super olein 13–16°C (Pantzaris, 1997). Another test quoted in tables specifying vegetable oils is the titre, which is the temperature at which a liquid oil starts to solidify under controlled conditions (Gunstone et al., 1986). Examples of titres are: palm oil 40–42°C, coconut oil 20–24°C, soya bean oil 15–18°C, sunflower oil 16–20°C, rapeseed oil 6–10°C and linseed oil 19–21°C. The solid fat index (SFI) and content (SFC) measure the proportion of the solids in an oil at various temperatures. Specifications of oils and fats usually include a solid fat profile, which is a curve relating temperatures to SFI or SFC.

Other thermal properties

The smoke point, which is the temperature at which a heated oil begins to give off smoke, is an important index to assess the quality of frying oils. It should be about 240°C for industrial deep frying oils, but may be some 10 degrees lower for oils used for domestic purposes. The flashpoint (flashes of burning when exposed to a flame) and fire point (full burning when ignited) are important temperature indicators for safety. The flashpoint is generally 90–140°C higher than the smoke point and the fire point another 50–60°C above the flashpoint. The build-up of free fatty acids in particular, but also other contaminants, have a lowering effect on the smoke and other temperature points, rapidly making oils unsuitable and also dangerous for frying purposes. Refined sunflower, groundnut, sesame and palm olein are among the vegetable oils with the highest smoke points.

1.3.4 Nutritional and health aspects of vegetable oils

Source of energy

A major nutritional function of edible oils and fats is the supply of energy, 38 kJ (9 kcal) per g of oil compared to about 19 kJ (4.5 kcal) per g for carbohydrates and proteins. The average daily energy requirement for Asian adult persons (55 kg mean body weight) according to the FAO and WHO recommendations (FAO, 1972) is a minimum of 8500 kJ (2000 kcal), to be provided by a balanced diet containing 50% carbohydrates, 30% lipids (oils and fats) and 15% proteins. This would mean a daily intake of 70 g (2500 kJ) or 25 kg edible oils and fats per year, but in reality average consumption is often less than half the recommended quantity, e.g. in the Philippines 8 kg, India 11 kg and in Indonesia 15 kg. This situation is in stark contrast with the 47 kg (European Union) and 51 kg (United States) of edible oils and fats consumed annually per person in some developed countries (Mielke & Mielke, 2001). Inadequate dietary energy is an important cause of malnutrition in Asia and increasing the availability of vegetable oils is a most efficient way of alleviating this problem. Especially young children have difficulty in digesting large quantities of unrefined carbohydrate-rich food. Generally, oils and fats with lower melting characteristics have a better digestibility.

Triglycerides in the food are partly hydrolyzed by pancreatic lipase and micelles (colloidal solutions) of 2-monoglycerides and free fatty acids are absorbed by the intestinal wall. Here they are esterified into new triglycerides, which are then transported through the lymphatic system and the bloodstream as chylomicra (tiny globules of emulsified fat) to the various body tissues to provide energy by oxidative combustion or to be deposited in adipose (fat storage) tissue (Vles & Gottenbos, 1989).

Membranes' phospholipids and metabolic regulators

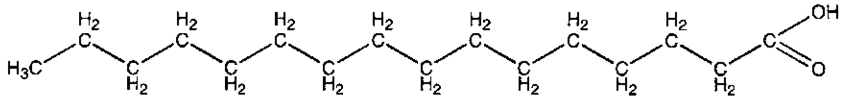
About half the normal (70 g) daily oil and fat intake is converted into energy. The remainder provides fatty acids for incorporation into phospholipids, which are synthesized in the body and form the main components of cell membranes and other bi-layer lipid structures in animals and humans, e.g. myelin nerve sheath and eye retina (Graille & Pina, 1999; Stauffer, 1996). The diglyceride component of most phospholipids (see Figure 1c) contains one saturated and one unsaturated fatty acid, about 20% have two unsaturated and a small fraction two saturated fatty acids. Although most of the fatty acids, except linoleic acid, can be synthesized in the body, phospholipid synthesis is much more efficient when these are readily available in the dietary oils and fats in a composition of 32% saturated, 45% mono-unsaturated and 23% polyunsaturated. Linoleic acid is an essential fatty acid, because complete absence in the diet will eventually lead to various deficiency symptoms (e.g. retarded growth and skin lesions). It is partly converted in the liver to γ-linolenic acid (C18:3) and subsequently to arachidonic acid (C20:4), which are both essential fatty acids. In addition to being important components of the membrane phospholipids, the essential fatty acids are also substrates for the biosynthesis of various metabolic regulators (eicosanoids), which influence amongst others the central nervous system, blood pressure, the aggregation of blood platelets and cardiac function. α-Linolenic acid, which is present in linseed, brassica oilseed and soya bean oil (Table 7), can partly replace the functions of essential fatty acids, but this may lead to inferior membrane phospholipids and metabolic regulators. High concentrations of this polyunsaturated fatty acid in the diet should therefore be avoided (Vles & Gottenbos, 1998).

Cholesterol

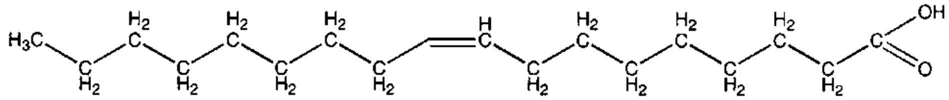
In contrast to animal fats, vegetable oils contain very little cholesterol. It is mostly synthesized in the body from lipid compounds into a steroid alcohol with four rings attached to a side chain of 8 hydrocarbons (Figure 1d) and it is often esterified to a fatty acid. Cholesterol plays a role in the proper functioning of cell membranes and many hormones are derived from it. In the liver, cholesterol is converted into cholic (bile) acids, which are excreted in the intestines and work as emulsifiers facilitating the digestion of fat (Stauffer, 1996). Cholesterol is transported in the bloodstream in lipoprotein particles, which are composed of cholesterol, cholesterol esters, triglycerides, phospholipids and highly specific proteins (Vles & Gottenbos, 1998). High-density lipoprotein (HDL) transports excess cholesterol from the cells to the liver and other organs for conversion into bile or hormones. Low-density lipoprotein (LDL) delivers cholesterol to various body tissues, but it may also become the cause of atherosclerosis by forming plaques on injured arterial walls.

There is ample evidence from epidemiological, clinical and biochemical research that high levels of LDL in the blood increase the risks of cardiovascular diseases. The composition of dietary fatty acids influences blood cholesterol levels. Saturated fatty acids (C14:0 and longer chains) increase LDL levels, while unsaturated fatty acids have a lowering effect. On the other hand, the short-chain saturated fatty acids (C8:0–C12:0) present in the lauric oils (coconut and palm kernel) are shown to have no adverse effects on LDL levels. Their high digestibility makes them very suitable for infant foods and in therapeutic diets for patients with fat maldigestion problems (Vles & Gottenbos, 1989). Trans isomers of unsaturated fatty acids, as a result of hydrogenation, also appear to raise the level of LDL in the blood. On the other hand, the effects of type and quantity of dietary fatty acids on LDL levels are confounded with other risk factors including lifestyle, such as stress and lack of physical exercise, smoking, overweight, diabetes as well as genetic predisposition.

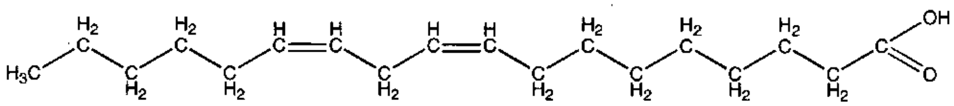
Generally, there are good reasons for recommending a lowering of saturated



Palmitic acid, C16:0 (saturated)

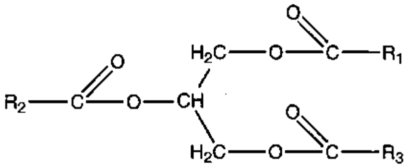


Oleic acid, C18:1 (unsaturated)

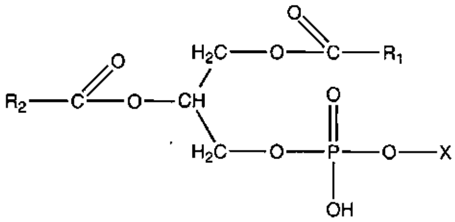


Linoleic acid, C18:2 (polyunsaturated)

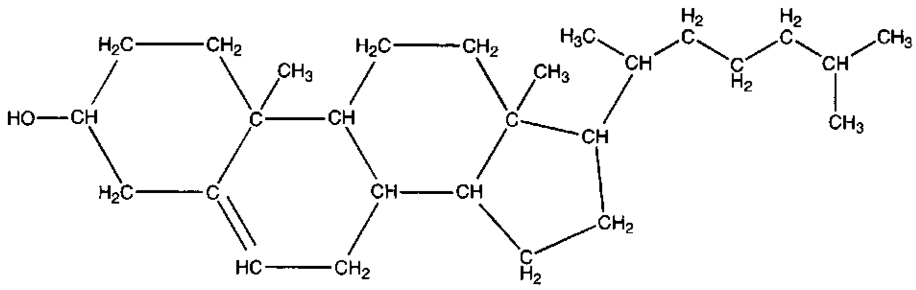
a) Major fatty acids



b) General structure of a triglyceride (triacylglycerol). R1, R2 and R3 are the hydrocarbon chains of the fatty acids



c) General structure of a phospholipid. R1 and R2 are fatty acids, X is one of a number of alcoholic groups, e.g. choline, ethanolamine and serine



d) The structure of cholesterol

Figure 1. The chemical structures of vegetable oils, their components and related substances.

and increasing unsaturated oils and fats in the diet, particularly in countries where total fat consumption is excessive. However, there is a difference between saturated animal and vegetable fats. For instance, palm oil contains about 50% saturated fatty acids, but nevertheless behaves nutritionally like an unsaturated oil and does not increase LDL levels in the blood. This could be explained by the predominant composition of the triglycerides in vegetable oils, with saturated fatty acids on the outer 1- and 3-positions and an unsaturated fatty acid on the inner 2-position. Hydrolysis during pancreatic digestion leads to 2-monoglycerides with unsaturated fatty acids, which are easily absorbed by the intestinal wall. Many of the longer-chain saturated fatty acids give rise to insoluble calcium salts that cannot be absorbed and are excreted (Graille & Pina, 1999).

Vitamins

Oils and fats are carriers of the lipophylic vitamins A, D, E and K and facilitate their absorption. Vitamin A is formed in the body by oxidative cleavage of carotenoids, β-carotene in particular, which are available from vegetables and fruits and also from crude palm oil. Deficiency in vitamin A causes loss of night vision and eventually total blindness. Vitamin D, which is needed in particular for proper bone development in children, is produced by conversion of cholesterol in skin exposed to sunshine (ultraviolet irradiation). Most vegetable oils are good sources of vitamin E or tocopherol, which has the properties of an anti-oxidant inhibiting autoxidation of polyunsaturated fatty acids. The main symptom of vitamin E deficiency in animals and humans is loss of fertility. Vitamin K is produced by the bacterial flora in the large intestine. Inadequate level of bile acids and antibiotics treatments that affect the intestinal bacteria may lead to vitamin K deficiency symptoms, especially prolonged bleeding after injury, due to poor blood clotting (Stauffer, 1996; Vles & Gottenbos, 1989).

1.3.5 Nutritional aspects of oilseed meals

The average chemical composition of 11 oilseed meals is presented in Table 8. These data are useful as indicators of major variation in composition between meal types, but of course they cannot reflect the considerable variation encountered within the same commodity due to differences in cultivars, agronomic and processing conditions and also in analytical methods. The cake after oil extraction is ground to a meal and dried to 7–11% moisture content according to type of oil crop. Residual oil content depends on method of extraction, being much lower after solvent (1–5%) than after mechanical extraction (7–9%). The higher the oil content the higher the energy value of the meal.

Crude protein contents vary from 20–50%. Soya bean, sunflower (hulled seeds), groundnut (shelled) and sesame meals have particularly high crude protein contents (≥44%). Rapeseed, cottonseed, safflower and linseed meals contain 36–42%, but palm kernel, copra and maize-germ meals have only half as much (21%). The protein quality depends on composition and concentration of amino acids, especially the essential amino acids. In oilseed meals, lysine, methionine and cysteine content are emphasized, because these are the amino acids frequently in limited supply in the grain-based feeds used for pig and poultry (Bell, 1989). Soya bean and rapeseed meals are high in lysine (>6% of total protein), the others contain only half of that or less. On the other hand, soya bean meal contains less methionine and cysteine than other meals. Sesame meal is

Table 8. Composition of major oilseed meals[1].

Commodity	Content (%)					
	Moisture	Oil[2] (e.e.)	Crude protein[3]	Carbohydrates		Ash
				c.f.[4]	d.c.[5]	
Soya bean	11	1	48	4	30	6
Palm kernel	10	7	21	15	42	5
Rapeseed	9	4	39	11	31	6
Sunflower (hulled)	7	3	47	12	23	8
Groundnut (shelled)	9	1	47	13	25	5
Cottonseed	9	2	42	12	28	7
Coconut (copra)	7	7	21	12	46	7
Maize (germ)	8	9	21	17	41	4
Sesame	8	9	44	6	23	10
Safflower (hulled)	12	7	40	9	26	6
Linseed	9	5	36	10	34	6

[1] Data averaged and adjusted to nearest whole figure.
[2] Oil (e.e.) = residual oil determined by ether extraction.
[3] Crude protein = N × 6.25.
[4] c.f. = crude fibre or unavailable carbohydrates.
[5] d.c. = digestible carbohydrates, available to monogastric animals.
Sources: Bell, 1989; Vohra, 1989.

particularly high in methionine (>3%). Excessive heating during oilseed processing can have a negative effect on lysine and other essential amino-acid contents.

Carbohydrates are of two types: (a) structural polysaccharides from cell walls, which are unavailable to monogastric animals, usually called crude fibre and (b) energy reserve sugars and starch-like polysaccharides, which are digestible by all types of animals (Vohra, 1989). Carbohydrate and protein contents are inversely related, but the fraction of crude fibre over total carbohydrates varies with the type of meal. Soya bean, sesame and safflower meals are particularly low in crude fibre content. The content of available carbohydrates varies from 26–34% in most meals. However, in palm kernel, copra and maize-germ meals the available carbohydrate (41–46%) contents are considerably higher, as are the crude fibre contents (15–17%) in palm-kernel and maize-germ meals. The seed hulls are high in crude fibre and hulling reduces this fraction in the meal considerably. Seeds may be hulled or not before crushing for oil extraction, or hulls may be added to the meals afterwards, depending on the purpose of the meal. Ruminants require a higher crude fibre content in the feed than monogastric animals. Generally, oilseed meals are supplements for use in animal feeds (Bell, 1989). Choice of type of oilseed meal and exact formulations in the feed will depend on content and quality of protein and carbohydrates, but also on palatability, digestibility and presence of toxic or antinutritional factors.

Sunflower and groundnut meals are also good sources of the water-soluble vitamins of the B-complex.

The ash content includes minerals. Some oilseed meals are rich in dietary minerals, but availability is often lower than contents would suggest, due to the presence of phytates and other insoluble complex compounds. Sunflower meals in particular are high in P, Ca, K and Fe minerals.

1.3.6 Toxic and antinutritional substances

Some oilseeds contain toxic or antinutritional factors, which may still be present in the oil but particularly in the presscake after processing. Certain factors can be eliminated or reduced by heat and other pretreatments of the seeds. Proper formulations with different meal types are applied to avoid toxic concentrations in the feeds. The oils and meals from oil palm, sunflower, coconut, maize (germ) and safflower are free of significant amounts of such compounds.

Soya bean seeds contain a number of antinutritional substances, such as trypsin inhibitors (causing poor digestibility of proteins), haemagglutinins (inducing clotting of red blood cells), an oligo- or glycopeptide with goitrogenic action (interfering with iodine uptake) and phytates (causing reduced uptake of phosphorus and other minerals). All three factors are largely inactivated by heating through boiling, steaming or toasting of the seeds. Soya beans also contain small amounts of heat-stable factors, including saponins (glucosides inhibiting activity of proteolytic enzymes), isoflavone glucosides (estrogenic effects) and oligosaccharides (raffinose and stachyose) causing flatulence. Fermentation reduces many of these negative effects (Salunkhe et al., 1992).

Traditional rapeseed contains high concentrations of erucic acid (30–50%) and glucosinolates (1–4%). Erucic acid absorbed in large quantities increases the risks of cardiovascular diseases. Glucosinolates produce (iso)thiocyanates and nitriles (pungency in oil and meal) upon hydrolysis by the enzyme myrosinase. These are goitrogenic factors interfering with the iodine uptake and thyroxine synthesis in the thyroid gland (Salunkhe et al., 1992). Cooking of the flaked seed inactivates the myrosinase. Canola is a type of rapeseed developed by breeding with almost no erucic acid (see Table 7) and very low glucosinolate content (0.1–0.4%). Minor antinutritional factors in rapeseed are tannins (forming complexes with proteins, minerals and vitamins and so reducing bioavailability) and sinapine causing some chicken to produce eggs with a fishy flavour (Bell, 1989).

Groundnut is a legume like soya bean. Its seeds also contain lectins (haemagglutinins), trypsin inhibitors, goitrogens, phytates and flatulence factors, and methods of inactivation are similar. Cottonseeds contain highly toxic gossypol, a complex phenolic compound which induces depressed appetite and weight loss. It also causes discolouration of egg yolks. Gossypol can be inactivated by adding ferrous salts to the meal. Linseed meal for feeding purposes needs further processing to remove mucilage, to hydrolyze the cyanogenic glucoside linamarin (by the endogenous enzyme linase), and to inactivate vitamin B_6 antagonists (by heating). Heating also removes the cyanide resulting from the hydrolysis of linamarin (Bell, 1989).

Prolonged storage of poorly dried seeds can lead to aflatoxin contamination of oils and especially meals. Aflatoxins are secondary metabolites of the moulds *Aspergillus flavus* and *A. parasiticus* and already at very low concentrations (>1 ppm) highly toxic and carcinogenic to most animals (Bell, 1989). Allowable maximum safety levels of aflatoxin contamination in foods for human consumption vary from 5–30 parts per billion (Weiss, 2000). Poorly stored groundnuts and maize in particular are most susceptible to contamination with aflatoxins, but also cottonseed and copra are associated with this problem. Of particular importance in maize are fumosins. These are mycotoxins produced by *Fusarium moniliforme* and associated with oesophageal cancer. Methods of control include first of all prevention by ensuing proper conditions during seed (or copra) storage and transport, and monitoring before processing. Contaminated seedlots should be destroyed at all times. Aflatoxin contamination in oils is removed during the lye treatment (at pH>8) as part of the refining process. It is possible to detoxify meals to some extent by heating and various chemical treatments (Ranasinghe, 1999; Weiss, 2000).

1.4 Botany

The 63 species listed in Table 9 represent only a minor fraction of those plant resources from which vegetable oils and fats can be extracted for edible or non-food purposes. It includes all major oil crops of the world and those of local importance or which could potentially be cultivated in South-East Asia. They belong to 27 families (25 dicotyledons and 2 monocotyledons). For the *Palmae* family 6 oil-bearing species are treated including the two most important oil crops of South-East Asia, *Cocos nucifera* and *Elaeis guineensis*. The *Euphorbiaceae* is another family with 6 oil-bearing species indicated in Table 9, but all produce non-edible oils including *Ricinus communis* and *Vernicia* spp. Other families with major oil-bearing species are the *Compositae* (*Carthamus tinctorius*, *Helianthus annuus*), *Cruciferae* (*Brassica juncea*, *B. napus* and *B. rapa*), *Gramineae* (*Zea mays*), *Leguminosae* (*Arachis hypogaea*, *Glycine max*), *Linaceae* (*Linum usitatissimum*), *Malvaceae* (*Gossypium barbadense* and *G. hirsutum*), *Pedaliaceae* (*Sesamum orientale*) and *Oleaceae* (*Olea europaea*).
Some 14 species are annual or biennial herbs belonging to the families *Compositae* (3), *Cruciferae* (3), *Gramineae* (2), *Labiatae* (2), *Leguminosae* (2), *Linaceae* and *Pedaliaceae*. The other 49 oil-bearing species are perennial shrubs, trees or palms. Seeds are the main oil containing plant parts in almost all mentioned species, except for the fruit mesocarp of *Elaeis guineensis* and *Olea europaea* (Table 9). The oil (storage lipids) in the cells of seed or mesocarp is contained in bodies called oleosomes (Napier et al., 1996). In some seed, such as rapeseed, soya bean and groundnut, the oil is concentrated in the cotyledons, in many others in the endosperm (Vaughan, 1970).

1.5 Ecology

1.5.1 Climatic factors

There is great variation in the ecological requirements of oil crops, which include plant species belonging to tropical, subtropical or temperate climates. An overview of ecological data for the major oil crops of South-East Asia is given in Table 10.
Much of the South-East Asian region is situated within the humid tropics. The climate is characterized by mean daily temperatures of >24°C in the lowlands with little seasonal variation, relative humidity of >70% at midday, annual

Table 9. Taxonomic and morphological data on 63 plant species producing oils and fats.

Family	Species	Type of plant	Plant parts containing oil
Bombacaceae	*Pachira* spp. (2)	tree	seed
Chrysobalanaceae	*Parinari anamensis*	tree	seed
Compositae	*Carthamus tinctorius*	herb	seed
	Guizotia abyssinica	herb	seed
	Helianthus annuus	herb	seed
Cruciferae	*Brassica* spp. (3)	herb	seed
Dipterocarpaceae	*Shorea* spp. (3)	tree	nut
Euphorbiaceae	*Reutealis trisperma*	tree	seed
	Ricinus communis	shrub, tree	seed
	Triadica sebiferum	tree	seed (sarcotesta, kernel)
	Vernicia spp. (3)	shrub, tree	seed
Flacourtiaceae	*Scolopia chinensis*	shrub, tree	seed
Gramineae	*Oryza sativa*	herb	fruit (endosperm)
	Zea mays	herb	fruit (endosperm)
Guttiferae	*Garcinia* spp. (2)	tree	seed
	Pentadesma butyracea	tree	seed
Labiatae	*Hyptis spicigera*	herb	seed
	Salvia hispanica	herb	seed
Lauraceae	*Cinnamomum japonicum*	tree	fruit, seed
	Persea thunbergii	tree, shrub	seed
Lecythidaceae	*Lecythis* spp. (4)	tree	seed
Leguminosae	*Arachis hypogaea*	herb	seed
	Glycine max	herb	seed
Linaceae	*Linum usitatissimum*	herb	seed
Malvaceae	*Gossypium* spp. (2)	shrub	seed
Meliaceae	*Chisocheton* spp. (3)	tree	seed
Myristicaceae	*Horsfieldia* spp. (2)	tree	seed
	Knema spp. (2)	tree	seed
Oleaceae	*Olea europaea*	tree	fruit (mesocarp)
Palmae	*Astrocaryum* spp. (2)	palm	fruit (mesocarp), seed
	Attalea cohune	palm	seed
	Cocos nucifera	palm	seed
	Elaeis guineensis	palm	fruit (mesocarp), seed
	Jessenia bataua	palm	fruit (mesocarp)
Pedaliaceae	*Sesamum orientale*	herb	seed
Pittosporaceae	*Pittosporum resiniferum*	tree, shrub	fruit
Polygalaceae	*Xanthophyllum lanceatum*	shrub, tree	seed
Rutaceae	*Tetradium fraxinifolium*	tree	seed
Sapindaceae	*Paranephelium* spp. (4)	tree	seed
Sapotaceae	*Diploknema* spp. (2)	tree	seed
Simmondsiaceae	*Simmondsia chinensis*	shrub	seed
Theaceae	*Camellia sasanqua*	shrub, tree	seed

rainfall of >1800 mm well-distributed over the year (only 2–3 months with less than 100 mm) and >2000 hours of sunshine per year (Anonymous, 1993). About 20% of the area is mountainous (> 400 m altitude) with cooler climates. Mean temperatures decrease by about 0.6°C for each 100 m of elevation in equatorial regions and the amplitudes of day and night temperatures widen (Braak, 1946).

Oil palm and coconut are crops typical of the lowland humid tropics. The climatic conditions in South-East Asia are more suited to the oil palm than those of West Africa, particularly the better rainfall distribution throughout the year and higher number of sunshine hours. These are the main factors contributing to the much higher oil yields obtained in countries such as Malaysia, Indonesia and Papua New Guinea. Altitude and latitude are more restrictive for oil palm than coconut, because lower temperatures are detrimental to growth and production of the former at an earlier stage. Oil-palm yields become economically unattractive above 400 m altitude near the equator and beyond 10–12° latitudes, while the coconut can still be productive in coastal regions at 20° latitudes and in equatorial uplands up to 1000 m altitude. However, cold-tolerant oil-palm accessions have been collected in the Bamenda Highlands (Cameroon) and above 1000 m altitude near Lake Tanganyika (Tanzania) (Blaak & Sterling, 1996).

Soya bean and groundnut are basically short-day annual crops of the lowland tropics and subtropics. However, both have been successfully adapted by selection and breeding to the summer season of temperate climates or the cooler climates of the tropical highlands. In South-East Asia groundnut grows best in the lowlands and soya bean in the somewhat cooler climate of submontane tropical areas. Sesame, sunflower and cotton are mostly grown further from the equator, e.g. in Burma (Myanmar), northern Thailand and Vietnam. Sesame can be grown under hot and humid conditions, but sunflower requires a relatively cool and dry climate, which is only found at higher altitudes in equatorial regions. Cotton is best cultivated in drier areas under irrigation. The remaining major oil crops listed in Table 1 are not grown to any large extent in South-East Asia, except maize, but this is only grown as a cereal. Rapeseed requires relatively cool climates, such as the winter season in subtropical India and China, or the summer season in temperate climates of China, Europe, Canada and Australia. Safflower is a crop of the semi-arid subtropics, castor and linseed are cultivated in the subtropics and warm temperate regions, while olive needs the seasonal and relatively dry climate typical of the Mediterranean region for satisfactory yields. The wood-oil tree (*Vernicia montana*) is well adapted to the lower montane climate of the tropics, but it is of limited economic significance in South-East Asia.

1.5.2 Soils

Soil is a dynamic medium comprising disintegrated rock particles, water, air, organic matter and living organisms. Soil formation involves physical, chemical and biological processes that are accelerated by high temperatures and rainfall. Fertility of soils depends on their chemical and structural properties such as acidity, organic matter content, texture and ability to retain nutrients

Table 10. Ecological requirements of major oil crops of South-East Asia.

Crop	Latitude		Altitude at equator (m)	Temperature range (°C)[1]	Rainfall range (mm)[2]	Soil pH
	°N	°S				
Oil palm	12	10	0 – 400	(18–) 24–33	(1500–) 1800–2500	4.2–6.5
Coconut	20	20	0 – 1000	(15–) 22–32	(1000–) 1500–2500	5.0–8.0
Soya bean	55	55	0 – 2000	(10–) 21–30	(350–) 500–750	5.8–7.0
Groundnut	45	40	0 – 1200	(15–) 25–32	(300–) 500–1000	4.5–6.5
Sunflower	55	40	1000 – 1500	(6–) 23–27	(400–) 500–700	5.7–8.1
Cottonseed	47	30	0 – 1000	(10–) 24–34	(450–) 800–1200	5.5–8.5
Sesame	40	35	0 – 2000	(10–) 25–35	(400–) 600–900	5.5–8.0

[1] in brackets: temperature below which growth is severely reduced.
[2] per year for tree crops; per growing season for annuals; in brackets: rainfall below which growth is severely reduced.
Sources: Hartley, 1988; Munro, 1987; Ohler, 1999; Weiss, 2000.

and water. Many tropical soils are strongly weathered due to rapid formation and degradation and are low in plant nutrients. The process of degradation is aggravated by imprudent soil management. Less than one-fifth of the tropical soils have a fair to high level of fertility. These are mainly soils formed on recent alluvial or volcanic sediments (Anonymous, 1995).

The general distribution of major soil groups in the humid tropics of Asia is as follows (Anonymous, 1993; Mohr et al., 1972):
- latosols developed over igneous or sedimentary rocks, including oxysols (4%) and ultisols (35%), which are generally deep and well-drained red to yellowish acidic soils with good physical properties and low to moderate nutrient reserves;
- inceptisols (24%), which are mostly deep, well-drained and fertile sedentary soils of volcanic origin (andepts) or non-volcanic origin (tropepts); some are poorly drained but often highly fertile soils (aquepts);
- entisols (24%), which include young well-drained alluvial soils (fluvents), infertile sandy soils (psamments and spodosols) and shallow soils on steep hillsides (lithics);
- histosols (organic) and other minor soil types (13%).

Oil palm and coconut can be grown on many of these soils, the main requirements being soil depth of at least 1.50 m, free drainage and good water-holding capacity. Soils may vary from sandy loams to heavy clays for oil palm, but coconut grows better on the lighter soil types. Coconut is salt-tolerant, in contrast to oil palm, and thrives well in sandy coastal soils. The best soils for soya bean are well-drained loamy clays, while lighter soils are preferred for groundnut production. Acid soils ($pH < 5.5$) will reduce the activity of N-fixing bacteria in these legume crops (Weiss, 2000). Sesame, sunflower and cotton can be grown on a wide range of well-drained soils, but only cotton is fairly salt-tolerant. Ranges of preferred soil pH for the 7 oil crops of South-East Asia are indicated in Table 10.

1.6 Agronomy

1.6.1 Production systems

Basically, three production systems can be distinguished in oil crops. These are: collection of oil-bearing fruits or seeds from wild and semi-wild palms and forest trees, cultivation in small landholdings and commercial production in large-scale plantations.

Collection

In tropical West Africa and Brazil, the oil palm exists in semi-wild groves as a result of shifting cultivation and spontaneous establishment in cleared areas (Hartley, 1988). The fruit bunches are harvested for the extraction and local consumption of palm oil, while the kernels are sold. The palms are also frequently tapped for palm wine. The fruits, nuts or seeds of several tree species of the humid tropical forests are collected by indigenous people for their oils and fats. For instance the nuts of *Shorea* spp. (tengkawang) growing in the forests of Kalimantan (Borneo) and other areas of South-East Asia are collected for the edible fat. The seeds of *Reutealis trisperma* (Philippine tung), which grows naturally in forests of the Philippines, yield a drying oil for various non-food uses.

Smallholdings

The size of smallholdings in South-East Asia is generally 0.5–4 ha. Capital inputs are usually low, few improved practices are applied and tasks are done manually. Oil palm started as an estate crop in South-East Asia and large-scale plantations dominate in Malaysia and most other countries. However, in Indonesia about 32% of the present area consists of smallholdings, usually organized around a nucleus estate with a large oil mill (Jacquemard & Jannot, 1999). More than 90% of all coconuts in South-East Asia are grown in small landholdings (Ohler, 1999). Coconuts are traditionally planted in garden plots and often grown with fruit trees. The coconut is so common in the region that almost all backyard gardens have one or a few palms, which supply the household with coconut meat, milk and oil. The major annual oil crops of South-East Asia, such as soya bean, groundnut, sesame, cotton and sunflower, are almost entirely grown in small landholdings, usually in rotation with rice and other crops and sometimes in mixed cropping systems.

Commercial plantations

Large-scale production of oil crops such as soya bean, rapeseed, groundnut and sunflower, is common in the Americas and Europe. In South-East Asia only oil palm and to a small extent coconut are produced in large plantations. For oil palm, individual estate size varies from a few hundred to 10 000 ha. Several estates may belong to one private or public company and there are a few very large companies in Indonesia owning more than 150 000 ha of oil-palm plantations (Jacquemard & Jannot, 1999). Costs of establishing an oil-palm plantation together with the necessary infrastructure and oil extraction mill are high. Nevertheless, the return on investment in oil-palm plantations in South-East Asia has been much higher generally during the past decade than for any of the other plantation crops, e.g. cocoa or rubber. This has been a major factor in the tremendous expansion of oil-palm production in the region.

1.6.2 Propagation

The major oil crops of South-East Asia are propagated by seed. In addition to careful cleaning, drying and storage to retain high viability, seeds for planting require additional treatment to break seed dormancy in the case of oil palm, some groundnut types and sunflower.

Seed-nuts of oil palm are subjected to a heat treatment for 60–80 days at about 39°C followed by cooling and rehydration to induce a flush of rapid germination. This is followed by 10–14 months in a polybag nursery to grow the newly germinated seeds into seedlings ready for transplanting into the field (Hartley, 1988). In contrast, mature coconuts start germinating soon after harvesting. Coconuts for seed are usually stored in a cool place for a few weeks before placing them in a germination bed. Well-germinated coconuts are raised in nurseries for 3–8 months to obtain transplantable seedlings (Ohler, 1999).

The dormancy of fresh sunflower and groundnut seeds (Virginia type) can be overcome by exposure to ethylene before sowing, but it disappears naturally after a few months storage. Annual oil crops are sown directly in the field, where seedling emergence will occur within 5–15 days for soya bean, cotton and non-dormant seed of groundnut and sunflower, depending on depth of planting, soil moisture and temperature. Seedling emergence of sesame may be a few days slower (Weiss, 2000).

The development of methods of clonal propagation by in vitro embryogenesis is well advanced in the oil palm, but the persistent and unpredictable problems of abnormal flowering in some clones still remain unsolved (Corley & Stratford, 1998). Similar methods of vegetative multiplication of the coconut are still in the experimental stage (Bourdeix, 1999).

1.6.3 Field preparation and planting

Oil palm and coconut

In the case of new plantations a proper topographical and soil survey to determine suitability for oil-palm or coconut cultivation should be carried out first. This is followed by planning the layout of plantation blocks, roads and sites for oil mill and various buildings. Clearing forest land includes underbrushing, tree felling and controlled burning, lining of plant rows, digging and refilling of planting holes. In non-forest areas, disc ploughing followed by several harrowings can clear the land of strong-growing weeds and other vegetation. When replanting old plantations the stumps and stems of old palms should be totally removed to avoid basal stem rot disease (*Ganoderma* spp.), as well as infestations of the rhinoceros beetle (*Oryctes rhinoceros*). Coconut stems provide useful timber. Oil-palm and coconut plantations are usually established on flat or gently undulating land. Where soil permeability is poor, the construction of a drainage system may be necessary. Planting on steep hills will require terracing or construction of individual platforms (Ohler, 1999; Piggot, 1990). A leguminous cover crop is often sown after land preparation or soon after planting to protect the soil from erosion, suppress weeds and add to the soil humus and nitrogen supply. The main cover crop species used are *Calopogonium muconoides* Desv., *Centrosema pubescens* Benth. and *Pueraria phaseoloides* (Roxb.) Benth., often in a mixture. Except in regions with no distinct dry season, the best time for transplanting into the field is at the beginning of the main rainy season. This gives the young palm time to form a good root system before the next dry season arrives. Oil palms are usually planted 9 m apart in a triangular pattern, which gives 143 plants/ha. Tall coconuts are planted at 8–9 m distance and dwarf palms at 7 m spacing in a triangular or square configuration. Such plant densities are a compromise to balance competition for light, water and nutrients of young and mature palms aimed at maximizing economic returns over the total duration of a plantation.

Oil-palm development schemes for smallholders follow similar procedures for field preparation and planting, usually with technical and financial support from the nearby nucleus plantation. Coconut smallholdings are generally not organized in formal schemes, mainly because there is no need for immediate oil extraction and the main products (green coconuts and copra) can be sold directly at the farm gate or on the local market.

Annual oil crops

In South-East Asia the farmers often grow soya bean and groundnut directly after paddy-rice by planting seeds 20–25 cm apart between the rice stubble without tillage, or even broadcast soya bean in the standing rice, and so utilize residual soil moisture. With sufficient rainfall or supplementary irrigation available during the full crop cycle, field preparation prior to sowing will produce higher yields. Cultivation involves ploughing to break up the soil for improved aeration and water infiltration, and harrowing to kill weeds and prepare seedbeds. Similar preparations are adequate for sunflower and cottonseed, but sesame with its smaller seeds requires a finer seedbed. Seeds may be broadcast, but are more often sown by hand in rows spaced at 40–50 cm for soya bean and groundnut, 50–70 cm for sesame and sunflower and 80–100 cm for cotton. Rows on ridges facilitate drainage after heavy rainfall or surface irrigation under dry conditions. Farmers usually sow 2–5 seeds per plant hill to compensate for suboptimal seed quality and if necessary thin out to normal plant densities after seedling emergence. Seed rates for sole-crop smallholder plots are therefore higher than those for mechanized production systems (see Table 14).

In larger commercial farms, land is prepared by tractor-drawn implements and precision seed drills ensure regular plant spacing and correct planting depth. Plant densities for each crop vary with soil and climatic conditions: 250 000–400 000 plants/ha for soya bean and sesame, 80 000–150 000 plants/ha for groundnut and 30 000–60 000 plants/ha for sunflower and cotton (Weiss, 2000).

1.6.4 Intercropping

Oil palm is best grown as a sole crop, because the dense canopy of mature palms allows insufficient light transmission to the undergrowth. Leguminous cover crops established at field planting make place for shade-tolerant plants such as ferns after the canopy has closed some 5–6 years later. Intercropping with annual food crops during the first 2–3 years after planting is possible, but may increase risks of structural and nutritional degradation of the soil. For that reason it is usually discouraged in smallholder schemes. Combinations of oil palm at conventional or wider spacings with cocoa or coffee have been tried on Malaysian plantations without much success in regard to additional economic returns (Hartley, 1988).

Coconut, on the other hand, is commonly intercropped with food and cash crops in coconut-based farming systems, which are more profitable than sole-cropped coconut (Das, 1999; Opio, 1999). The canopy of coconuts lets through 20% of the total solar energy to the crops underneath in 10-year old plantations, and this gradually increases to 50% in 40-year old plantations at conventional spacings. The interplanted crops also do not compete too strongly for water or nutrients with the more deep-rooted coconut palms. Smallholders in Asia intercrop coconuts with food crops, including root and tuber crops, cereals, pulses such as groundnut and soya bean, vegetables, bananas and other fruits. Mature coconuts provide optimum shade for cocoa and coffee, while their stems make good supports for black pepper. Cocoa under coconut is an important combination in Malaysia and Papua New Guinea (Wood, 1989). Multiple-storey cropping systems with cocoa, coffee or black pepper forming the middle storey below the coconut canopy and pineapple or annual crops cultivated at ground level, can be successful under optimum conditions of soil, rainfall and crop management (Nair, 1979, 1983).

Soya bean and groundnut are intercropped or strip-cropped with other crops such as maize, sorghum, cassava, banana, sugar cane and fruit trees. Yields are lower mainly due to shading, but the combination of crops is often more profitable to the smallholder. Groundnut is generally more tolerant of shade than soya bean (Weiss, 2000).

1.6.5 Plant nutrition

Nutrient removal

Estimates of macro-nutrient removal by the harvested products of some major oil crops are presented in Table 11. In the perennial oil palm and coconut large amounts of nutrients are also immobilized in the trunks and crown. More nutrients will also be removed in the annual oil crops, if plant stover is not left on the field and ploughed back into the soil. Oil palm appears to be very efficient in the use of nutrients per t of oil. Soya bean and groundnut require particularly high amounts of N, but that is partly explained by the high protein content of the seeds. In the case of coconut, Cl is absorbed in quantities comparable to a macro-nutrient.

Table 11. Nutrient removal by harvested product of major oil crops in South-East Asia.

Crop	Yield/ha per year or per season		Nutrient removal (kg/ha)					
	product	oil (t)	N	P	K	Ca	Mg	Cl
Oil palm	25 t fruit bunches	5.8	70	10	90	30	20	
Coconut	7000 fruits (= 1.7 t copra)	1.0	36	6	70	5	6	36
Soya bean	1.0 t seed	0.2	80	10	40			
Groundnut	1.8 t seed	0.9	85	7	15	10	4	
Sunflower	1.5 t 'seed'	0.7	40	6	26	3	5	
Sesame	1.5 t seed	0.7	45	21	9			

Sources: Hartley, 1988; Ohler, 1999; Weiss, 2000.

Fertilizer use

For sustainable crop production it is necessary to replenish the nutrients lost during cultivation and removed by the harvested crop. This can be achieved by applying organic and mineral fertilizers, but also by cultivating legumes as an intercrop, in crop rotation or as a cover crop.

Organic fertilizers include farmyard manures and composts prepared from agricultural and domestic waste materials. They supply not only nutrients through mineralization of the organic matter, but also improve the soil structure and its ability to absorb nutrients by increasing organic matter content. Disadvantages are the large quantities needed for effective results and therefore high costs of transportation, as well as the rather unbalanced nutrient composition.

Mineral or inorganic fertilizers are available as single-nutrient or compound (mainly N, P and K) products.

In coconut, N and K are the major nutrients needed and it is the only known crop requiring Cl in quantities comparable to a macronutrient (Ohler, 1999). Generally, N and K are also the most important nutrients for optimum oil-palm growth and production; significant responses to P and Mg are found in some soils (Hartley, 1988). Fairly reliable methods of foliar diagnosis have been developed for oil palm and coconut to determine the nutrient status of the palms. In conjunction with the results of fertilizer trials this provides the means to harmonize fertilizer application with cropping levels and thus to avoid excessive use of mineral fertilizers and their potentially harmful effects to the environment. While the leguminous cover crop provides some nutrients to young oil palms, coconuts may obtain permanent nutritional benefits from the interplanted crops in coconut-based farming systems.

In South-East Asia mineral fertilizers are seldom applied in smallholdings of oil crops in spite of evidence showing that even low rates may increase yields. High costs and poor access to sources of supply are reasons for low utilization in crops like soya bean and groundnut by subsistence farmers. They also tend to give priority to spending available resources on fertilizers for cereal food crop production. Actually, groundnut and soya bean need few additional nutrients when grown after highly fertilized crops. It is estimated also that these legumes obtain about half of their N requirements from symbiotic fixation by

Rhizobium bacteria in the root nodules. Soya bean and groundnut respond positively to a dose of 20 kg/ha of N fertilizer at the early stage of growth. Positive yield responses to P, K, Ca and S fertilizers are obtained in soya bean and groundnut depending on soil type. Sesame responds positively to N (higher oil content) and sunflower to K and Ca fertilizers.

Deficiencies in micronutrients are often linked to specific soil conditions and can be rectified by low doses (1–4 kg/ha of the element) applied to the soil or as foliar sprays. Boron is among the most frequently reported deficient micronutrients in oil crops.

1.6.6. Crop protection

Diseases

Oil palm is relatively free from major diseases in South-East Asia (Turner, 1976). Basal stem rot (*Ganoderma* sp.) is often related to replanting old coconut or oil-palm plantations, and crown disease is a transient physiological disorder in young palms. Some fungal diseases of nursery seedlings can be effectively controlled by fungicides and cultural methods. Plant quarantine measures should prevent the inadvertent introduction of Fusarium wilt and Cercospora leaf spot from Africa and oil-palm diseases from tropical America.

Coconut, on the other hand, is affected by several serious diseases (Ohler, 1999). Most devastating are the yellowing and wilt diseases that are caused by mycoplasm-like organisms and are present in all important coconut areas in South-East Asia. They include Malaysian, Natuna and Socorro wilts. They resemble the disastrous lethal yellowing diseases of tropical America and Africa. No effective control measures exist except that some dwarf coconut types appear more resistant than tall varieties. Cadang-cadang is an important coconut disease in the Philippines and is caused by a viroid. Fungal diseases include basal stem rot (*Ganoderma* sp.), stem bleeding (*Thielaviopsis* sp.), leaf blight (*Pestalotia* sp.) and leaf spot or rot (*Drechslera* sp.).

The annual oil crops all harbour several diseases. Serious diseases in soya bean and groundnut include fungal and bacterial leaf spots, rusts and virus infections (Weiss, 2000). In groundnut there are also soil-borne problems of bacterial wilt (*Pseudomonas solanacearum*) and aflatoxin in the seeds caused by *Aspergillus flavus* infection. The most important diseases in sunflower include Sclerotinia wilt, rust and downy mildew. Sesame is affected by bacterial and fungal leaf spots and so-called phyllody, a disease probably caused by a mycoplasma and important in Burma (Myanmar). Crop rotation helps to reduce disease incidence and there is also host resistance to some of these diseases.

Pests

All oil crops are affected by numerous insect pests. Methods of integrated pest management (IPM) of most oil-palm insect pests were developed in Malaysia (Wood, 1976) and have been adopted generally in South-East Asia. By applying biological methods of control and well-timed applications of narrow-spectrum insecticides in combination with close monitoring it has been possible to prevent major outbreaks of important oil-palm pests and to reduce economic dam-

age to very low levels. Implementation of IPM is effective in oil palm in South-East Asia, particularly the monitoring and biological aspects of control, because it is a plantation crop and even smallholder schemes are usually concentrated in large blocks. The situation is less ideal in coconut, where more than 90% of the palms are on smallholder plots although often concentrated in coastal areas. Nevertheless, relatively simple preventive measures to control important insect pests like the rhinoceros beetle (*Oryctes rhinoceros*) and weevils (*Rhynchophorus* spp.) can also be effective in coconut (Mariau, 1999).
In annual oil crops the damage due to leaf-eating insects, aphids (vectors of virus diseases), pod and seed borers and storage insects is often large. Intercropping can significantly reduce infestations of many insect pests (Weiss, 2000). IPM is generally impractical in the scattered small plots of annual oil crops like soya bean and groundnut. Farmers apply insecticides, but do not always wait until certain thresholds of crop damage have been reached, or may not apply the recommended types and rates of insecticides. This can lead to residues from pesticides in the seed. In sunflower insecticides that are toxic to pollinating insects such as bees may affect seed yields.
Other pests include nematodes (in groundnut and soya bean), birds (in sunflower) and rats (in oil palm and coconut).

1.7 Harvesting and post-harvest handling

1.7.1 Annual oil crops

Crops of soya bean, rapeseed, sunflower, groundnut, sesame, safflower and linseed are usually mature within 3–4.5 months after sowing. Season and cultivar (early and late-maturing types) are main factors of variation in the length of the cropping period. In Asia these crops are grown predominantly by smallholders and manual harvesting is the common practice.
Mature whole plants are pulled up or cut, or only the head is removed in the case of sunflower, and taken to a mud or concrete floor for drying in the sun. About 4–6 days later the 'seeds' are removed from the plants by threshing with sticks or cattle, winnowed, cleaned and further dried in the sun or sheltered place. Rapeseed and sesame in particular are harvested before full maturity to avoid considerable yield losses caused by early seed shattering in the field. Storage of oilseeds for prolonged periods under humid tropical conditions requires well-dried seeds (6–8% moisture content for most oilseeds) and cool and dry conditions to prevent early deterioration. Rapeseed is one of the easiest types of seed to store when properly dried. In the case of groundnut, the pods are picked by hand from the dried plants and seeds are often stored in the shell. Groundnut seeds stored under humid conditions and with a moisture content higher than 10% are prone to aflatoxin contamination. Soya bean seeds are also very difficult to store for longer periods in tropical climates, except in air-conditioned warehouses.
Cotton has a growth period of 4.5–6 months including 2 months of hand-picking of the opened fruits (seedcotton). The seeds are a by-product of the ginning process (removal of the lint) and need further cleaning (removal of the fuzz) and drying to a moisture content of 8% before they can be stored under cool and dry conditions. Annually grown castor is ready for harvesting within 5–6 months

after sowing. Whole panicles are cut at 2-week intervals and left to dry on a floor for about a week before seeds are collected, cleaned and stored.
In large-scale production systems outside Asia, the major oilseed crops are harvested with grain combine-harvesters with some specific adaptations according to the type of crop. This is followed by artificial seed drying and storage in stores or silos with controlled aeration. Uniform plant type and seed ripening are important characteristics of cultivars suitable for mechanized harvesting (Weiss, 2000).

1.7.2 Perennial oil crops

Oil Palm

In contrast to dry oilseeds which can be stored for a considerable period of time before oil extraction, freshly harvested fruit bunches of the oil palm have to be taken to the oil mill as quickly as possible for steam sterilization in order to deactivate the enzyme lipase and kill all micro-organisms in the wet fruit mesocarp. This will prevent a rapid rise in free fatty acid content and general degradation of the palm oil. On large oil-palm plantations the oil mill is always strategically positioned and connected to the plantation blocks by a network of roads (or rail tracks) to ensure efficient transport of the fresh fruit bunches. Oil-palm schemes including smallholders generally include a nucleus plantation with an oil mill serving both the plantation as well as these so-called outgrowers. The plantation's transport system also collects the crop from the outgrowers at a number of collection points, to ensure timely arrival of all harvested fruit bunches at the mill. Oil-palm harvesting is still a manual operation, with the aid of a chisel or Malayan knife on a long pole, since all mechanical devices developed so far have proven too costly.
After cracking the kernels to remove the shell and drying them to 6% moisture content, they can be stored for a considerable period of time before oil extraction, just like other oilseeds.

Coconut

Coconut is largely a smallholder's crop. Fruit harvesting and all post-harvest handling is performed manually. The nuts are left to dry in a shaded place. Husked and opened nuts are dried in a kiln or hot-air dryer, the copra (endosperm) is removed and further dried to 6% moisture content. Well-dried copra can be stored for some time before oil extraction. Humid conditions during storage increase the chances of aflatoxin contamination and general degradation of oil quality.

Olive

Manual harvesting is still predominant in olive orchards. Mechanical harvesting aids include trunk and branch shakers. A further step towards full mechanization is the recent development of self-propelled overhead harvesting machines in combination with hedge-rowed olive shrubs. Olive and oil-palm fruits are similar in that the high moisture content of the mesocarp is favourable to enzymatic action. Olive fruits should also be processed soon (within 3–4 days) after harvesting to minimize degradation of the oil (Young et al., 1986).

1.8 Processing

1.8.1 Oil extraction

Modern extraction of oilseeds includes some basic operations similar to traditional methods still applied in some rural areas, such as seed crushing and cooking of the ground seed mass before oil extraction under pressure (Weiss, 2000). However, many innovations in processing machinery (e.g. continuous oil expulsion by screw presses) and extraction technology (solvent extraction in particular) have resulted in much higher extraction efficiency and larger mill output, as well as in cleaner crude oils and almost oil-free meals.
Oil extraction is performed by 4 different methods:
- in a single mechanical operation with high-pressure expellers,
- by a combination of pre-pressing with an expeller followed by solvent extraction of seeds,
- by solvent extraction of seeds,
- by wet expulsion of fruits with a high water content in addition to the oil in the mesocarp, such as those of the oil palm and olive;

(Young et al., 1986).
The various stages involved in the four methods of processing seeds or fruits into crude oil and meal are depicted in Figure 2.
Oil content is the main factor determining the method of extraction to be applied to seeds (Carr, 1989). Mechanical pressing alone or more often in combination with solvent extraction is generally used for seeds with a high oil content (>40%), including rapeseed, sunflower, groundnut, sesame, safflower and also copra and palm kernels. Direct solvent extraction is more efficient for seeds with a low oil content (< 20%) such as soya bean, but can also be used for high oil-containing but permeable raw materials like copra and palm kernels.

Oilseeds

Pretreatment Seedlots may first require additional cleaning and drying on arrival at the oil mill. Hulling or decorticating involves seed cracking and separation of hulls from kernels. It is applied to most seeds, except the very small ones like safflower and rapeseed, in order to increase oil-extraction efficiency and also reduce crude fibre content in the residual meals. This is followed by grinding to reduce particle size and flaking by rolling, then heating the seed mass in stack cookers (at 12% moisture content and 85–95°C) and subsequent redrying (to 2–3% moisture) before the seed mass is extracted for oil. Cooking serves many purposes: disruption of oil cells, reduction of oil viscosity, coagulation of the proteins and fixation of phospholipids (facilitates separation of oil from the cake and reduces refining costs), general reduction of microbial load, inactivation of enzymes and detoxification. A new development in oilseed processing equipment is the extruder, a mechanical device similar to a screw press (but without choke) that replaces traditional grinding, flaking and cooking operations and produces a seed mass ready for oil extraction in a very short time (Weiss, 2000).

Method & processing stage	1 **High-pressure expulsion**	2 **Pre-expulsion + solvent extraction**	3 **Solvent extraction**	4 **Wet expulsion (oil palm)**
Raw material	Seeds	Seeds	Seeds	Fresh fruit bunches
Pre-treatment ↓	Cleaning, drying Hulling/decortication Grinding, flaking Cooking Re-drying	Cleaning, drying Hulling/decortication Grinding, flaking Cooking Re-drying	Cleaning, drying Hulling/decortication Grinding, flaking Cooking Re-drying	Sterilization Fruit stripping Digestion of fruits under steam (95°C)
Oil extraction ↓	Seed mass fed to high-pressure screw press	Pre-pressing of seed mass in screw press Solvent extraction of pre-pressed cake	Solvent extraction of flaked and cooked seed mass	Hot digested fruit mass fed to screw press
Cleaning ↓	Separation of oil from foods and dirt by setting and filtration	Oil from pre-pressing cleaned by setting and filtration Miscella (oil + solvent) cleaned by filtration Solvent recovery from oil and cake Steam stripping of oil Toasting of cake	Miscella (oil + solvent) cleaned by filtration Solvent recovery from oil and cake Steam stripping of oil Toasting of cake	Separation of oil from water and solids by clarification Vacuum drying
Cake processing ↓	Grinding Conditioning Pelleting	Grinding Conditioning Pelleting	Grinding Conditioning Pelleting	Separation of nuts from fibre Nut cracking Kernel & shell separation Kernel drying Kernel oil extraction by methods 1, 2 or 3
Final products	Crude oil Meal (3–6% oil content)	Crude oil Meal (0.5–1% oil content)	Crude oil Meal (0.5–1% oil content)	Crude palm oil Crude palm kernel oil Palm kernel meal

Figure 2. Methods of oil extraction in oil crops.

Extraction The earlier batch-type hydraulic presses have been largely replaced by single-shafted or twin-shafted screw presses, which allow continuous operation and expel the oil more efficiently. Presses used for single-stage mechanical high-pressure expulsion and for pre-expelling in combination with solvent extraction are similar. They consist of a horizontal wormshaft or auger assembly, which revolves within a tapering steel barrel with slots for drainage of expelled oil and choke gears on each end to regulate pressure and discharge of the cake. In the case of prepressing, the speed and choke are adjusted to allow a faster throughput at much lower pressure. The objective here is not maximum (>90%) oil extraction as in the first method, but to obtain a seed cake of good permeability and reduced oil content (15–20%) for the next stage of solvent extraction (Young et al, 1986). The operation of most solvent extractor equipment is based on percolation of hexane (petroleum derivative; boiling point 65–70°C) through the granulated cake at 40–60°C, producing a miscella of solvent with oil and an extracted cake with only 1% oil content. Direct solvent extraction operates on the same principle, but with extra attention to seed pretreatment (rigorous cleaning and larger particle size). Solvent extraction plants require high standards of operation to minimize the risk of fire and explosion (inflammable mixtures of dust and hexane vapours).

Cleaning The oil expelled from screw presses requires removal of suspended solids or 'foots' by settling and filtration. The miscella (hexane + oil) from the solvent extractor is first filtered to remove foots. The oil is then recovered by evaporating the solvent and finally cleaned of all traces of hexane by steam stripping. The cake is passed through a desolventizer/toaster to remove all hexane and excess moisture.

Cake processing The cake discharged from the press or solvent extractor is ground into a meal by hammer or revolving-disc mills. The meal is often further processed into pellets to avoid excessive dust formation during handling and transport.

Final products In some instances the quality of crude oil may be good enough for direct use as salad or cooking oil, but generally it will require further refining first. Meals produced by high-pressure expulsion have a higher oil content (3–6%) than those produced by solvent extraction (0.5–1%).

Oil palm

The objectives of sterilization of fresh fruit bunches, usually with steam in pressurized horizontal boilers (final temperature reaching 130°C), are as much loosening and softening of the fruits as arresting free fatty acid formation (Hartley, 1988). Fruits are then stripped from the bunches in rotating drums and subsequently digested in steam-jacketed vessels (95°C) to break up the mesocarp before oil extraction. Most modern palm-oil mills use twin-shafted screw presses. The liquor draining from the presses – a mixture of oil (65%), water (25%) and solids (10%) – is passed over screens (to remove larger impurities) into settling (clarification) tanks (heated by steam coil) to separate the oil from water and solids (sludge). The oil is further clarified in centrifugal separators, vacuum dried and sent to storage tanks for crude palm oil. Various methods of bio-degradation have been developed to convert the de-oiled sludge (palm oil mill effluent) into environment-friendly products.

The cake extruded from the press consists of fibre with some residual oil and nuts, which are separated by pneumatic, mechanical or hydraulic means. The fibre mass can be used as fuel for the mill boilers. The nuts are dried and size-graded before feeding into centrifugal nutcrackers. Separation of the kernels from the broken shells, formerly in a clay-bath in which the kernels float and shell bits sink to the bottom of the tank, now takes place in a specially designed hydrocyclone. The kernels are redried before storage. Oil extraction of kernels is similar to that of oilseeds.

Olive

Olive fruits are crushed and mashed into a paste before extraction by repeated mechanical pressing. In contrast to oil palm and most oilseeds, oil extraction takes place without heating (Di Giovacchino, 1997). The oil is separated from the watery mix ('margine') by clarification in a similar way to palm oil, but again without heating. Oil from the first pressing is usually of such good quality that further refining is unnecessary (virgin olive oil). Residual oil in the cake may be further recovered by solvent extraction and used for nonfood purposes. The remaining cake is usually not used as stockfeed but can serve as organic fertilizer.

Small-scale oil extraction in rural areas

One of several traditional methods of extraction involves boiling of pounded (macerated) oilseeds, fresh coconut endosperm, or oil-palm fruits in water and skimming off the floating oil. The 'ghani' mills of South Asia and parts of South-East Asia (e.g. Burma(Myanmar)) express oilseeds by friction in a mortar and pestle device driven by animal or electric power. The extraction efficiency of these methods is low (60–70%) and the remaining cake may still contain 10% oil. The development of hand-operated screw and hydraulic presses, but especially the recent introduction of inexpensive small-scale expellers, similar in design to the horizontal screw-presses of large oil mills and powered by small diesel engines or by electricity, have greatly increased the extraction efficiency of village oil mills, as well as the quality of edible oils. Solvent extraction is seldom used in small-scale operations on account of costs of equipment and also the safety risks involved (Weiss, 2000).

1.8.2 Refining

A large proportion of freshly extracted oils from oilseeds is consumed directly without further refining by the local populations of Asia as is crude palm oil in West Africa. However, crude vegetable oils contain impurities – dirt, meal fines, water, phosphatides (phospholipids), free fatty acids, partial glycerides, waxes, oxidation products, pigments (carotenoids and chlorophyll) and traces of metals – of which some cause progressive degradation of quality over time and also interfere with manufacturing processes (Stauffer, 1996; Young et al., 1986). For those reasons, industrially processed vegetable oils are subjected to

Operation	Methods	Impurities removed
Degumming ↓	Water (+ phosphoric acid)	Phospholipids, pigments trace metals, carbohydrates, protein
Neutralization ↓	(a) Caustic soda (b) Steam	Free fatty acids, phospholipids, pigments, water sobules
Washing, Drying ↓	Hot water Vacuum dryer	Soap (lye), water
Bleaching ↓	De-aerated bleaching earth Filtration	Pigments, oxidation products, sulphur, traces of soap and metals
Deodorization	Steam stripping (250°C) Cooling, filtration	Fatty acids, mono- and diglycerides, oxidation products

Figure 3. Refining of crude vegetable oils.

further refining to obtain so-called RBD (refined, bleached, deodorized) quality oils. The main operational steps of the refining process, the methods applied and impurities removed successively are shown in Figure 3.

Degumming is the separation of phosphatides from the oil by adding hot water or steam and sometimes also phosphoric acid, followed by centrifugation. It improves the results of the next step in the refining process, i.e. neutralization or deacidification, and is particularly important for solvent extracted oils, e.g. of soya bean and rapeseed, which contain up to 2–3% phosphatides. Treatment of the oil with a dilute caustic soda solution will convert the free fatty acids into soap, which is removed by repeated centrifugal action and washing with hot water. The refined oil is then vacuum-dried before the next step of bleaching to remove pigments, oxidation products and other remaining impurities by adsorption to activated bentonite clay and filtration.

The oils of sunflower, sesame, safflower and maize contain relatively large amounts of waxes, which cause clouding at low temperatures. Before bleaching, these oils are therefore cooled to 5°C, mixed with water, and allowed to stand for several hours before the aqueous wax suspension is removed by centrifugation (Stauffer, 1996).

Finally, the oil is deodorized by injecting live steam through hot (200–275°C) oil to remove undesirable odours and flavours. The result after cooling and final filtration is refined vegetable oil of RBD grade, containing about 0.02% free fatty acids, with a zero peroxide value and a very pale yellow colour.

In the case of palm and lauric (coconut and palm kernel) oils, which generally contain more (2–5%) free fatty acids but are low in phosphatides, physical refining with steam can be used to distill off all free fatty acids instead of neutralizing these chemically by alkali refining. This method reduces the number of steps in the refining process and the loss of oil in the by-products (Carr, 1989; Young et al., 1986).

1.8.3 Modification

Refined oils are often processed further to modify their chemical and physical properties and so increase their usefulness in different food products. Such processes include hydrogenation, interesterification and fractionation. Hydrogenation or hardening increases oxidative stability and converts liquid oils to semi-solid plastic fats for use in margarines, shortenings and other fats. The hydrogenation of oils is usually applied during the refining process before the final stage of deodorization (Carr, 1986). Interesterification also changes melting and crystallization characteristics by rearranging the positions of fatty acids in the triglycerides, but without producing trans fatty acids as can happen during hydrogenation. It finds application in producing a so-called 'non-trans' dietary margarine from soya bean and other oils high in polyunsaturated fatty acids. It also improves plasticity and creaming properties of shortenings (Stauffer, 1996).

Fractionation or winterization is a process by which different fractions are separated by slow cooling of heated (70–75°C) RBD-grade oils down to 6–10°C (Young et al., 1986). This induces crystallization of triglycerides with high melting points, which can then be removed by filtration or centrifugation from the liquid fraction. For example, fractionation of palm oil yields palm stearin and olein. The solid fractions can be used as component of margarines, shortening and frying fats and the olein fraction as salad oils with low cloud point, i.e. no precipitation at refrigerator temperatures.

1.9 Genetic resources and breeding

1.9.1 Genetic resources

Plant breeding tends to narrow the genetic variation of a crop and often a few excellent cultivars dominate in technology-based agriculture to the exclusion of all else (Simmonds, 1981). Continued progress in crop improvement, which also takes into account future changes in environmental, agronomic and socio-economic demands, requires easy access to adequate sources of genetic variability. The collection, conservation and characterization of germplasm comprising wild and domesticated plant types, landraces and old cultivars of hundreds of crop species has developed over the past 50 years into a highly specialized activity in so-called genebanks established by national and international agricultural research organizations (FAO, 1996). The management strategies of such ex situ plant genetic resources are evolving from mere collection and maintenance of individual accessions to optimization of genetic diversity and to active exploitation of the genetic potential for crop improvement. These latter aspects are enhanced by the application of biometrical and molecular genetics (van

Table 12. Germplasm collections of major oil crops.

Crop	Principal germplasm repository and/or co-ordinator[1]	Important collections at NARS
Field collections		
Oil palm	NIFOR, Nigeria MPOB, Malaysia	Ivory Coast, Democratic Republic Congo, Ghana, Papua New Guinea
Coconut	COGENT	Philippines, Indonesia, India, Ivory Coast, Tanzania
Olive	OWC-C, Spain IOOC	Italy, Greece, Israel
Seed banks		
Soya bean	AVRDC, Taiwan CAAS, China INTSOY, United States	India, Indonesia, Japan, South Korea, Thailand, Australia
Rapeseed	–	United States, Canada, France, Germany, India, China, Japan, Australia
Sunflower	USDA-NPIS, United States, VIR, VNIIMK, Russia	Russia, France, Yugoslavia, Romania
Groundnut	ICRISAT, India	United States, Indonesia, Philippines, China
Cotton	NSSL, United States	United States, China, India, etc.
Maize	CIMMYT, Mexico	several countries in America, Asia and Africa
Sesame	NBPGR, India	Russia, United States, China
Safflower	USDA, United States	India, China
Linseed	USDA, United States VIR, Russia	France, Belgium, Netherlands, Germany
Castor	ICGR & IOCR, China VIR, Russia	United States, India, Brazil, Ethiopia

[1] IPGRI is the overall co-ordinator for most crops.

Hintum, 2000). The International Plant Genetic Resources Institute (IPGRI) has the mandate of promoting agricultural biodiversity in general and of coordinating global genebank activities with emphasis on plant genetic resources in developing countries (IPGRI, 1999).

An overview of genebanks with large germplasm collections of major vegetable oil crops is presented in Table 12. Germplasm of tree crops such as oil palm and coconut cannot be stored for long periods as 'seeds' and genebanks consist of large field collections. This also applies to the olive, which is mostly vegetatively propagated. Germplasm of the annual oil crops is effectively conserved as stored seed.

Oil-palm genebanks of NIFOR in Nigeria and MPOB in Malaysia consist of large field collections with 1000 and 1700 accessions respectively, which were collected from the centre of high genetic diversity in south-east Nigeria and other sites in Africa in the period 1956–1994 (Rajanaidu et al., 2000). Smaller collections are also maintained in other oil-palm research centres in the tropics. The Coconut Genetic Resources Network (COGENT) and IPGRI coordinate the conservation of more than 700 accessions present in field collections in the Philippines, Indonesia, India and several other countries (Bourdeix, 1999). Progress has been made with cryopreservation of oil-palm and coconut embryos and pollen (Assy-Bah & Engelmann, 1992; Rohani et al, 2000). This may provide a safe and less expensive alternative for long-term storage of genetic resources to field genebanks, which require considerable resources of land, staff and upkeep and remain vulnerable to losses by natural disasters and diseases.

The International Olive Oil Council (IOOC) supports the collection and conservation of wild olive germplasm and landraces in field genebanks in Spain (OWC, Cordoba) and other countries. Genetic resources of tung-oil trees and wood-oil trees appear to be limited to the maintenance of small work collections by NARS in China, the United States and Malawi.

For soya bean, groundnut and maize large collections of more than 13 000 accessions each are available in the genebanks of the relevant international agricultural research centres: AVRDC (Taiwan), ICRISAT (India), CIMMYT (Mexico) and IITA (Nigeria). In the United States there are major germplasm collections for soya bean (INTSOY), sunflower (NPIS), cottonseed (NSSL), safflower (USDA) and linseed (USDA). China maintains large collections of soya bean (CAAS) and castor (ICGR & IOCR) and Russia of sunflower (VIR & VNIIMK), linseed (VIR) and castor (VIR). The NBPGR in India has the principal germplasm repository for sesame. Rapeseed germplasm is distributed over several genebanks of national agricultural research systems (NARS) in Europe, North America, China and India.

Collection of germplasm for all oil crops mentioned in Table 2 except rice is of minor importance or non-existent except for jojoba (United States) and niger seed (Ethiopia, India).

1.9.2 Breeding

Breeding and genetics have contributed considerably to the establishment and improvement of oil crops (Knowles, 1989a). Traditionally, most oil-crop breeding has been in the domain of public agencies, but in America and Europe many private companies are now also involved in oil-crop breeding and seed production. Private sector activities in Asia include rapeseed, sunflower and cottonseed in India and oil palm in Malaysia, Indonesia and Papua New Guinea.

The general objective of plant breeding is the development of crop cultivars with the potential of providing maximum economic benefits to the growers. This usually requires simultaneous selection for plant type and vigour, ecological adaptation, yield, quality and other characters. Disease and pest resistances may assume the highest priority in breeding, especially when these have become a threat to the profitability or even survival of the crop. Selection progress depends on the breeding plan applied, which in turn is to a large extent influenced by the species' life cycle (annual or perennial), and mating system (self-pollinating or cross-pollinating) (Simmonds, 1981). The life cycle and mating system of major oil crops is indicated in Table 13.

Table 13. Mating system and life cycle of major oil crops.

Crop	Self-pollinating	Cross-pollinating
Perennial		
Oil palm		×
Coconut		×
Olive		×
Annual		
Soya bean	×	
Rapeseed (*B. juncea*, *B. napus*)	×	
Rapeseed (*B. rapa*)		×
Sunflower		×
Groundnut	×	
Cotton	×	
Maize		×
Sesame	×	
Sunflower	×	
Linseed	×	
Castor		×

Perennial oil crops

Practically all woody perennials are cross-pollinators (Simmonds, 1981), including oil palm, coconut and olive. Breeding plans in the oil palm are comparable to those applied in maize and sunflower, including methods of reciprocal recurrent selection within genetically divergent subpopulations and F1 hybrid seeds as final result. The floral biology of the oil palm (monoecious, with female and male flowers on separate inflorescences) and large multiplication factor (>5000) enable efficient and economically viable mass production of seeds, even though it depends entirely on hand pollination. The discovery around 1940, that pure stands of palms yielding the preferred thin-shelled Tenera fruits can only be obtained by crossing Dura with Pisifera palms, has been another strong impetus to the exclusive use of F_1 hybrid seed in all oil-palm plantings. On the other hand, in coconut about 95% of all plantings are still open-pollinated progenies after mass selection, partly due to longer breeding cycles (>10 years) and because this monoecious palm carries only a few (20–60) female flowers (and large numbers of male flowers) on each inflorescence. Consequently, the multiplication factor is low (50–100) and emasculation is required as an additional operation of seed production. The considerable hybrid vigour exhibited by hybrids between certain Tall and Dwarf populations has encouraged the initiation of advanced breeding programmes based on reciprocal recurrent selection also in the coconut. These have already lead to F_1 hybrids yielding 30–100% more than the best open-pollinated selections and so justifying the additional efforts and costs of F_1 hybrid seed production. The olive represents a classic example of fruit-tree breeding, in which cultivars are clones from phenotypically or genotypically selected trees. Seed germination is usually poor and olive seedlings have a long (4–9 years) juvenile phase.

Breeding objectives include:
- For oil palm: maximizing oil yields (per palm and per ha) and more recently quality (change in fatty acid composition) of palm oil (Gascon et al, 1989; Hartley, 1988). Disease resistance (Fusarium wilt in Africa, sudden death in South America, crown disease and *Ganoderma* in South-East Asia) is sometimes locally given high priority.
- For coconut: diseases, including those threatening the survival of the whole crop in certain regions (e.g. the various wilts and yellowing diseases), are a very important factor, but unfortunately breeding has not been able to provide answers in most cases, mainly because of lack of genetic resources with adequate host resistance (Bourdeix, 1999; Satyabalan, 1989).
- For olive: cold tolerance, early bearing, yield, regular production and some efforts to disease resistance (Brousse, 1989; Lavee, 1990).

Annual self-pollinating oil crops

Soya bean and groundnut are strictly self-pollinating species with very little natural outcrossing and therefore requiring painstaking pollination methods to achieve cross-breeding. In other self-pollinating oil crops like cotton, sesame, safflower and linseed, natural cross-pollination may be higher, 1–10%, and in rapeseed (*B. napus* and *B. juncea*) even up to 30%. Selfing in these species will therefore require isolation of the flowers by bagging during anthesis. The breeding process includes line and pedigree selection after crossing and back-crossing, all leading to homozygous and uniform cultivars. These are true to type and can be multiplied in seed blocks with simple precautions such as guard-rows and minimum distances (specific for each crop) to avoid illegitimate outcrossing. F_1 hybrid cultivars with considerable hybrid vigour for yield have been successfully developed during the past two decades for cotton and *B. napus* rapeseed. In cotton such F_1 hybrids find application in South Asia and China, where seed production is economically feasible because of low labour costs for emasculation and hand pollination (Hau et al., 1997).

The following are examples of crop specific breeding objectives, in addition to the general aims of higher yields and oil content:
- For soya bean: less sensitivity to photoperiod and temperature, early maturing, disease resistance (rust, downy mildew, anthracnose, bacterial pustules and blight, viruses), improved oil quality (fatty acid composition) and elimination of beany flavour (Fehr, 1989; Weiss, 2000).
- For groundnut: earliness and drought tolerance, reduced seed dormancy, disease resistance, e.g. rusts, leaf spots, bacterial wilt and aflatoxin-producing *Aspergillus flavus* (Clavel & Gautreau, 1997; Coffelt, 1989).
- For cotton: earliness, disease resistance (bacterial blight and Fusarium wilt) and low gossipol content by glandless plants (Hau et al., 1997; Kohel, 1989).
- For sesame: compact plants, earliness, disease resistances (little progress so far) and non-shattering (Ashri, 1989; Weiss, 2000).
- For safflower: spineless plants, early maturity, thin seed hulls, resistance to foliar diseases in particular (Knowles, 1989b; Weiss, 2000).

Annual cross-pollinating oil crops

Open-pollinated, composite (mixture of improved selections) or synthetic (mixture of inbred lines) cultivars of sunflower, maize and castor are still widely used in countries with predominantly smallholder and subsistence farming systems. Breeding procedures, which involve recurrent mass or family selection, are relatively simple and seed can be produced in well-isolated seed blocks at fairly low costs. Elsewhere, F_1 hybrid cultivars completely determine the production of these three crops because of the much higher economic returns obtained as a result of hybrid vigour and plant uniformity. Breeding procedures are complex, requiring a number of measures including the development of genetically diverse subpopulations (e.g. by reciprocal recurrent selection). These form the source of inbred lines which, after confirmation of good combining ability for all desired agronomic and physiological characteristics, are selected as parents of F_1 hybrids. Large-scale seed production is based on monoecious flowering (requiring mechanical or manual removal of male flowers on the female parent line), as is the case for maize and castor, or on cytoplasmic male sterility (CMS) of the female parent, as in sunflower and also recently developed castor hybrid cultivars.

The situation is somewhat different in rapeseed. Considerable hybrid vigour for yield is present in *B. rapa* and also in the self-pollinating *B. napus*, but only in recent years have F_1 hybrid cultivars started to replace the open-pollinated varieties, particularly in North America and Australia. Seed production of F_1 rapeseed hybrids is based on self-incompatibility and CMS (Banga, 1998).

Crop-specific breeding objectives include:

- For sunflower: reduced plant height, oil quality (high oleic acid content), and resistance to lodging, to diseases (e.g. downy mildew and rust), to broomrape and birds (Fick, 1989; Vear, 1992).
- For rapeseed: triple-zero (no erucic acid, low in glucosinolates and linolenic acid) cultivars, day-neutral *B. napus* cultivars suitable for the subtropical winters or tropical highlands, herbicide tolerance, resistance to diseases (e.g. black leg, leaf spot and black rot), non-shattering and resistance to lodging (Downey & Röbbelen, 1989; Renard et al., 1992).
- For castor: short plants, early maturing, indehiscent and thin-walled capsules (non-shattering) and disease resistance (Atsmon, 1989; Weiss, 2000).

Molecular breeding

Plant biotechnology has evolved, particularly during the past decade, into an applied science providing powerful additional tools for plant breeding with the potential of increasing selection efficiency and creating new approaches to hitherto unattainable objectives. Molecular breeding has basically two main applications of plant biotechnology: molecular markers and transgenic plants. Molecular marker technology is applied, also in many major oil crops, for germplasm characterization and management, detecting genetically divergent breeding subpopulations (e.g. to predict hybrid vigour), accelerating gene introgression from related species and for MAS (molecular marker-assisted selection). MAS enables early selection of important major genes (e.g. disease resistance or oil quality) with molecular marker(s) closely linked to the gene controlling the trait. In the case of polygenic traits (e.g. components of yield) a more complex QTL (quantitative trait loci) analysis is required for the identification of significantly linked markers. A prerequisite to such a QTL analysis is the availability of a saturated genetic linkage map (Mohan et al, 1997).

Generally, successful genetic transformation is still limited to characters controlled by major genes for which gene isolation and transfer is relatively easy. It also requires the possibility of routine application of transformation technologies and regeneration of plants from in-vitro explants or cell cultures. These are well established in crops like soya bean, rapeseed, cotton, maize and oil palm but not yet in sunflower and coconut. Tolerance to glyphosate or glufosinate herbicides and insect resistance based on the Bt gene (derived from *Bacillus thuringiensis*) are the main characters so far successfully expressed and commercialized. The global area of transgenic crops in 2000 (James, 2001) was 44.2 million ha (compared to 1.7 million ha in 1996), of which more than 80% is grown in the United States and Canada and the rest in Europe, South America, China, South Africa and Australia, while so far none are grown in South-East Asia. Transgenic soya bean has the lead with 25.8 million ha, followed by transgenic maize (10.3 million ha), transgenic cotton (5.3 million ha) and rapeseed/canola (2.8 million ha). Other interesting projects concerning genetic transformation in oil crops, such as changing the fatty acid composition of the oil by manipulating oil-synthesis pathways, have just started to be commercialized for rapeseed in the United States (Downey & Taylor, 1996), but are still in the research phase for the oil palm in Malaysia (Corley & Stratford, 1998).

The prevailing negative public perception of transgenic crop plants in several industrialized countries (Europe in particular) as well as developing countries can be a temporary obstacle to the introduction and unrestricted cultivation of transgenic cultivars of important oil crops in South-East Asia. One could add to this also the lack of adequate legislation for proprietary rights and biosafety in some countries.

1.10 Seed supply systems

A seed supply system involves a complex chain of activities and processes from 'gene to marketable seed'. Plant breeding and release of new cultivars is followed by the multiplication of seed over several generations (from breeders to foundation and certified seed), seed quality control, processing and conditioning, storage and transport, demand assessment, marketing and distribution (Jaffee & Srivastava, 1992). The extent of recurrent demands for fresh seed of improved cultivars of annual oilseed crops depends on factors such as ease of on-farm reproduction and cost of seed in relation to crop revenue.

Annual oil crops

Soya bean and groundnut cultivars are pure lines easily reproduced on-farm a number of times before genetic (mixing with other cultivars) and physiological (seed-borne diseases and pests) deterioration of seed quality induces the grower to purchase fresh seed of certified quality. Rapid loss of seed viability under hot and humid conditions can also be a factor stimulating more frequent de-

Table 14. Seed rate, yield and multiplication factor for major oilseed crops.

Crop	**Seed rate (kg/ha)**	**Seed yield (t/ha)**	**Multiplication factor**
Soya bean	40–75	0.5–3.0	12–40
Rapeseed	7–8	1.5–4.0	200–500
Sunflower	9–10	0.8–2.5	80–250
Groundnut	50–100	0.7–2.4	14–30
Cotton	20–30	0.7–2.3	50–100
Maize	20–25	1.5–4.0	100–160
Sesame	5–10	0.5–1.5	100–150
Safflower	12–20	0.8–3.0	60–150
Linseed	20–40	0.8–1.5	40–400
Castor	10–20	0.8–1.5	40–400

Sources: Grubben & Soetjipto Partohardjono, 1996; van der Maesen & Sadikin Somaatmadja, 1989; Weiss, 1983, 2000.

mands for fresh seeds of soya bean and groundnut cultivars. Seeds of other self-pollinating crops such as rapeseed (*B. napus* and *B. juncea*) and sesame can be stored for longer periods of time, but higher natural outcrossing may accelerate genetic decline in farm-saved seed and so necessitate more frequent purchases of fresh seed. In open-pollinated, composite or synthetic cultivars of cross-pollinating crops such as sunflower and *B. rapa* rapeseed the genetic decline in farm-saved seed is even faster because of the mating system and segregation. A seed replacement rate of 20% (i.e. fresh seed of certified quality purchased once in every 5 years) is considered adequate for most self-pollinated oilseed crops and 30–50% for cross-pollinators to maintain cultivar identity and optimum crop production. Most F_1 hybrid cultivars require the purchase of fresh seed for each new crop to avoid a dramatic genetic decline in production already in the first generation of farm-saved seed.

The market value of seed of annual oilseed crops also depends very much on seed rates and multiplication factors (Table 14). The seeds of improved soya bean and groundnut cultivars have therefore a lower market value (about 1.5 times the value of the oilseed crop) compared to open-pollinated seed of sunflower or rapeseed (4–6 times the crop). The seed price of F_1 hybrid cultivars is often 12–18 times that of the oilseed crop (Louwaars & van Marrewijk, 1996).

In Europe and America the seed supply systems are almost completely privatized. Plant variety protection (plant breeders' rights) and the strong demand by the growers for high quality seed enables seed companies to recover a reasonable profit margin also on low-value seeds of self-pollinated crops. Private and public sectors collaborate closely in creating a legal and regulatory environment favourable to the development of a dynamic private seed industry (van der Vossen, 1996). Seed supply systems in South and South-East Asia vary considerably in the degree of development and private sector involvement, but they all have in common that state seed corporations are the main suppliers of improved seed of self-pollinated crops such as rice, wheat, pulses and oilseeds. These are strategically important food crops produced almost entirely by small and resource-poor farmers from on-farm saved or informally produced seed. The improved seed supplied by the public sector plays an essential role in periodically refreshing farmers' seed stocks of popular cultivars and also in facilitating the introduction of new improved cultivars. However, seed production targets to meet optimum seed replacement rates (10–20%) are seldom achieved, except for rice in Indonesia and the Philippines. Public seed system projects have been inclined to give priority to cereals and the quantities of improved seed of pulses and oilseeds are often not more than 1–5% of total annual seed requirement. The seed market for self-pollinated crops remains unattractive to the private seed industry because of low profit margins and insecurity with regard to plant variety protection (van der Vossen, 1997).

Perennial oil crops

The annual demand for oil-palm seed of the 'D x P' hybrid type is 120–140 million 'seeds' (Anonymous, 1996). More than 85% of this quantity is used for new planting and replanting of old oil-palm fields in South-East Asia, the rest in West Africa and Central and South America. These seeds are supplied by more than 25 specialized seed production centres of large private oil-palm companies or public research institutes in Malaysia (40–50 million), Indonesia (35–60 million), Papua New Guinea (10–12 million), Costa Rica (15–25 million), Nigeria (3 million), Ivory Coast (2 million) and 1–2 million seeds each in Benin, Ghana, Democratic Republic Congo, Cameroon and Colombia. An additional service often provided by these centres includes pregermination of the seed by heat treatment before distribution. The price of oil-palm seeds is not related to crop revenue but rather based on production costs plus a reasonable profit margin. There is considerable variation in seed quality, but some suppliers have a reputation for consistently producing seed of very high quality (e.g. producing almost 100% Tenera palms). Hybrid seed production of coconut is comparable to that of oil palm, except that the low multiplication factor and large seed (fruit) size are serious impediments to mass production and distribution. Coconut 'seed' production is mainly a public sector responsibility, e.g. in India, Indonesia, the Philippines and Ivory Coast. An estimated 15% of new coconut plantings over the past decade have been raised from hybrid seeds (Bourdeix, 1999).

1.11 Prospects

1.11.1 Demand and supply

World demand for oils and fats is expected to grow steadily from 117 million t in 2000 (see Table 4) to at least 175 million t (84% of vegetable origin) in 2020 (Mielke & Mielke, 1999). Major determining factors are the ever-increasing world population, by an estimated 1.5. billion to 7.5 billion, and a rise in per-capita consumption of oils and fats as a result of individual income growth in several countries. In developing countries edible oils and fats are essentially used for food, and average consumption per person will still be low to moderate (14–21 kg/year). However, the dietary intake of oils and fats in most industrialized countries has reached saturation levels (42–52 kg/year/person) and observed growth in consumption largely concerns nonfood applications.

The major vegetable oils are commodities with considerable possibilities for mutual substitution, and the future share of each in the total supply will be determined by available land resources, oil yield per ha (highest for the oil palm) and production costs per t of oil (lowest for palm and kernel oils). Growth in production of annual oilseed crops may slow down in some countries as a result of scarcity of arable land and water resources, competition with cereal production, or abolition of agricultural subsidies (e.g. rapeseed and sunflower in the European Union). Availability of soya bean oil depends primarily on the demand for the economically more valuable soya bean meal for livestock production, which is expected to develop more slowly than the demand for oils and fats. On the other hand, palm-oil production will continue to expand considerably, particularly in South-East Asia, and reach an estimated 40 million t per year in 2020. By that time palm-oil supplies will be capable of providing 27% of the total annual demand for vegetable oils (148 million t) against an estimated 25% for soya bean oil, 15% for rapeseed oil, 11% for sunflower oil, 4% each for groundnut and cottonseed oils, 3% for maize oil and 2% for olive oil. Lauric oil production will increase to about 10 million t (7%) over the same period, with equal contributions from copra and palm kernels. The remaining 2% of the supply includes sesame, linseed, safflower and castor oils.

The estimated share of palm oil in the international trade of oils and fats in 2020 (65 million t) will be 45%, of soya bean oil 22%, and 6% each for brassica oilseeds and sunflower oils. Exports of palm, palm-kernel and coconut oils from Malaysia and Indonesia combined may then account for 60% of world trade. About 13 of the 22 main producing countries are net importers of oils and fats, with China, India and the European Union being the largest (Mielke & Mielke, 1999).

With such a dominant share in the world trade, it is not surprising that large stocks of palm oil following years of record production can have a depressing effect on prices, as was the case in the years 2000–2001 (<US$ 230 per t of crude palm oil). The production of perennial crops like the oil palm cannot be adjusted within a short span of time, but annual oilseeds (e.g. rapeseed and sunflower) usually respond quickly with a decrease in sown area because production becomes uneconomic at such low market prices. Old stocks disappear and the balance between demand and supply is re-established in subsequent years with concurrent recovery in price levels (>US$ 400 per t). In other words, prices for vegetable oils will continue to fluctuate with recurrent dips due to overproduction, but each time followed by a fairly quick recovery and a generally upward trend over the longer term (Mielke & Mielke, 1999, 2001).

The demand for oil meals will increase to some 290 million t per year by 2020 and soya bean will continue to provide 55% of total demand (Mielke & Mielke, 1999). Rapeseed meal (11% of total demand) will show the largest growth in China and India, while Russia, Ukraine and Argentina will mainly produce sunflower meal (7% of total demand). Groundnut meal will show declining growth, palm-kernel meal a sharp increase in line with palm oil production and copra meal production will not show much growth. The largest net exporters of oil meals are the United States, Argentina and Brazil; the largest importers the European Union and China.

1.11.2 Research

In the plantation crop oil palm, maximum economic returns remain the highest priority. The oil palm outstrips all other oil crops as the highest and most efficient producer of vegetable oil. In South-East Asia oil yields of 7 t/ha have been obtained recently under optimum conditions of climate, soil and crop management. Nevertheless, combined efforts in plant breeding, crop physiological and agronomic research are expected to result in annual oil yields of more than 10 t/ha in the medium-long term. It is necessary to bear in mind, however, that these yields can only be sustained by sound agronomic practices including soil conservation methods and systematic fertilizer applications. Nevertheless, such production levels should provide opportunities for meeting increasing demands for palm oil from existing areas under oil-palm cultivation after they have been replanted with higher yielding cultivars. Further large-scale conversion of natural forests into plantations, as is taking place in some South-East Asian countries, would then no longer seem necessary.

Coconut does not appear to have such a bright future as an oil crop. In the world market it already faces increasing competition from palm-kernel oil and in the longer term possibly also from rapeseed that is genetically modified to produce lauric oil. On the other hand, as a smallholder crop in the coastal areas of the tropics, coconut will continue to be a very important supplier of multi-functional food and other products to the local communities. Sometimes, it is practically the only tree crop that can be grown in the prevailing ecosystem. A quickly growing world market for healthy and environment-friendly products should also offer new opportunities for the coconut export trade. This will require more research to develop viable coconut-based farming systems and novel processing technologies for local industries to manufacture diversified coconut products. Growing networks of internationally-supported coconut research on the application of biotechnology offer prospects of eventually solving some of the major constraints in coconut production, devastating yellowing and wilt diseases in particular.

Soya bean and groundnut in South-East Asia are considered more as food crops rich in proteins and fats that are grown with other crops simultaneously or in rotation. Research is, therefore, focused on higher yields and crop security within the context of existing or new cropping systems. Early maturity, resistance to biotic and abiotic stress factors and greater capacity for symbiotic nitrogen fixation will continue to be important criteria in selection and research programmes in progress in Indonesia, Thailand and other South-East Asian countries.

Progress in changing the fatty acid composition of seed oils by genetic modification is considerable. The transgenic rapeseed producing lauric oil has shown that metabolic engineering of plant storage lipids is possible without affecting the physiology and agricultural performance of the crop (Murphy, 1994). Before long a range of genetically modified cultivars of major (annual) oil crops will be available that produce custom-made oils for nutritional, industrial and pharmaceutical purposes (Vageesbabu & Chopra, 1999; White & Benning, 2001). However, production costs will ultimately define their market potential. For instance, coconut and palm-kernel oils are likely to remain cheaper alternatives to lauric oil from rapeseed, unless the latter were to have technological advantages or be protected by trade barriers. On the other hand, the application of genetic modification techniques may make it possible to produce certain specific oils for industrial and pharmaceutical applications, that are now only present in wild or underutilized plants, at required quantities and at lower costs.

2 Alphabetical treatment of genera and species

Brassica L. (oilseed crops)

Sp. pl. 2: 666 (1753); Gen. pl., ed. 5: 299 (1754).
CRUCIFERAE

$x = 8$ (B genome), 9 C genome), 10 (A genome); *B. juncea*: $2n = 36$ (AABB); *B. napus*: $2n = 38$ (AACC); *B. rapa*: $2n = 20$ (AA)

Major taxa and synonyms

- *Brassica juncea* (L.) Czern. cv. group Oilseed Mustard (cv. group name proposed in Prosea 8: 105 (1993)); other classifications of cultivars of *B. juncea* (L.) Czern. that are grown for their oilseeds: var. *juncea*, Juncea Group, Mustard Group, Raya Group.
- *Brassica napus* L. cv. group Colza (cv. group name proposed in Prosea 8: 284 (1993)); other classifications of cultivars of *B. napus* that are grown for their oilseeds: subsp. *napus*, subsp. *oleifera* auct., Napus Group, Oil Rape Group.
- *Brassica rapa* L. cv. group Oilseed Turnip (cv. group name proposed here); other classifications of cultivars of *B. rapa* that are grown for their oilseeds: Winter Turnip Rape Group (Oleifera Group, Navette d'hiver Group), Spring Turnip Rape Group (Praecox Group, Navette d'été Group), Tori Group (Dichotoma Group), Brown Sarson Group, Yellow Sarson Group (Trilocularis Group).

Vernacular names General: rapeseed, brassica oilseed.

- *B. juncea* cv. group Oilseed Mustard: Indian mustard, brown mustard, sarepta mustard (En). Moutarde indienne, moutarde brune (Fr). Indonesia: sawi, sesawi. Malaysia: sawi, pahit, kai choy. Philippines: mustasa (Tagalog). Cambodia: khat naa. Laos: kaad khièw. Thailand: phakkat-khieo, phakkat-khiepli (central). Vietnam: c[ar]i canh, c[ar]i b[ej] xanh.
- *B. napus* cv. group Colza: rapeseed, oilseed rape (En). Colza oléagineux (Fr).
- *B. rapa* cv. group Oilseed Turnip: rapeseed, turnip rape, toria, sarson (brown or yellow) (En). Navette (Fr).

The name summer or spring rapeseed refers to annual types of *B. rapa* and *B. napus* sown in spring; the name winter rapeseed to biennial types sown in autumn. The corresponding names in French are: navette de printemps and navette d'hiver for *B. rapa* and colza de printemps and colza d'hiver for *B. napus*.

Origin and geographic distribution The primary centre of origin of *B. juncea* is believed to be the foothills of the Himalayas in central Asia. From here, three secondary centres developed: one in India and one in the Caucasus for the oilseed forms and one in China for the leafy forms. The occurrence of both parent species in the Middle East, however, poses strong evidence to also consider that region as a primary centre. Primary centres of origin for *B. napus* are western Europe, for *B. rapa* the Mediterranean and Afghan-Pakistan regions. Domestication of *B. rapa* and *B. juncea* as oilseed crops of the cool season probably started more than 4000 years ago in South and East Asia. Rapeseed and to a lesser extent Indian mustard have retained a prominent position as sources of edible oil in India, Pakistan, Bangladesh and China and continue to do so today. By the 14th Century, *B. rapa* had become a major crop in the Netherlands and subsequently in other countries of north-western Europe in response to ever increasing demands for lamp oil. Some 300 years later, a new type of rapeseed (*B. napus*) was also developed in the Netherlands, more resembling a kale plant, without the turnip-like root and producing an oil equally suitable for lighting and industrial lubrication. Rapeseed cultivation in Europe started to decline towards the end of the 19th Century with the advent of electricity and petroleum products. Traditional rapeseed oil never attained general popularity as an edible oil in Europe because of its peculiar pungency. In the 1960s, higher yielding cultivars of both *B. rapa* and *B. napus* collectively known as canola or 'double zero' were developed. The oil and residual meal from these cultivars were not pungent and had improved nutritional value. This resulted in a tremendous increase in rapeseed oil production in Europe and Canada, as the oil became fully interchangeable with other major edible vegetable oils and the meal became a substitute for soya bean meal. Present rapeseed production in northern Europe and central China is mainly based on biennial or winter types of *B. napus*, while summer types of *B. rapa* predominate in Canada and northern China where winters are severe. Brassica oilseed production in South Asia is based on annual *B. rapa* and *B. juncea* types, the latter covering 10–20% of the total production area.

Uses The oil of canola rapeseed cultivars in Europe and Canada ('double zero') has a very low erucic acid and glucosinolate content and finds wide application as cooking oil and in the manufacture of margarine, shortening and other food products. However, in South Asia the unrefined oil of traditional rapeseed (*B. rapa*) and Indian mustard (*B. juncea*) cultivars is preferred as a cooking oil to the bland-tasting canola oil because

of its flavour and pungency. The seed, especially that of *B. juncea*, is also used as condiment. After oil extraction, the cake or meal has a high protein content, but is unfit as feed for monogastric livestock unless derived from canola-type cultivars or treated by a rather expensive industrial process to remove the toxic glucosinolates. Cultivars bred for extra high erucic acid content in the oil are used for industrial purposes.
Different cultivars of these *Brassica* species are grown as leafy, stem and root vegetables, as well as forage and silage crops (see Prosea 8).

Production and international trade The average annual world production of rapeseed during the period 1996–2000 was 36 million t, equivalent to 13.5 million t of oil, from 25 million ha in 51 countries. This represents a three-fold increase since 1980 and rapeseed is now the third most important source of vegetable oil after soya bean and oil palm. Leading rapeseed producers are the European Union (9.5 million t), China (9.2 million t), Canada (7.4 million t), India (5.0 million t) and Australia (1.5 million t). International trade in rapeseed oil amounts to 2 million t/year. Major exporters are Canada and the European Union, while practically the entire crop in China and South Asia is consumed domestically. About 12% of the total rapeseed meal (22 million t in 2000) was exported, mainly by Canada, China, eastern Europe and India.

Properties Dried rapeseed contains per 100 g approximately: water 7 g, protein 22–25 g, oil 30–45 g, carbohydrates 24 g, fibre 2 g and ash 4–7 g. The energy value averages 2285 kJ per 100 g. The fatty acid composition of the oil of traditional cultivars of the 3 *Brassica* taxa is quite similar, and differences between cultivars of one cultivar group can be as large as differences between cultivar groups. The proximate composition of oil from traditional cultivars is: palmitic acid 2–4%, palmitoleic acid 0.2–0.5%, stearic acid 0.8–1.5%, oleic acid 8–33%, linoleic acid 12–21%, linolenic acid 8–14%, arachidic acid 0.5–1.2%, eicosenoic acid 6–12%, behenic acid 0–1%, erucic acid 25–55%, lignoceric acid 0–1% and nervonic acid 0–2%. Eicosenoic acid and erucic acid are long chain monoenoic acids that have anti-nutritional and toxic properties, and are associated with an increased risk of cardio-vascular ailments. Where these oils are traditionally used there is generally little awareness of the possible health risks, but the average daily intake per person of such oils is also low. The 'double-zero' cultivars of both *B. rapa* and *B. napus* are low in eicosenoic acid (0.9–2.5%) and erucic acid (0.2–1.5%) but much higher in oleic acid (55–63%) and also higher in linoleic acid (20–24%) contents. The latest 'triple-zero' cultivars also have a low linolenic acid content (3%) which improves the odour of the oil in cooking. The oil-free meal is rich in protein (36–44%) of a satisfactory amino acid composition, containing per 100 g protein approximately: lysine 6 g, methionine 2 g and cystine 2.5 g. The meal of such cultivars is suitable not only in ruminant feed, but also in pig and poultry feed, because the glucosinolate content is less than 10% of the 1–4% contained in traditional pungent rapeseed cultivars. Following disruption of cells during oil extraction or digestion, the glucosinolates are broken down by the enzyme myrosinase into glucose and isothyocyanates or nitriles, which may cause malfunction of the thyroid gland and consequently result in serious illness in humans and monogastric animals. When used as organic fertilizer the meal of high glucosinolate rapeseed cultivars has been found to reduce nematode infestations in the soil. The 1000-seed weight of all rapeseed cultivars ranges from 2–5 g.

Description Annual or biennial herbs, 0.5–2 m tall. Taproot firm, 60–80 cm deep, numerous laterals in the top 30–50 cm of the soil; root system of *B. napus* and *B. juncea* more extensive than that of *B. rapa*. Stem erect or ascending, up to 2 cm in diameter, branched, greenish becoming yellow at maturity. Leaves bright to pale green, glabrous or slightly hairy; first true leaves pinnatifid, often with large apical lobe, petiolate, forming a rosette or on a short stem; leaves on flowering stems alternate, lanceolate, petiolate or sessile and clasping the stem, becoming smaller towards the top. Inflorescence an indeterminate raceme, 50–100 cm long, without bracts, borne terminally on main stem and branches; flowers tetramerous, bisexual; sepals erect, light green; petals yellow, spatulate, clawed; stamens 6, in 2 whorls, inner whorl of 4 long stamens, outer one of 2 short ones; nectaries 2, between the base of the ovary and the short stamens; ovary superior with false septum and 2 rows of campylotropous ovules, stigma globose. Fruit a silique, with convex valves, with indehiscent seedless beak, glaucous turning straw-coloured at maturity, 10–40 seeded. Seed globose, 1–3 mm in diameter; seed coat finely reticulate, yellow-brown, brown or black. Seedling with epigeal germination, taproot thin, cotyledons cordate.
- *B. juncea*: roots not tuberous; vegetative plant with rosette of leaves; basal leaves of flowering plant petiolate, with a very large terminal segment, highest leaves with short petiole; leaves

Brassica juncea (L.) Czern. – 1, flowering branch with leaves; 2, flowering and fruiting branch; 3, seed.

bright green. Flowers with pale yellow petals, 7–10 mm long. Silique 3–5 cm long.

- *B. napus*: roots slender; vegetative plant with leaves on short stem; basal leaves of flowering plant petiolate, highest leaves sessile and partly clasping stem; leaves glaucous. Flowers with pale yellow to bright yellow petals, 11–15 mm long. Silique 5–11 cm long.
- *B. rapa*: roots tuberous; vegetative plant with rosette of leaves; basal leaves of flowering plant petiolate, highest leaves sessile and fully clasping stem; leaves bright green. Flowers with bright yellow petals, 6–10 mm long. Silique 4–7 cm long.

Growth and development Properly dried *Brassica* seed will germinate within 2–4 days in moist soil, but freshly harvested seed may show slight dormancy. In annual rapeseed cultivars, flower initiation starts 2–6 weeks after seedling emergence and this is soon followed by rapid elongation of the main stem ('bolting'), flowering and seed set. In South Asia, the growth cycle from sowing to harvesting takes 75–100 days for *B. rapa* and about 4 months for *B. juncea* cultivars. In contrast, winter rapeseed cultivars of *B. napus* or *B. rapa* grown in north-western Europe have a crop duration of 10–11 months. They are sown in September with bolting starting in March, flowering in May and harvesting in July. *B. rapa* types are generally more winter-hardy than *B. napus* due to the leaf rosette formed in young plants which provides extra protection for the growing point against frost damage. Flowering starts at the base of racemes and may extend over a period of 3–5 weeks. *B. rapa* is allogamous with a sporophytic system of self- incompatibility, controlled by one locus with several S-alleles. Cross-pollination is effected by insects, mostly honey-bees. An exception is the autogamous *B. rapa* cv. group Yellow Sarson in South India. *B. napus* and *B. juncea* are self-pollinating, but up to 30% outcrossing may occur due to bees and other insects which are strongly attracted to rapeseed flowers. Under favourable growing conditions, about 50–70% of the flowers will set fruit with viable seeds. Seeds mature within 35–40 days after anthesis. Fruits of *B. rapa* are straw-coloured at maturity, while those of *B. napus* may still be greenish when containing fully ripe seeds. This is due to higher chlorophyll content in the fruit wall. Crop ripening follows the same pattern as flowering: from the base to the top of the plant.

Other botanical information The genetic relationship between the six cultivated *Brassica* species is usually presented in a triangular diagram with the diploid species *B. oleracea* L. ($2n$ = 16, BB genome), *B. nigra* (L.) Koch ($2n$ = 18, CC) and *B. rapa* ($2n$ = 20, AA) placed at the corners and the three allotetraploid species on the sides. *B. carinata* A. Braun ($2n$ = 34, BBCC) probably arose from natural interspecific hybridization between *B. nigra* and *B. oleracea*, *B. juncea* ($2n$ = 36, AABB) between *B. rapa* and *B. nigra*, and *B. napus* ($2n$ = 38, AACC) between *B. rapa* and *B. oleracea*. Recent work with molecular markers has provided further evidence of this relationship.

B. carinata (Abyssinian mustard, Ethiopian mustard, gommenzer) is only known from cultivation in Ethiopia and northern Kenya; a cooking oil is extracted from the seeds, the cake is used as a medicine, crushed seeds are consumed in soups or as spice and leaves are also eaten as a vegetable. The plants reach a height of up to about 2 m; basal leaves of flowering plants are petiolate, highest leaves sometimes subsessile; leaves light green; flowers with bright yellow petals, 6–10 mm long; silique 2–6 cm long. In Ethiopia annual seed production is estimated to be 20 t. In other parts of the world, e.g. in Canada, *B. carinata* is becoming more popular and is considered a promising oilcrop.

Ecology Rapeseed crops are cultivated between 60°N and 40°S in temperate climates, at 1500–2000 altitude in the tropics and during the cool season in the subtropics. Optimum temperatures for growth and seed set are 18–25°C. Winter types of *B. napus* and *B. rapa* are resistant to frost down to −10°C at the early vegetative stage. This allows sowing to be done in autumn where moderate winters prevail. For these cultivars, low temperatures are needed for vernalization. Extended periods at 30–35°C or higher during flowering and seed set have a negative effect on yield and oil content. Photoperiodic requirements of *B. napus* and *B. rapa* cultivars vary greatly from 10 to over 20 hours and some are day-neutral. Cultivars tend to be locally adapted and may not reach maturity outside their normal photoperiodic range. Water requirements for satisfactory yields are 400–500 mm, mainly during the vegetative and flowering periods. In the subtropical regions of South Asia, *B. juncea* and *B. rapa* are grown during the dry and cool winter ('rabi') season on residual soil moisture after the monsoon crops. Rapeseed can be grown on a wide range of soils, provided these are free-draining because even short periods of waterlogging are detrimental to young crops. A pH of 6.5–7.6 is suitable for optimum growth. Rapeseed tolerates a fair amount of salinity.

Propagation and planting Rapeseed retains a high viability for more than 4 years when stored dry (6% moisture content) and cool (below 18°C). Rapeseed is sown directly in the field either by manual broadcasting or machine-drilling in rows 20–45 cm apart, at seed rates of 5–9 kg/ha. The seed rate and spacing may be varied considerably without a significant effect on yield, because rapeseed has a considerable ability to compensate for irregular plant stand by increasing branching. Optimum seedling density is about 160 plants per m^2, while optimum final plant density is 60–80 plants per m^2. Since seeds are small, the seed bed should be well prepared, level and free of weeds. Recommended planting depth is 0.5–2 cm, depending on soil type and cultivar. The time of sowing is important; late sowing is detrimental to growth and production for rapeseed grown in summer at higher latitudes or during the cool season in the subtropics. Early sowing may also reduce flea beetle damage but early sowing of winter rapeseed increases the risk of frost damage. In the United States, canola is sown about 6 weeks prior to the anticipated onset of hard frost to ensure that seedlings have 6–8 leaves and a well-developed crown prior to the onset of severe weather. On the alluvial plains of South Asia, *B. juncea* is sometimes sown under zero- tillage conditions in lowland fields just before or immediately after the rice harvest.

Husbandry Weed control in rapeseed crops is very important during early establishment. Two rounds of hand weeding or mechanical weeding are usually sufficient. Once stems begin to elongate and branch, weeds are effectively suppressed. Rapeseed is very sensitive to most herbicides, including pre-emergence ones. When soil moisture or rainfall becomes deficient, supplementary irrigation shortly before flowering and another application during seed filling can produce economic yield increases. Rapeseed can produce reasonable yields on soils with low nutrient status, but it responds well to organic or chemical fertilizers, particularly N. Rapeseed is rarely fertilized in South Asia, but it may benefit from residual nutrients of the previous crop. A typical fertilizer recommendation for an intensive summer rapeseed crop with a seed yield of over 2 t/ha is: N 40–50 kg, P 50–60 kg and K 25–30 kg per ha in the seed-bed and another 40–50 kg N as top dressing before flowering. Boron deficiency can be rectified by applying B fertilizer 1–2 kg/ha. Rotation with rapeseed is known for its beneficial phytosanitary effect on cereals, but it may also cause a problem of volunteer seedlings in the consecutive crop. Seed set and consequently yields are often improved considerably by placing beehives near flowering rapeseed fields, normally at a rate of 7–10 hives per ha. The resulting honey production provides an additional source of income.

Diseases and pests More than 15 diseases are common to rapeseed. Widespread diseases, which sometimes cause severe crop losses include leaf spot (caused by *Alternaria brassicae*), blackleg (caused by *Leptosphaeria maculans*, syn. *Phoma lingam*), stem rot (caused by *Sclerotinia sclerotiorum*), clubroot (caused by *Plasmodiophora brassicae*), white rust (caused by *Albugo candida*) and black rot (caused by *Xanthomonas campestris*). Some of the measures that reduce disease incidence are crop rotation, fungicidal sprays and disinfection of seeds before sowing.

Numerous insect pests are known to attack rapeseed from young seedlings to the mature crop but occurrence and the degree of damage vary considerably between continents and regions. The most

damaging pests are pollen beetles (*Meligethes* spp.), seed-pod weevils (*Ceutorhynchus* spp.), flea beetles (*Phyllotreta* spp.), aphids (e.g. *Brevicoryne brassicae*), armyworm (*Spodoptera exigua*) and diamond-back moth (*Plutella xylostella*). Insecticidal sprays toxic to bees and other pollinating insects should be avoided during flowering of rapeseed fields.
Other important pests are nematodes (*Meloidogyne* spp., *Pratylenchus* spp. and *Heterodera* spp.) and the parasitic broomrape (*Orobanche* spp.). Crop rotation with non-*Brassica* crops is the only practical means of reducing infestation.

Harvesting Signs of maturity of rapeseed crops are the yellowing of stems and pods, rattling sound of fruits when shaken and dark colour of the seeds. Harvesting is best done before the whole crop is fully mature to avoid yield loss due to seed shattering and a deterioration in quality. Therefore, further drying is needed before threshing to separate the seed from the fruits. Manually harvested rapeseed is usually spread on a threshing floor to dry in the sun before threshing. For the same reason, machine harvesting is often followed by windrowing to dry the crop before threshing.

Yield World average yield of rapeseed is about 1.4 t of seeds per ha while that from smallholders in India or China is often not more than 500–800 kg/ha. Spring-sown rapeseed on large-scale farms in the Canadian prairies and Australia produce 900–1600 kg seeds/ha while winter rapeseed crops of Europe yield 2000–4000 kg seeds/ha.

Handling after harvest The high oil content and small seed size require rapeseed to be handled efficiently and to be dried to 6–8% moisture content to prevent rapid deterioration in quality. Clean and dry rapeseed stores well for at least one year. In South Asia, about 30% of the rapeseed is still processed in small-scale oil mills that are bullock-driven or power-driven pestle and mortar devices called 'ghanis'. Much of the rapeseed oil produced in this manner is sold unrefined, sometimes after filtration. This type of crude oil has a pungent flavour and a rather dark colour due to the seed coat pigments. The oil from 70% of the crops is extracted in larger mills by mechanical expellers or by solvents. Advanced rapeseed processing involves several steps, including cleaning, flaking and cooking, oil extraction by screw press or by solvent or by a combination of both, filtration and refining through degumming, de-acidification, bleaching and deodorization. The resulting oil is light coloured and has a bland taste. The meal obtained after oil extraction of canola-type rapeseed cultivars can be used to prepare various products for the stock-feed industry, e.g. protein concentrates and isolates.

Genetic resources Germplasm collections of *Brassica* oilseed are maintained by agricultural institutes in Europe, Canada, the United States, India, Japan and China. The International Plant Genetic Resources Institute (IPGRI) in Rome keeps a database on global resources for *Brassica* species. The possibility of interspecific hybridization, aided by embryo culture, in vitro fertilization and protoplast fusion, allows the exploitation of the large genetic diversity present in certain species, notably *B. juncea*, *B. oleracea* and *B. rapa* for the improvement of oilseed crops. This applies particularly to *B. napus* because genetic variation in this species is rather limited.

Breeding Common methods of developing improved cultivars from available landraces have been recurrent mass and family selection in case of the outcrossing *B. rapa* and pure line and pedigree selection for the self-pollinating *B. juncea* and *B. napus*. Breeding objectives are higher seed yield and increased oil content, reduced seed shattering, shorter and more erect plant habit, environmental adaptation, especially cold tolerance in Europe, earlier maturity in India and tolerance to stress and salinity. Further objectives include thinner seed coat resulting in less crude fibre in the meal and resistance to important diseases and pests. Better knowledge of the chemical components of the oil and their genetic control, as well as the development of analytical techniques applicable to single seeds without impairing viability, has resulted in considerable advances in breeding for higher seed and oil quality. Low erucic acid content is controlled by two recessive genes with additive effects, low glucosinolate content by at least three genes and low linolenic acid content by one gene. The 'double-zero' and 'triple-zero' or canola cultivars were developed by introgression of these characters through backcrossing into existing cultivars, and they have dominated rapeseed production in Europe, Canada and Australia since the 1980s. During the last decade, F_1 canola hybrids have started to replace open-pollinated cultivars. There is considerable hybrid vigour for seed yield (20–70%) in *B. rapa*, as well as in *B. napus*, particularly between parents of diverse origin. In vitro anther or microspore cultures to produce haploids for instant inbred lines is more successful in *B. napus* than in *B. rapa*. Large-scale production of F_1 hybrid seed is based on self-in-

compatibility or cytoplasmic male sterility (CMS) with fertility restorer genes. Sources of CMS systems are interspecific crosses, protoplast fusion and recently, also genetic transformation. The transgenic systems of CMS are claimed to be free from the persistent problems of poor growth caused by chlorosis and low female fertility linked to the other systems. Resistance to herbicides, especially atrazine, which is an important cost-reducing factor in rapeseed production, was successfully introgressed into *B. napus* and *B. rapa* cultivars from Bird's rape, which is a wild form of *B. rapa*. Transgenic canola rapeseed cultivars with resistance to glyphosate or glufosinate herbicides have become available recently as well.
Daylength-neutral *B. napus* cultivars suitable for cultivation during the short-day, cool season of the subtropics have been developed by introgression of photo-insensitivity from other *Brassica* species into *B. napus*. Such cultivars are higher yielding than local *B. rapa* landraces and also more tolerant of temporary waterlogging.

Prospects The present trend of expanding rapeseed production is likely to continue, particularly in India and China, where canola-type cultivars will also gradually replace the traditional, high erucic acid and high glucosinolate landraces. The remaining technical problems of hybrid seed production should be solved soon and F_1 hybrid cultivars will then dominate in most rapeseed-producing countries on account of their considerably higher yield potentials, with the possible exception of smallholder production systems of South Asia where the pungent oil is preferred. Molecular breeding technology is well advanced in rapeseed, which offers opportunities for rapid gene transfer from unrelated species with regard to host resistance to important diseases, pests and weeds and also for the production of novel industrial oil and pharmaceuticals.
Rapeseed cultivars developed in South Asia, especially the day-neutral *B. napus* types, may fit well into existing cropping systems in the tropical highlands of South-East Asia.

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H. Toxopeus

Carthamus tinctorius L.

Sp. pl. 2: 830 (1753).
COMPOSITAE
$2n = 24$

Vernacular names Safflower, false saffron (En). Carthame (Fr). Indonesia: kasumba (general), kembang pulu (Javanese), rale (Buginese). Malaysia: kesumba. Philippines: kasubha (Pilipino, Tagalog), kasabha (Bisaya), kasaba (Ilokano). Thailand: kham (general), khamfoi (northern), kham yong (Lampang). Vietnam: h[oof]ng hoa; c[aa]y rum.

Origin and geographic distribution Safflower is known only from cultivation and probably originated in the Middle East. Other centres of diversity are Afghanistan, Ethiopia and India. It has long been domesticated, initially for the orange dye obtained from the florets. It was identified as growing in Egypt in 2000 BC. Its use as an oil crop probably came later, but also dates back to pre-Christian times. The 'Revenue papyrus' of Ptolemy II of 259–258 BC states that the king had a monopoly of production and marketing of safflower along with sesame and castor oils. Safflower was probably introduced into China around

200–300 AD, where it was initially cultivated for its dye. It was grown extensively in many areas, particularly along the Chang Jian (Yangtze river) and in Sichuan (Szechwan). Safflower was introduced into Japan from China probably about the third Century AD. The oil was little used in cooking until the 20th Century, but it is now a major import in Japan. From the Middle East, the crop also spread westward into Europe and the Americas. It is grown on a small scale throughout South-East Asia, where it is most important in Thailand.

Uses The edible oil extracted from the seed is now the main product of safflower. Although the oil is suitable for paint production, it is used almost exclusively in cooking, making salad dressings and margarine. Cultivars with a high oleic acid level make safflower oil a major olive oil extender, one of the reasons for the crop's rapid expansion in Spain. In Australia, cultivars yielding oil with a high linoleic acid content are preferred. The oil has industrial uses.

Safflower has long been grown for the dye extracted from the florets. Depending on the dyeing procedure and the addition of other colourants and mordants, it imparts a yellow, red, brown or purple colour to cloth. With the introduction of cheap synthetic dyes, its importance as a dye source has greatly declined. However, dyes are still produced on a small scale for traditional and religious purposes. As a natural food colourant it is a substitute or adulterant for true saffron. Florets are commonly mixed with rice, bread, pickles and other food to give them an attractive orange colour.

The seed cake can be used as animal feed. Increased protein and lysine content, reduced fibre content and the removal of the bitter principle matairesinol monoglucoside make safflower meal more attractive to stock feed manufacturers. Safflower meal and flour from decorticated seeds are high-protein human diet supplements. The flour can be added to wheat flour to make breads and pies.

In Asian countries, the young leaves are eaten as a vegetable and seeds are used in cooking and as bird feed. Safflower herbage is valuable as green fodder or stored as hay or silage.

Safflower has a prominent place as a cosmetic ingredient and to a minor extent in medicine. In China, the flowers are used to treat illnesses such as cerebral thrombosis, male sterility, rheumatism and bronchitis, to induce labour and as a tonic tea to invigorate blood circulation and the heart. Safflower-based medicines also show beneficial effect on pain and swelling associated with trauma.

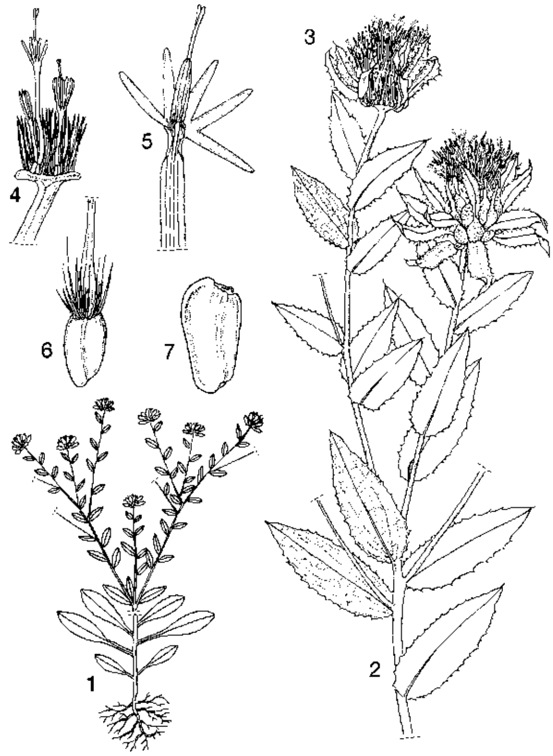
Production and international trade World production of safflower has steadily declined since the mid-1970s, when world production of oil was about 630 000 t and exports about 210 000 t. The decline was mainly due to competition from hybrid sunflower and brassica oilseed and the great expansion of soya bean production in South America. Major producers of safflower are India, the United States, Mexico, Kazakhstan, Ethiopia, Argentina, Australia and China. Most growers now market their crop domestically and only export the surplus.

Properties Fruit of white-hulled commercial safflower is composed of hull 30–40% and seed (kernel) 60–70%. The seed may contain 35–60% oil. The proportion of hull was higher in the past and a handicap to commercial production, but the introduction of thin or reduced hulls may hamper mechanical harvesting and processing. The seed contains a drying oil and the average unsaturated fatty acid composition of commercial safflower oil is: oleic acid 10–15%, linoleic acid 70–80% and traces to zero of linolenic acid. The saturated fatty acids are palmitic acid 5–7% and stearic acid 2–3%. However, differences between cultivars are large: cultivars classified as containing very high linoleic acid have 5–7% oleic acid and 87–89% linoleic acid, while high oleic acid cultivars contain 75–80% oleic acid and 14–18% linoleic acid. Safflower oil is stable and does not alter at low temperatures or when heated. It is pale or golden yellow and has a bland or nutty flavour depending on the processing method. The oil's high linoleic acid content, low colour values, low free fatty acids, low content of unsaponifiable compounds and absence of linolenic acid and waxes make it suitable for the production of high quality paints, alkyd resins and coatings. After oil extraction from undecorticated safflower, the residual cake contains: protein 20–22(–25)%, hull 60%, residual fat 2–15% and crude fibre 30–40%. The presscake from decorticated fruit contains up to 42% protein. This high fibre content limits its value as livestock feed, but removing the hulls may be too costly. Undecorticated meal can be used only to supplement a grain, lucerne and silage ration to fatten cattle. It cannot be fed to pigs, except in small quantities, nor to poultry. However, hulled seedmeal with a good protein supplement can be given to pigs.

The florets of safflower contain two major pigments: the water-soluble, yellow carthamidin and the formerly important dye carthamin, which is orange-red and soluble in alkaline solutions. Florets have 0.3–0.6% carthamin. Flavonoids, glycosides, sterols and serotonin derivatives have been identified from the florets and seeds. Some of them, e.g. matairesinol, may have medicinal properties.

The 1000-seed weight is 40–80(–100) g.

Description Erect, much-branched, glabrous, annual herb, 30–180 cm tall. Root system well developed, brownish-greyish, taproot thick and fleshy, penetrating up to 3 m depth, horizontal laterals thin, occurring mainly in the upper 30 cm. Stem cylindrical, solid with soft pith, woody near base, striate, greenish-white. Leaves spirally arranged, sessile, exstipulate; blade oblong to ovate-lanceolate, 4–20 cm × 1–5 cm, lowest ones largest, margin spinose-dentate, glossy dark green, herbaceous when young, turning firm and stiff. Inflorescence a terminal, urn-shaped head, about 4 cm long and 2.5–4 cm in diameter, containing only disk florets; involucral bracts numerous, spirally arranged, outer ones oblong, constricted above the base, 3–7 cm × 0.5–1.6 cm, upper part leafy and spinescent, erect or spreading, not appressed, with long hairs on the lower margin, lighter green than the leaves, lower part appressed, whitish-green, long-hairy outside, especially on the margin, glabrous inside; towards the centre of the head, the constriction becomes less apparent and the leafy part disappears; innermost bracts lanceolate, 2–2.5 cm × 1–4 mm, apex spinescent, ciliate; receptacle flat to conical, with abundant, erect, whitish bristles 1–2 cm long and 20–80 bisexual florets (a few marginal ones sterile); floret tubular, sessile, actinomorphic, about 4 cm long, glabrous, mostly orange-red becoming dark red during flowering, sometimes yellow; corolla 5-lobed, tube 18–22 mm long, lobes spreading, narrowly oblong to linear, 7 mm × 1 mm; stamens 5, epipetalous, inserted at the mouth, filaments 1–2 mm long, anthers 5 mm long, connivent, forming a column; ovary ellipsoid, 3.5–4.5 mm long, one-celled, one-ovuled, bearing a disk on top; style slender, 28–30 mm long, glabrous, pushing up through staminal column; stigma 5 mm long, bifid, yellow, with short hairs. Fruit an achene, obovoid, often obliquely so, 5.5–8 mm × 3–5 mm, 4-angled with clearly visible ribs, glabrous, glossy white but often pale brown near top, sometimes with a pappus; pappus variable from head to head and from fruit to fruit, generally the innermost fruits in a head bearing the biggest pappus, the outermost ones none; a fully developed pappus consists of several complete, dense circles of paleae clasping the scar of the corolla; paleae narrowly oblong to linear, 6 mm × 0.2 mm, white, glabrous, flat, base bent inwards, margin ciliate, apex obtuse or acute. Seed exalbuminous. Seedling with epigeal germination, strong taproot, hypocotyl greenish-white; cotyledons leaflike, obovate, 3 cm × 1 cm when plumule starts growing, 6 cm × 1.5 cm when full-grown, greyish pale-green, when young with darker green dots; first leaves lanceolate with tapering base.



Carthamus tinctorius L. – 1, growth habit; 2, flowering branch; 3, head cut lengthwise; 4, detail of a head; 5, apical part of a floret slit open; 6, ovary with pappus; 7, achene with pappus.

Growth and development After germination the seedling enters the rosette stage, characterized by slow growth, production of many leaves near the ground surface and development of a deeply penetrating taproot. When sown in spring, safflower generally has no rosette stage, while a long rosette stage occurs when it is autumn-sown. During the rosette stage plants are tolerant of frost, allowing them to overwinter. Safflower is a long-day plant. Flowering is normally initiated by approximately 14 hours of daylight, but this can be modified by temperature, high temperature accelerating flowering. Salinity and cultivar type may also accelerate the onset of flowering. Day-length neutral cultivars also exist. In contrast to its relatively slow initial growth, safflower grows rapidly after the stem begins to elongate. When the plant is 20–40 cm tall, lateral branches start to develop. Stem elongation and branching are followed by the development of a flower head at the tip of each stem. After the completion of growth of secondary branches and the formation of flowering heads (75–100 days after sowing), florets start to appear in the heads. Flowering begins in the head of the main axis, followed by the most mature of the main branches; secondary and tertiary branches follow sequentially. Flowering normally begins at the head's margin, proceeds centripetally and takes 3–5 days to complete. Total flowering extends over 10–40 days. Safflower is basically self-pollinated, pollination ensuing as the style and stigma grow through the surrounding anther column at the base of the corolla. However, a high degree of crossing can occur, particularly in thin-hulled types. Bees or other insects are generally necessary for optimum fertilization and maximum yields. Male and female sterility occurs. Structural male sterility is linked with the thin-hull character and delayed anther dehiscence in this type is used to produce hybrid seed. A well-developed safflower head contains 15–30 or more achenes which mature in 4–5 weeks after flowering.

Other botanical information Because *C. tinctorius* has been cultivated over a wide area since ancient times, and because cross-pollination is fairly common, variability in safflower is great. The morphological differences are most obvious in branching (height, density), the leaves (presence or absence of rosette leaves, armed or unarmed leaves), involucral bracts (form, pubescence, spiny or entire margins), number and size of heads per inflorescence, flower colour (reddish, orange, yellow, white), and fruit (achene) (size, presence or absence of pappus). For oil crops, ecological differences allow distinction of 3 types of populations: early ripening (small bushy plants), late ripening (medium large plants) and very late ripening (tall plants). Several botanical varieties have been distinguished in the literature on safflower, but as safflower is known only from cultivation, a classification system into cultivars and cultivar groups would be most suitable but does not yet exist. In India, the former Soviet Union and the United States many cultivars are known. The primary uses of the cultivars could define the major groups, such as cultivars for oil production, forage production or ornamental purposes.

Safflower is closely related to the wild, diploid (all $2n = 24$), annual species *C. curdicus* Hanelt (western Iran), *C. gypsicolus* Ilj. (from the Caspian Sea to the Aral Sea), *C. oxyacanthus* M. Bieb. (from Iran and Iraq to north-western India), *C. palaestinus* Eig (desert areas from southern Israel to western Iraq) and *C. persicus* Willd. (syn. *C. flavescens* auct., non Willd.) (Turkey, Syria, Lebanon). It is thought that *C. palaestinus* (self- compatible) is the progenitor of the weedy species *C. oxyacanthus* (mixture of self-compatible and self-incompatible types) and *C. persicus* (self-incompatible) and these weedy species are thought to be the parental species of *C. tinctorius*; these 4 species can intercross in all combinations and produce fertile hybrids and it is possible that introgression of the weedy and cultivated species may still take place (natural hybrids occur). *C. nitidus* Boiss., another diploid species with 24 chromosomes, is difficult to cross with safflower and the hybrids are sterile. The crossing possibilities of *C. tinctorius* with *C. curdicus* and *C. gypsicolus* are not known. Other *Carthamus* species are less related to safflower and have different chromosome numbers. The taxonomy of *Carthamus* is still under discussion, both at species and genus level. In a wide genus concept, about 50 species are accepted; in a narrow concept about 15 annual species remain in *Carthamus*, while the perennial taxa are classified in other genera including *Carduncellus* Adans., *Femeniasia* A. Susanna de la Serna, *Lamottea* Pomel and *Phonus* J. Hill.

Ecology Safflower is basically a crop of semi-arid, subtropical regions, but its range has been greatly expanded by selection and breeding. It is distributed within latitudes 20°S and 40°N and its cultivation has recently even spread into Canada. In the tropics it is mostly grown at 1600–2200 m altitude, but large-scale commercial production is concentrated in semi-arid areas below 1000 m. Seed yield and oil content fall with increasing altitude. Seedlings can tolerate −7°C, some cultivars even down to −12°C. They become more susceptible to frost damage after the rosette stage. Average temperatures of 17–20°C appear to be best for vegetative growth, while the optimum temperature for flowering ranges from 24–32°C. Adequate soil moisture reduces the adverse effect of higher temperatures.

Safflower requires about 600 mm of rainfall with a major portion falling before flowering. Under dry, windy conditions, which are most suitable for safflower production because of the low disease incidence, 800–1000 mm are required. In places where there are no hot, dry winds, reasonable yields can still be produced as long as 300 mm of rain is available before flowering. Because of its extensive root system, safflower can be grown largely on residual soil moisture. If pre-planting soil moisture covers about two-thirds of the total water requirement, the remainder can be supplied by rainfall.

In the United States and Australia, 1500–2500 mm of irrigation water is required to produce a high-yielding commercial crop. In Israel, safflower needs a minimum of 600 mm rain plus a similar amount from irrigation. In Tanzania, 400 mm rainfall plus 450 mm irrigated water are the minimum requirements but crops supplied with 2250 mm of irrigation water in the dry season produce twice the wet season yield, partially due to less damage from diseases and pests. A rain-fed crop in India requires 650–1000 mm, but in the dry season under irrigation, it needs 1800–2100 mm (less if the preceding crop is rice).

Safflower is grown by smallholders on a wide range of soils with pH 5–8. For large-scale production, fairly deep, well-drained, sandy loams of neutral reaction are preferred. Highest yields are obtained in dry regions on sandy loams with irrigation. Regardless of their fertility, shallow soils seldom produce high yields, and this is invariably due to insufficient moisture. Safflower is considered to be salt-tolerant, although many commercial cultivars are salt-sensitive. It is especially tolerant of sodium salts, but less so of calcium and magnesium salts. Salinity delays initial seedling emergence, while very high levels reduce germination. However, safflower is a suitable crop for saline soils, especially the recent highly salt-tolerant cultivars.

Propagation and planting Chisel ploughs or subsoilers should be used to fracture compacted soil layers within the root zone because safflower is deep-rooted. Ideally, safflower should be sown 3–5 cm deep into moist soil, but when topsoil is dry and loose, seed may be planted 10–15 cm deep. Most seed drills are suitable for sowing safflower, but should be recalibrated. It is sometimes recommended that furrow-openers be fitted to seeder units and the furrows to be only partially closed after sowing. Seed rates depend on cultivar and growing conditions. For large-scale rain-fed crops seed rates average 30 kg/ha, under irrigation 60 kg/ha. Wide rows, 35–60(–90) cm with close in-row spacing generally gives the highest yield. Safflower can compensate for spatial variation by producing more secondary and tertiary heads per plant. However, while the seed yield may be little affected, less oil will be produced as seeds from these heads are generally smaller and have a low oil content.

Husbandry Safflower is readily integrated into mechanized small grain production. Mechanical weeding of young safflower is difficult, and pre-planting cultivation should aim at maximum weed reduction. A light harrowing before emergence effectively kills young weeds. While safflower is still small, finger weeders and rotary hoes can be used, but when plants reach about 15 cm in height, weeding should be limited to the inter-row. However, careful hand weeding gives the highest yield. Pre-emergence herbicides combined with mechanical inter-row weeding are widely used in commercially grown safflower, but no effective post-emergence herbicide is available.

Nitrogen is the most important nutrient, phosphate requirement is moderate, and potassium is required only where there is a major local deficiency. At the levels normally applied, fertilizers generally have little direct effect on seed composition or oil percentage. However, by increasing seed yield, they increase total oil yield. Contact between seedlings and fertilizer should be avoided and N applications split when the rate is above 100 kg N/ha. Up to 150 kg N/ha is applied to current high yielding cultivars grown under irrigation. When rain-grown, these cultivars are given about 50 kg N/ha. Phosphate fertilizers are normally residues from animals and crops or rock phosphate. However, 5–12.5 kg P/ha has been recommended for smallholder crops in India, Iran, Pakistan and Afghanistan.

Intercropping safflower is possible, but not common in smallholder fields because the yields are low as a result of crop competition. Safflower should not be planted on the same land for two consecutive years because it is susceptible to soil-borne fungal diseases.

Diseases and pests Many diseases have been recorded on safflower, but few limit commercial production. Rust, caused by *Puccinia carthami*, is the most important disease attacking young safflower. Foliar diseases are prevalent in places where rainfall occurs between the late bud stage and near maturity and the most serious and widespread is leaf blight caused by *Alternaria carthami*. Root rots caused by *Fusarium oxysporum* and *Phytophthora* spp. including *P. cryptogea* and *P. drechsleri* are widespread and very damaging. *P. drechsleri* causes a serious disease of surface-irrigated safflower and its incidence and severity is

increased if the crop has undergone moisture stress.
The majority of insects that attack safflower are of little economic importance and do not require control. *Perigea capensis* attacks at all stages of development and is common in South-East Asia, India and Pakistan. Bollworm (*Helicoverpa* spp.) occurs in all countries that grow safflower and it may be of varying importance. However, specific insects such as the safflower fly (*Acanthiophilus helianthi*) can virtually preclude safflower growing. It is necessary to balance chemical control against allowable damage because complete control is seldom possible or profitable in safflower cultivation.

Harvesting Harvesting of safflower usually begins 35–40 days after maximum flowering, when plants are quite dry but not brittle, bracts on heads turn brown and fruits have a moisture content below 8%, preferably 5%. Grain combine harvesters are quite suitable although they cannot cut as fast as in wheat or barley. Harvesting safflower is comparatively simple since the crop does not generally lodge or shatter. A mature crop is relatively immune to damage and may be left standing in the field for one month with little loss. Light cold rain or frost does little damage. However, certain cultivars germinate in the head if periods of warm wet weather occur at maturity. For smallholders, the extended harvesting period allows individual heads to be collected as they ripen. Generally, however, plants are uprooted, heaped and dried in the field for a few days and threshed to remove the seeds.
For the dye production, flower heads are collected every second to third day before they fade. Harvested florets are washed and later dried.

Yield The average yield of safflower grown under rainfed, intensive cultivation has increased steadily to 1500 kg/ha and nearly twice this under irrigation. Average yields in India are about 500 kg/ha.

Handling after harvest Safflower fruit can be stored in bulk, where possible in grain bins, provided the seed moisture content is 5–8%. Safflower can be processed by most commercial oilseed plants either by pressure, solvent extraction or a combination of both. There are no special requirements. Carthamin is extracted from the flowers by first washing out the cathamidin in ample water and subsequently extracting the flowers with a sodium carbonate solution. Carthamin is precipitated from the solution using diluted acid.

Genetic resources Considerable research into safflower's genetics and breeding has been carried out, including work on many related species considered valuable sources of genetic material. A gene bank is maintained by the United States Department of Agriculture at Washington State University, a world germplasm collection at Solapur, India and major collections in China, Ethiopia, Israel, Pakistan, Spain and the Russian Federation.

Breeding Reducing the hull percentage is a major objective in breeding safflower. Current cultivars with less fibre (17% of the fruit and 38% of the seed) and a higher protein content are preferred by stock feed manufacturers. Seed composition, oil content and quality (in terms of component fatty acids) are influenced by environment, including latitude, altitude, day and night temperatures and amount of rainfall during flowering and seed setting.
The discovery of a gene causing partial male sterility allowed more detailed study of heterosis and related processes. A mass emasculation technique has been developed, and in vitro techniques enable large-scale production of selected strains. A variety of other methods under the general heading of genetic engineering are reported. There is a major need to expand safflower's adaptation through genetic research and breeding.

Prospects The use of dyes from natural sources in food products is gaining popularity because of possible harmful effects from synthetic colourings. In industrialized nations where research has linked health and diet, demand for unsaturated oils has increased, thereby creating a growing market for such oils as health foods, especially in North America, Germany and Japan. Both trends may lead to an increasing demand for, and production of, safflower.

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Cocos nucifera L.

Sp. pl.: 1188 (1753).

PALMAE

$2n = 32$

Synonyms *Cocos nana* Griff. (1851).

Vernacular names Coconut (palm and fruit) (En). Cocotier (palm), coco (fruit) (Fr). Indonesia: kelapa (general), nyiur (Malay), krambil (Javanese). Malaysia: kelapa. Papua New Guinea: kokonas. Philippines: niyog (Pilipino, Tagalog), iniug (Ibanag), lubi, ungut (Bisaya), laying (Manobo). Burma (Myanmar): ong. Cambodia: doong. Laos: phaawz. Thailand: ma phrao (general), khosaa (Karen-Mae Hong Son), dung (Chong-Chanthaburi). Vietnam: d[uwf]a.

Origin and geographic distribution *C. nucifera* is native to the coastal regions of tropical Asia and the Pacific, but its primary centre of origin is the subject of speculation. Fossil coconuts have been found as far apart as India and New Zealand. The ability of the thickly husked and slow germinating fruit of wild coconut (called Niu Kafa type) to remain viable after floating long distances at sea ensured wide natural dispersal in the Indo-Pacific long before domestication may have started in Malesia. The domesticated coconut (called Niu Vai type) has a robust stem and large fruits, which however cannot survive long periods of floating at sea because of thinner husks and shells and quicker germination. Initial dissemination of the domesticated coconut coincided with migrations of Malesian peoples to the Pacific and India, which started some 3000 years ago. Where wild coconut already occurred, there was opportunity for introgression with domesticated types, as both retained full crosscompatibility. Polynesian, Malay and Arab navigators played an important role in further dispersal of coconut into the Pacific, Asia and East Africa. The coconut became truly pantropical in the 16th Century after European explorers had taken it to West Africa, the Caribbean and the Atlantic coast of tropical America.

Uses The coconut palm has been called the 'tree of life', the 'tree of heaven' and 'one of nature's greatest gifts to man' because of its value as provider of so may useful products. For domestic oil extraction the fresh endocarp of mature fruits is grated and squeezed with hot water; for industrial production the endosperm is dried to copra and taken to the mill for oil extraction. High-grade oil is used for cooking or in the manufacture of margarine, shortening, filled milk, ice-cream and confectioneries. Oil of lower grades is processed into soap, detergents, cosmetics, shampoos, paints, varnishes and pharmaceutical products. Remnant fatty acids and alcohols and methyl esters find application as components of emulsifiers and surfactants. The presscake or copra meal is a good feed.

Coconut milk or cream (Indonesia/Malaysia: 'santan'; Philippines: 'gata') pressed from freshly grated endosperm mixed with water has been a traditional ingredient in many Asian food and bakery products. It is now also marketed in pasteurized and homogenized canned or powdered form. After preparing coconut milk by boiling grated fresh coconut meat a presscake remains. In Java it is considered a delicacy, named 'blondo' or 'galendo'. Skimmed milk powder, produced after boiling fresh coconut milk and removing the floating oil, contains 25% hydrolyzed starch and can be mixed with water to make a beverage. Protein can be separated by ultrafiltration and spray-dried into a white powder, which is very suitable for infant nutrition. Coconut skim milk is an essential ingredient of a gelatinous delicacy ('nata de coco') in the Philippines used in sweetened desserts, ice-cream and confectionery. Shredded or thinly sliced and desiccated fresh coconut endosperm is a favourite side-dish and ingredient in many confectionery, bakery and snack food products. Ball copra is an Indian speciality produced by slow drying, dehusking and shelling of the whole mature nut. It is used to prepare sweets offered during religious

and cultural rites and in traditional medicine.
The nut cavity is filled with water that tastes sweet when the coconut is young. Coconut water is now commercially preserved without altering its typical flavour. It can also be used in the production of 'nata de coco', which is a gelatinous dessert produced by the action of bacteria on coconut water or diluted coconut milk, developed in the Philippines. It is a source of inexpensive growth hormone products for horticulture, such as the Cocogro developed in the Philippines. The tender, jelly-like endosperm of young coconuts is a delicacy consumed directly or grated and mixed with food. The haustorium or apple of germinating coconuts can be eaten fresh.

The shell of the nut can be made into household utensils and decorated pots, converted into shell charcoal (suitable for activation) or used as fuel. Finely ground coconut shell is used as filler for resin glues and moulding powders. Green husks yield white coir (yellow fibres) for making ropes, carpets, mats and geo-textiles. Brown coir from husks of mature fruits is used in brushes (long bristle fibres), mattresses, upholstery and particle board (short fibres). Coir dust or coco peat is a component of potting mixtures (water-holding capacity of 700–900%), light building materials, thermal insulation, adhesives and binders.

A sweet sap containing about 15% sucrose is tapped from unopened inflorescences. It is a refreshing toddy when consumed fresh and it transforms into a light alcoholic wine when fermented. A by-product of palm wine is vinegar. Boiling fresh sap yields palm syrup and sugar. Distillation of palm wine yields a potent arak.

The leaves are used to thatch roofs (Indonesia: 'atap'); the leaflets are plaited into mats, baskets, bags and hats; immature leaflets are made into traditional decorations and small bags or containers for food; the midribs of the leaflets are formed into brooms. The palm heart, which consists of the white, tender tissues of the youngest, unopened leaves at the stem apex, is considered a delicacy. Young palms (3–4 years) have the heaviest palm heart, weighing 6–12 kg.

The wood of old palms is very hard, but a freshly felled trunk can be sawn with a special tungsten carbide-tipped saw blade. Preservative treatment of sawn lumber is needed if it is to be used for construction or any outdoor use. Coconut wood is also suitable for furniture, household utensils and tool handles.

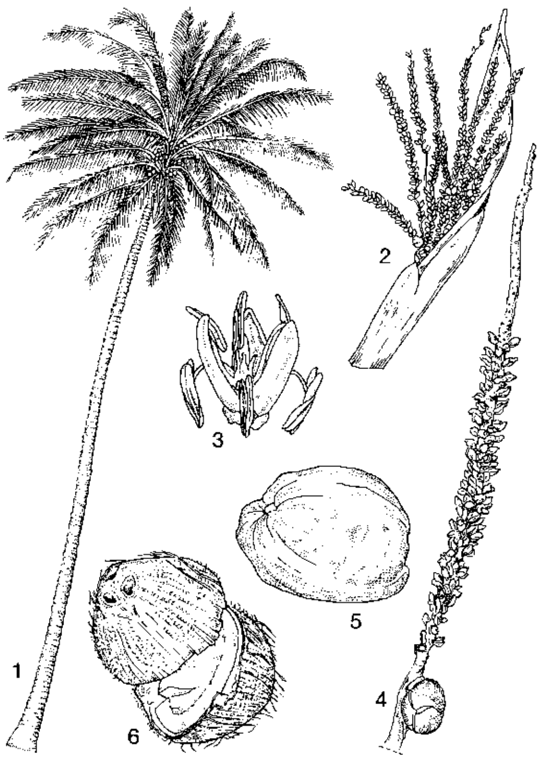
Medicinal uses have been attributed to coconut. The roots are considered anti-pyretic and diuretic. Its decoctions are used against venereal diseases in Malay Peninsula while an infusion is used in Indonesia to treat dysentery. Milk of young coconut is diuretic, laxative, anti-diarrhoeic and counteracts the effects of poison. The oil is used to treat diseased skin and teeth and mixed with other medicines to make embrocations. The kernel of young fruit is mixed with other ingredients and rubbed on the stomach against diarrhoea. The kernel is prepared in Indo-China as a potion to treat ulcers of the skin and the nasal mucous membrane. Coconut palm has also an ornamental value. The palms' often slanting stems and graceful crowns bordering a white beach along a blue sea are hallmarks of the tropics which attract tourists.

Production and international trade Average annual world production of copra in 1995–2000 was estimated at about 5.0 million t, equivalent to 3.1 million t oil and 1.7 million t coconut meal. This may represent less than 55% of the actual production from 11 million ha of coconut, owing to considerable home consumption and sales of young coconuts for drinking. Coconut is mainly a smallholder crop and less than 10% of the total area consists of estates. Asia and the Pacific account for 89% of world production, Latin America and the Caribbean for 5% and Africa for 3%. The major coconut producers are the Philippines (39% of world production), Indonesia (24%), India (14%), Mexico (4%), Vietnam and Papua New Guinea (each about 3%). Estimated areas (in million ha) planted with coconut are: Indonesia 3.71, the Philippines 3.16, India 1.67, Sri Lanka 0.49, Thailand 0.41, Malaysia 0.29, Papua New Guinea 0.21 and Vietnam 0.20. With about 1.7 million t of oil traded annually, coconut is now the 7th most important supplier of vegetable oil in the global market. However, it has a special position in the market together with palm-kernel oil as a major source of lauric oil. The Philippines and Papua New Guinea export about 80% of their national coconut oil production in contrast to Indonesia which exports only 20–30% and India which exports almost none. About 50% of the coconut meal produced annually in the world is exported, about 500 000 t by the Philippines and 300 000 t by Indonesia.

Properties Fresh, mature coconut fruits weigh 1.1–2.5 kg and consist of husk (exocarp and mesocarp) 30–45%, shell (endocarp) 14–16%, endosperm 25–33% and free water in the cavity 13–25%. The proximate composition of fresh endosperm per 100 g edible portion is: water 35–52 g,

oil 34–45 g, protein 3–4 g, carbohydrates 9–11 g, fibre 2–3 g and ash 1–2 g. High quality copra has 63–68% oil, no more than 6% water and less than 1% free fatty acid. The fatty acid composition of coconut oil is: caproic acid 0.3–0.5%, caprylic acid 6–8%, capric acid 5–8%, lauric acid 45–50%, myristic acid 15–19%, palmitic acid 8–12%, stearic acid 2–4%, oleic acid 6–8%, linoleic acid 1–2% and arachidic acid 0.5%. More than 90% of the fatty acids are saturated. Lauric acid is an easily digestible source of energy and a precursor of the anti-microbial lipid mono-laurin, which enhances the human immune system. It is hardly deposited at all in body tissues.
Coconut milk contains approximately fat 15–35%, protein 3% and sugar 2%. Powdered coconut milk has: fat 60%, protein 7% and carbohydrates 27%; dried and powdered skim milk has fat 6%, protein 24% and carbohydrates 25%; spray-dried coconut protein powder contains protein 59%. Desiccated coconut contains fat 58%, protein 7% and carbohydrates 24%. Presscake contains fat 6%, protein 21%, carbohydrates 49% and crude fibre 12%. Coconut wood has a density of 400–600 kg/m^3, the basal annular outer parts as much as 850 kg/m^3; it is suitable as timber for construction purposes because of its moderate to high strength and lack of knots.

Description An unarmed, unbranched, pleonanthic, monoecious palm tree, with a terminal crown of leaves, up to 20–30 m in tall cultivars, 10–15 m in dwarf cultivars. Roots mostly in the top 1.5 m of soil, normally 6 m × 1 cm but in optimum soil conditions up to 30 m long. Stem cylindrical, erect, often curved or slanting, 20–40 cm in diameter but the swollen base ('bole') up to 60 cm, light grey, becoming bare and conspicuously ringed with scars of fallen leaves. Leaves sheathing, spirally arranged, pinnate, 4.5–6(–7) m long, up to 60–70 per plant of which one half still unfolded in the central spear; petiole stout with clasping, fibrous sheath at base, about one quarter of total leaf length, grooved above, rounded beneath; leaflets 200–250, linear-lanceolate, 50–120 cm × 1.5–5 cm, single folded lengthwise at base, apex acute, regularly arranged in one plane. Inflorescence axillary, protandrous, unopened (immature) looking like a spadix within a spathe, opened (mature) about 1–2 m long, consisting of a central axis with up to 40 lateral, spirally arranged, spike-like rachillae (branches) each bearing 200–300 male flowers and only one to few female flowers near the bare basal part; male flowers 1–3 together, sessile, 0.7–1.3 cm × 0.5–0.7 cm, pale yellow, with 3 small sepals, 3 larger petals, 6 stamens in 2 whorls and a rudimentary pistil; female flowers solitary, much larger than male flowers, globose in bud, ovoid at anthesis, 2–3 cm in diameter, enveloped by 2 small scaly bracteoles, sepals and petals each 3, suborbicular, sub-equal, persistent and enlarging in fruit, pistil with large 3-locular ovary, 3 sessile triangular stigmas and 3 nectaries near ovary base. Fruit a globose, ovoid or ellipsoidal fibrous drupe, indistinctly 3-angled, 20–30 cm long, weighing up to 2.5 kg; exocarp very thin, 0.1 mm thick, smooth, green, brilliant orange, yellow to ivory-coloured when ripe, usually drying to grey-brown in old fruits; mesocarp fibrous, 4–8 cm thick, pale brown; endocarp (shell, together with its contents called the 'nut' of commerce) ovoid, 10–15 cm in diameter, 3–6 mm thick, hard, stony, dark brown, indistinctly 3-angled with 3 longitudinal ridges and 3 large, slightly sunken pores ('eyes') at basal end, each with an operculum. Seed only 1, very large, with a thin



Cocos nucifera L. – 1, habit fruiting tree (much reduced); 2, opening inflorescence; 3, male flower; 4, inflorescence branch with male upper part (scars, flower buds) and a female lower part (one flower); 5, fruit; 6, opened coconut (endocarp).

brown testa closely appressed to endocarp and adhering firmly to endosperm ('meat') which is firm, 1–2 cm thick, white, oily; at basal end in endosperm a small peglike embryo 0.5–1 cm long is embedded (under one of the endocarp pores); in centre of seed is a large central cavity, partially filled with coconut water which is completely absorbed 6 months after harvesting.

Growth and development Mature fruits of most coconut cultivars start germinating soon after harvest. The embryo enlarges and the apical part emerges from the shell. At the same time, the cotyledon develops into a haustorium. The primary root emerges from the apical mass, followed by the plumule. As growth continues they emerge at opposite sides through the husk. Shoot emergence occurs about 8 weeks after placing coconuts in a germinating bed and another 5 weeks later, the first leaf starts to unfold. The leaves increase in size but remain entire until the seedling has 7–10 leaves, usually after one year's growth. Subsequent leaves become progressively pinnate.

Tall cultivars produce about 10 leaves during the first year, dwarf palms have 14. In subsequent years, larger and more leaves are formed, until full leaf size is attained and annual production levels off at 12–18 leaves for talls and hybrids and 20–22 leaves for dwarf palms. Since a leaf of a tall palm remains on the tree for about 2.5 years after unfolding, the leaf number in the crown levels off at 30–35 after 6 or 7 years. Leaf initiation until senescence takes about 4 years.

The root system consists of adventitious roots numbering 2000–4000 per palm. Decayed roots are replaced regularly; new roots emerge from the upper part of the thickened basal stem.

The regular development of both canopy and root system is well adapted to the constant environment of the humid lowland tropics. The long development periods of large organs give the palm a certain inflexibility to short-term stress. Under adverse conditions, flowering and fruiting are mainly affected, leading to smaller inflorescences and fewer female flowers; abortion of inflorescences; reduction in fruit set, nut size and filling; premature nut fall and tapering of the stem. Thus, stress affects yield much more than growth. The size of new leaves and roots has been fixed a long time in advance and cannot be adjusted to short-term stress periods. After long-term stress leaf emergence slows down which further reduces yield, since the emergence of inflorescences follows that of the subtending leaves.

At the rosette stage, the growing point continues to enlarge until the size of the leaf initials reflects the prevailing growing conditions; then trunk formation starts. At close spacing, height growth increases at the expense of flowering and fruiting. Precocity and yield are positively correlated with annual leaf formation, as an inflorescence appears in the axil of each leaf. Hence, dwarf varieties yield earlier and more than tall varieties. First flowering in tall varieties occurs at 5–7 years, in dwarf varieties after 2 years and in dwarf × tall hybrids about 3–4 years after germination. Growing conditions have great influence on these aspects. Coconut palms can be more than 100 years old, but highest yields are usually obtained between 10–20 years of age for talls and a few years earlier in dwarfs and hybrids.

During the first phase of anthesis which lasts 16–22 days, only male flowers open progressively from the top to the base of the upper spikes and down to the lowest spikes. Each male flower opens, sheds its pollen and abscises within 2 days. The first female flower at the top of the spadix becomes receptive about 3 weeks in tall or 1 week in dwarf palms after the spathe has opened and the stigmas of the last female flower at the bottom of the spadix turn brown 5–12 days later. Female flowers are nectiferous and sweet-scented. Pollination is both by insects and by wind (the pollen is dry). Each female flower remains receptive for 2–3 days.

Tall coconuts are generally allogamous because the male and female phases do not overlap while in dwarfs, self-pollination is common due to considerable overlap. Self-pollination can also occur when the female phase of one inflorescence overlaps with the male phase of a second inflorescence on the same tree. About 50–70% of the female flowers abort during the first two months due to poor fertilization or other physiological causes. Fruits are mature 11–12 months after anthesis, but may not drop until 15 months old.

Other botanical information *C. nucifera* is the only species of the genus *Cocos* L. A generally accepted classification system for the wide variability of coconut does not exist. Coconuts that are thought to be of natural origin are said to be of the 'Niu kafa type' (fruits long, angular, thick husked, floating easily, long lasting viability, slow germination); those which are thought to be developed under cultivation are of the 'Niu vai type' (fruits globose, thinner husk, not floating easily, increased endosperm, earlier germination). Niu kafa and niu vai are Polynesian words. Where these 2 types come into contact, introgression takes place.

Up to now, cultivated coconuts have been classified into 2 groups: tall palms (sometimes referred to as var. *typica* Nar.) and dwarf palms (sometimes referred to as var. *nana* (Griff.) Nar.). More than 95% of all cultivated coconuts are tall palms. Examples of tall cultivars are: 'Malayan Tall', 'Rennell Island Tall', 'Vanuatu Tall', 'Jamaican Tall' and 'West African Tall'. Dwarf palms are rare, but can be found in different ecotypes. Characteristics of dwarf palms are: weaker growth and slow height increment; slender stem; smaller leaves, inflorescences and fruits; precocity and rapid succession of inflorescences; high degree of self-pollination. The inheritance of dwarfness is not well understood but hybrids are usually intermediate in height increment and other characteristics to the tall and dwarf parents. Three different types of dwarf cultivars exist: the 'Niu Leka' from Fiji which differs only from the talls by its very short internodes and short rigid leaves, while it is also allogamous; the medium-sized palms such as 'Malayan Dwarf' from Indonesia, 'Gangabondam' from India and 'King' from Sri Lanka; and the small dwarf cultivars in various countries. Dwarfs are also differentiated based on the colour of leaf petiole of young coconuts, into green, yellow and red (orange or golden) dwarfs. In the Philippines, there are green dwarfs with large fruits, such as 'Tacunan', 'Kinabalan' and 'Catigan'.

The nuts of 'Makapuno' from the Philippines and the 'Kelapa Kopjor' from Indonesia have endosperms that fill almost the entire cavity. The endosperm is soft, has a peculiar taste and is considered a delicacy. The nuts do not germinate but the embryos can be cultured in vitro. This character may appear in any tall cultivar.

Classification in cultivated coconuts can best be done by distinguishing cultivar groups and cultivars. A promising classification system of coconut cultivars is based on the degree of introgression, which can be expressed in characteristics of the fruits: proportion of husk in the whole fruit, proportions of water, meat and shell in the husked fruit.

Ecology Coconut palm is essentially a crop of the humid tropics. It is fairly adaptable with regard to temperature and water supply and so highly valued that it is still common near the limits of its ecological zone. The annual sunlight requirement is above 2000 hours, with a likely lower limit of 120 hours per month. The optimum mean annual temperature is estimated at 27°C with average diurnal variation of 5–7°C. For good yields, a minimum monthly mean temperature of 20°C is required. Temperatures below 7°C may seriously damage young palms, but cultivars differ in their tolerance of low temperature. While most coconuts are planted in areas below 500 m, palms may thrive at altitudes up to 1000 m, although low temperatures will affect growth and yield.

Generally, palms grow in areas with evenly distributed annual rainfall of 1000–2000 mm and high relative humidity, but they can still survive in drier regions if there is adequate soil moisture. The semi-xerophytic leaves enable the coconut palm to minimize water loss and withstand drought for several months. In India, a monthly rainfall of 150 mm (with only a 3-month dry period) is enough, while in the Philippines, rainfall of 125–195 mm (1500–2300 mm annually) is ideal.

The coconut palm thrives in a wide range of soils, from coarse sand to clay, if soils have adequate drainage and aeration. Coconut palms are halophytic and tolerate salt in the soil well. Coconut can grow in soils with a wide range of pH but grows best at pH 5.5–7.

Propagation and planting Coconut palm is propagated by seed which is recalcitrant. The multiplication factor is low, as one tall palm will in general not produce more than 100–200 seednuts per year. Although coconut plants can be regenerated through somatic embryogenesis, genotypic differences in rate of embryo formation and difficulties in hardening of in-vitro plants have been a constraints to practical methods of large-scale clonal propagation so far. However, a field of clonal coconuts may soon be planted in Mexico. In vitro culture of excised embryos is also possible. It solves problems of plant quarantine restrictions and finds application in the international exchange of germplasm.

Seed-nuts are usually given a resting period of one month after harvesting. They are kept in a germination bed from where uniform seedlings can be transplanted to polythene bags or to nursery beds. The polybag method and regular fertilization have largely replaced the bare-root seedlings raised in beds. Seedlings that are 3–8 months old are transplanted in the field. They can be kept longer in the nursery bed but will then sustain a greater transplanting shock. Coconut is planted mostly at spacings of 8–10 m × 8–10 m, in a triangular or square system. Dwarf cultivars are planted at a spacing of 7.5 m × 7.5 m. Hedge planting may be used to facilitate intercropping, but the radial symmetry of the leaf arrangement does not tolerate extreme forms of row cropping.

Growers prefer wider palm spacing to prevent inter-tree competition. As the open crowns also transmit a fair portion of incident light coconut is well suited to intercropping. Coconut is occasionally grown with cocoa and coffee. Although this usually results in lower copra yields, the combined income from well-fertilized coconut and intercrop is much higher than that from coconut alone. In humid climates, cocoa is one of the best intercrops. In Malaysia, more than 1000 kg/ha of dry beans have been obtained from cocoa grown under coconuts. Coconut is also grown in mixed cropping systems with other trees like rubber, mango, cashew and banana. Under coconuts in the Philippines yields of bananas of 40–60 t/ha have been obtained. Pastures are sometimes established under the palms for use in mixed husbandry and green manures are occasionally planted. However, pasture and cover crops can only be grown and maintained when there is sufficient rain. Catch crops such as rice, maize, finger millet, sweet potato, cassava, vegetables and spices are often planted until the palms come into bearing. These crops should not be planted closer than 2 m to the palms.

Husbandry Weeding is essential, especially for young coconut palms. Green manuring is often practised to advantage. Fertilizing is required, especially on soils that have been cultivated for many years, but smallholders seldom apply fertilizers. If nutrient deficiencies largely limit growth and yield, responses to fertilizer application and other cultural practices can be observed within one year. Potassium and chloride are the major nutrients needed by the palm, followed by nitrogen, phosphorous and sulphur. Leaf analysis is an acceptable and quick guide to the fertilizer requirements of the palm. The annual crop nutrient removal of one hectare of coconuts, yielding 7000 nuts, is about: 49 kg N, 16 kg P_2O_5, 115 kg K_2O, 5 kg Ca, 8 kg Mg, 11 kg Na, 64 kg Cl and 4 kg S. An example of a yearly fertilizer recommendation per palm is a mixture of 0.4 kg N, 0.3 kg P_2O_5, 1.2 kg K_2O, 0.20 kg S and 0.90 kg Cl, applied in split applications in a band around the palm (1.0–1.5 m from the trunk) and split into 2 applications, at the beginning and end of the rainy season. Fertilizer doses depend on local conditions. Foliar and soil analyses help to determine the nutrient status of the palms. In several countries in Asia sea salt (NaCl) is commonly applied to coconut palms with positive effects on yields.

Irrigation is sometimes practised in dry areas where water is available and sea water may be applied occasionally as long as the salt content in the soil does not rise too high.

Diseases and pests Many diseases affect coconut palm. Important are yellowing diseases, such as lethal yellowing in the Caribbean, Cape St. Paul wilt, Kaincopé disease, Kribi disease in West Africa and lethal disease in Tanzania. These are caused by mycoplasma-like organisms. Generally, the symptoms of yellowing diseases are browning and collapse of spear leaves, yellowing of mature leaves, collapse of roots, premature nut fall, death of bud and later, of the tree. 'Malayan Dwarf' is highly tolerant of lethal yellowing but shows varying tolerance of other yellowing diseases. Tall palms are more susceptible.

Similar diseases of unknown etiology but suspected to be caused by mycoplasma-like organisms are Malaysian wilt in Malaysia, stem necrosis in Malaysia and Indonesia, Natuna wilt and leaf yellowing disease in Indonesia, Socorro wilt in the Philippines and the New Hebrides disease in Vanuatu. Malaysian wilt is characterized by premature nut fall; stiff, yellowish and smaller new leaves; wilting and drying of old leaves and eventual death of the palm. Palms with stem necrosis show shorter young leaves, die-back of leaflets, necrosis in the leaflet midrib, internal disorganization and necrosis of stem, bud, inflorescence and roots. Natuna wilt causes leaf wilting and bending in both young and old trees until leaves fall simultaneously with the nuts. Leaf yellowing disease causes intensive yellowing of the older leaves and at the advanced stage, the leaves are smaller and the whole crown is stunted. Symptoms of Socorro wilt are premature senescence of the outer whorl of hanging leaves or the drying of the leaves from the tip to the base until they drop, premature falling of nuts, failure of inflorescence to develop, and spathes becoming brown and dying. The few nuts that develop are usually deformed, oblong, small and with damaged kernels.

Kerala wilt, possibly caused by a virus, is an important disease in India. Cadang-cadang, caused by the cadang-cadang viroid (CCVD) is a devastating disease especially of flowering palms in the Philippines, particularly in the Bicol region and adjacent provinces (estimates of the affected area range from 250 000 ha to 400 000 ha). The symptoms are yellow mottling on leaves, formation of small and stiff leaves that usually break at the middle until only a group of small, erect and yellowish-green leaves remain at the top of the stem and production of fewer roots. The inflorescence is also affected; at the later stage of the disease, only male flowers develop and nut production stops. Although control methods are still unknown, the eradication of diseased palms and sterilization of knives that are used on the farms may help reduce the spread and incidence of cadang-cadang. Coconuts in Guam are infected by a disease similar to cadang-cadang, also caused by a viroid.

Bud rot occurs worldwide and is caused by the soil-borne fungus *Phytophthora palmivora* which is favoured by high humidity. It causes rotting of the spear and the growing point. It can be controlled by wider plant spacing, better aeration, drainage and weed control. Basal stem rot develops from an infection by the fungus *Ganoderma boninense.* The fungus first affects and destroys the roots and then the base of the stem turns reddish-brown and releases a brown, gummy exudate. Disease occurrence can be prevented through improved growing conditions, production techniques and proper sanitation measures. Control methods are eradication of affected palms and application of fungicide. Stem bleeding or oozing of reddish-brown liquid from the cracked stem is caused by *Thielaviopsis paradoxa.* Cultural management techniques and drenching the soil with fungicides effectively control the disease. Leaf blight caused by *Pestalotia palmarum* and leaf rot or leaf spot caused by *Drechslera halodes* (= *D. incurvata*) are widespread fungal diseases, while leaf blight caused by *Botryodiplodia theobromae* damages palms in Brazil, Malaysia, Sri Lanka and Trinidad especially during months of high temperatures and low relative humidity and rainfall.

Numerous insect pests attack coconut palms. The rhinoceros beetle (*Oryctes rhinoceros*) is widespread in South-East Asia and the Pacific. Its larvae tunnel through the apical bud leaving characteristic triangular cuts in opened leaves. When the growing point is attacked, the palm dies. Control is done by keeping the plantation clean and applying *Baculovirus oryctes* or the insect-pathogenic fungus *Metarhizium anisopliae* to breeding places. Recently, a male-produced aggregation pheromone was discovered to be a powerful attractant in selective trapping to reduce beetle populations. Different outbreak situations require specific control approaches. Other *Coleoptera* that inflict serious damage to coconut are *Promecotheca* spp. in Indonesia, Malaysia and the Philippines and *Brontispa longissima* in Indonesia, Malaysia and the Pacific. Larvae of *Promecotheca* spp. tunnel through foliar tissues while adults eat the underside of leaves. *B. longissima* larvae and adults feed on leaflet tissues and may defoliate the whole crown in severe cases. The weevils *Rhynchophorus ferrugineus* and *R. schach* in South Asia and Malaysia cause serious damage by their boring into the coconut stem. Many caterpillars feed on coconut leaves, such as *Hidari irava* in Indonesia and Malaysia, *Tirathaba* spp. in South-East Asia and the Pacific, *Setoria nitens* in Burma (Myanmar), Indonesia, Malaysia and Vietnam, *Parasa lepida* in India, New Guinea, China and South-East Asia and *Brachartona* (*Artona*) *catoxantha* in Indonesia, Malaysia, New Guinea and the Philippines. The scale insect *Aspidiotus destructor* is one of the most widespread pests of the coconut palm and can be controlled by an emulsion of soft laundry soap and kerosene in water. The white fly *Aleurodicus destructor* sometimes causes serious damage to coconut in Indonesia and the Philippines.

Harvesting Coconut fruits can be harvested about 11–12 months after flowering. The palm can be harvested every 2–3 months but rapidly germinating types should be harvested more frequently. Dwarf cultivars sprout in 45–60 days and must be harvested monthly. Climbing the palms and cutting the ripe bunches is still the harvesting method most practised. Gathering fallen nuts is easier, but there are more losses due to rat attack and theft. Some nuts may germinate on the tree and consequently, their kernel and oil content may have started to deteriorate. In some countries bamboo poles (up to 25 m long) with a knife attached to the top end are used to cut the ripe bunches, elsewhere monkeys (*Macacus nemestrina*) are trained to harvest ripe nuts.

Yield Smallholder plantations usually yield between 0.5–1 t of copra/ha. In Malaysia, average estate yields are about 1.5 t of copra/ha but the potential yield is about 3.5 t/ha. Well-managed plantations of selected local tall coconut palms in Indonesia yield 3.5–4.5 t copra /ha. Rehabilitated and fertilized tall coconut palms in small farms in the Philippines achieve an average annual yield of 2.8 t copra/ha or 83 nuts/tree per year. Plantations of dwarf coconut palms in Malaysia produce about 1.5–2 t/ha and even 3.5 t/ha under favourable conditions. Dwarf × tall hybrids combine the high number of fruits produced by the dwarf type with the larger size from the tall one and usually have a higher yielding potential than the parents. Experimental yields of more than 6–9 t/ha have been obtained in Ivory Coast and the Philippines.

Handling after harvest Harvested coconuts are stored in a protected place until the husks are completely dry. Dried coconuts are dehusked manually by striking and twisting them on a steel point that is placed firmly in the ground. Dehusking machines have been developed but have not been a success. After dehusking, nuts are split with a machete and the water is drained. The nut halves are placed in a kiln dryer or an indirect hot air dryer for 1–2 days, after which the endosperm is scooped out from the shell and dried further until its moisture content is less than 6%. Sun-drying is also practised but there is a higher risk of product deterioration especially during humid and rainy periods. Aflatoxin-producing moulds may affect the quality when the moisture content of dried copra exceeds 12%.

Coconut oil can be extracted from the copra (yield about 60%) by dry processing methods such as mechanical pressing and by using solvents. It can also be extracted from the fresh kernel through several wet processes. In traditional extraction coconut cream or milk is obtained from the grated fresh kernel by boiling it gently until the oil floats to the surface.

Whole or dehusked coconuts are also sold to coconut desiccation factories. To produce desiccated coconut, the shell and the brown testa are pared off, the white endosperm washed, steamed, pasteurized, shredded into small pieces of various sizes and forms, dried and packed.

Genetic resources Local coconut cultivars (ecotypes) are usually heterogeneous populations with some predominating characteristics. Cultivars with different names and growing in different areas are sometimes rather similar and maybe of the same origin. Germplasm collections are found in several research stations around the world. In 1978, the International Board for Plant Genetic Resources (IBPGR, now IPGRI) adopted a minimum list of descriptors to be used in collecting germplasm in the field. In 1980, it supported the survey and collection of coconut germplasm in priority areas in South-East Asia and provided funds for the collection of coconuts in Indonesia, the establishment of a coconut germplasm centre in the Philippines and collection of germplasm in the Pacific to be planted on one of the Andaman Islands to screen for Kerala wilt disease resistance for mainland India.

The Coconut Genetic Resources Network (COGENT), with IPGRI's administrative support, coordinates the conservation of more than 700 accessions in 15 countries. Major coconut germplasm collections include those of the Philipine Coconut Authority (PCA), the Research and Development Centre for Industrial Crops (RDCIC) in Indonesia, IPGRI-Asia, the Pacific and Oceania at Serdang, Malaysia, the Central Plantation Crop Institute (CPCRI) in India, the National Centre for Agricultural Research (CNRA) in Ivory Coast and the National Coconut Development Programme (NCDP) in Tanzania.

Germplasm conservation by field collections requires considerable resources of land, staff and upkeep and remains vulnerable to natural disasters and diseases. The cryopreservation of coconut embryos and pollen will enable the safe and inexpensive long-term storage of coconut genetic resources.

Breeding Breeding methods common to cross-pollinating species are applied to coconut palm. The long duration of one breeding generation (more than 10 years), low multiplication rate (1 : 50/100), recalcitrant and large 'seed' and the large areas of land required for field testing, are major obstacles to rapid selection progress. About 95% of all planted coconut palms in the world are open-pollinated progenies after mass selection within local ecotypes, often informally applied by the growers themselves.

Important selection criteria in coconut are: yield (kg copra per ha) and its components (number of nuts, copra content per nut), early production, disease resistance and drought tolerance. Selection for endosperm thickness is a minor factor of selection; oil content and quality are fairly constant; length of husk fibres is a selection criterion in Sri Lanka only. The flavour of immature coconut water varies with ecotypes, but has not been a criterion for formal selection as yet.

The genetic variance in coconut yield and its components is mainly due to additive genetic effects and the superior hybrids are the result of the general combining ability of the parents. Methods of (reciprocal) recurrent selection with genetically diverse subpopulations (dwarfs and talls) are now used in some coconut breeding programmes to increase substantial transgressive hybrid vigour for yield in new cultivars. Chemical and more recently, molecular markers are applied in coconut breeding to measure genetic divergence between sub-populations.

Dwarf × tall hybrids have considerable heterosis for yield and precocity, hence the focus of breeding programmes of several coconut research centres on such hybrids since 1960. Some 400 hybrids have been tested worldwide during the last 35 years; about 10 of these internationally at several locations. The coconut research centre at Port Bouet in Ivory Coast tested 123 hybrids, of which 35 produced 65% more than the 'West African Tall' standard cultivar. Four hybrids yielded even more than twice as much (3.4–4.5 t/ha copra), including PB121 ('Malayan Yellow Dwarf' × 'West African Tall') which has been planted widely also in South-East Asia. Host resistance to major diseases has high priority in some areas, but sources of resistance are not always available in the coconut, e.g. against Cadang-cadang disease in the Philippines.

Crosses for breeding purposes are made by hand pollination after emasculation and bagging of inflorescences. Pollen collected from the male parent can be stored (dry and under vacuum) for a considerable period. Large-scale seed production is based on pollination of previously emasculated inflorescences (not bagged) in isolated seed gardens planted solely with the female parent of the hybrid cultivar (usually a dwarf type). One hectare of seed garden produces yearly enough 'seed' for planting 50–60 ha only. Hybrid seed production is rather expensive and requires large land areas. An estimated 15% of all coconut palms planted during the last decade are hybrids. Examples of widely planted hybrid cultivars are: KB and KHINA series in Indonesia; the PCA 15 series in the Philippines; Sawi-1 (= PB121) and Chumphon 60 in Thailand and PB series (e.g. PB121) from Ivory Coast.

In some areas of the Philippines, the more robust tall palms are preferred as planting material. In 1992, a programme of 15 crosses between 6 tall types was carried out and best selected F_1 was planted in a seed garden to produce open-pollinated F_2 seeds with similar qualities as a synthetic (hybrid) cultivar. Cost of seed production is much lower, as no emasculation or artificial pollination are involved.

Prospects Some of the latest dwarf × tall hybrid cultivars of coconut palms can potentially yield more than 6 t/ha of copra per year (3.7 t of oil), but coconut palm does not appear to have a bright future as a plantation crop in the long term. Coconut oil already faces increasing competition in the world market from palm-kernel oil and both may eventually also be partly replaced by lauric oils produced by genetically transformed soya bean and brassica oilseed. On the other hand, as a smallholder crop in the coastal areas of the tropics, coconut will continue to be a very important supplier of multifunctional food and other products. Sometimes, it is practically the only crop that can be grown in the prevailing ecosystem (e.g. some Pacific Islands). A quickly growing world market for healthy and environmentally friendly products should offer new opportunities for the coconut export trade. However, this will require astute marketing, more research into the economic viability of smallholder coconut production systems (e.g. replanting, mixed intercropping and biological control of diseases and pests) and into novel processing technologies for local industries to manufacture diversified coconut products suitable for the international market.

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Elaeis guineensis Jacq.

Select. stirp. amer. hist.: 280 (1763).
PALMAE
$2n = 32$

Vernacular names Oil palm, African oil palm (En). Palmier à huile (Fr). Indonesia: kelapa sawit (general), kalapa ciung, kalapa minyak (Sundanese). Malaysia: kelapa sawit. Burma (Myanmar): si-ohn, si-htan. Cambodia: dôong preeng. Thailand: paam namman, ma phraao hua ling (central), maak man (peninsular). Vietnam: c[oj] d[aaf]u, d[uwf]a d[aaf]u.

Origin and geographic distribution *E. guineensis* is indigenous to the tropical rain-forest belt of West and Central Africa between Senegal and North Angola (12°N–10°S latitudes). There is fossil evidence for the Niger delta as a possible centre of origin. The natural habitat of this heliophile palm is assumed to be at the edges of swamps and along river banks, where there is little competition from the faster growing tree species. The abundance of oil-palm groves throughout the forest zone is attributed to early domestication by man, who in ancient times started to open up patches of primary forest for habitation and cultivation. In West Africa, oil palm has played a major role in the village economy for many centuries and unrefined palm oil is still the preferred cooking oil of the local populations.

The semi-wild oil-palm groves of north-eastern Brazil have a West African origin through the 17th Century slave trade. It gradually spread to other regions of tropical America and the original description of *E. guineensis* by Jacquin in 1763 was based on a specimen growing in Martinique. The introduction of the oil palm into South-East Asia started with four seedlings planted in the Bogor Botanic Gardens (Indonesia) in 1848. Offspring of these palms formed the basis for the oil-palm plantation industry, which started to develop from 1911 in Indonesia, mainly in Sumatra, and from 1917 in Malaysia.

The 19th Century trade in palm oil and kernels between West Africa and Europe was entirely dependent on the produce of the semi-wild palm groves. In response to increasing demands for more and better quality palm oil, commercial plantations also started to be established in Africa after 1920 (e.g. Congo). By 1938, annual world exports were about 0.5 million t palm oil (50% from South-East Asia) and 0.7 million t palm kernels (almost exclusively from Africa). Major new oil-palm developments started in the 1970s in South-East Asia (Malaysia, Indonesia, Thailand and Papua New Guinea), tropical America (e.g. Colombia, Ecuador and Costa Rica) and Africa (e.g. Ivory Coast, Cameroon, Ghana). Smaller oil-palm industries are also developing in the Philippines, Solomon Islands, China (Hainan), India and Sri Lanka. World palm oil production increased from 1.3 million t in 1960 (78% from Africa) to 12.1 million t in 1980 (83% from South-East Asia).

Uses Two types of oil are extracted from the fruit of *E. guineensis*: palm oil from the mesocarp and palm-kernel oil from the endosperm, in the volume ratio of approximately 9:1. Palm oil is used in many edible products, such as cooking oils, margarine, vegetable ghee ('vanaspati'), shortenings, frying fats, bakery and biscuit fats, potato crisps, pastry, confectionery, ice-cream and creamers. While red crude palm oil is an essential ingredient of the West African diet, the clear olein fraction is preferred as cooking oil in South-East Asia. About 10% of all palm oil, the inferior grades in particular and also refining residues, is used to manufacture soaps, detergents, cosmetics, candles, resins, lubricating greases, glycerol and fatty acids. Palm oil is also employed in the steel industry's tin plating and sheet steel manufacturing. Epoxidized palm oil is a plasticizer and stabilizer in PVC plastics. Crude oil and its methyl esters can be used as bio-fuel for diesel engines.

Palm-kernel oil is similar in composition and properties to coconut oil. It may be used as cooking oil, sometimes in blends with coconut oil as done in Indonesia, or in the manufacture of margarine, edible fats, filled milk, ice-cream and confectioneries. It is also used for industrial purposes, either as an alternative to coconut oil in high-quality soaps, or as a source of short-chain and medium-chain fatty acids. These acids are chemical intermediates in the production of fatty alcohols, esters, amines, amides and more sophisticated chemicals, which are components of many products like surface-active agents, plastics, lubricants and cosmetics. The presscake or palm-kernel meal is a valuable protein-rich livestock feed.

The empty bunch stalks, mesocarp fibres after oil extraction and the shells from the cracked nuts are used as fuel for the boilers of the palm-oil mill. Various other wastes from the palm-oil mill may be converted into fertilizers and other valuable products.

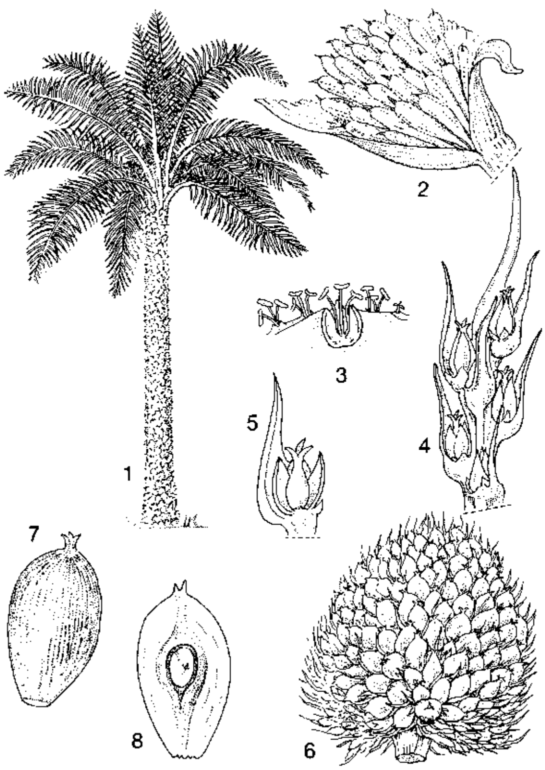
The popular African practice of producing palm wine by tapping the unopened male inflorescences, or the stem just below the apex of standing or felled oil palms, has not been adopted in South-

East Asia. The palm heart consisting of the soft tissues of undeveloped leaves around the apical bud is eaten as a vegetable.
Entire palm fronds are less suitable for thatching than those of the coconut because of irregular leaflet insertion. However, the leaflets are woven into baskets and mats; the leaflet midribs are made into brooms and the rachises used for fencing. Young leaflets produce a fine strong fibre for fishing lines, snares and strainers. Palm trunks, available at replanting, provide excellent materials for paper and board production, but this has not yet attracted much commercial interest.
Oil palm is sometimes planted as a garden ornamental and along avenues.

Production and international trade Between 1996 and 2000, annual world production of palm oil increased from 16.2 to 21.8 million t and the total area from 5.3 to 6.6 million ha. South-East Asia produced 86%, West Africa 7% and tropical America 6% of total palm oil supply. The largest producers of palm oil in 2000 were Malaysia with 10.70 million t, Indonesia with 6.65 million t, Nigeria with 0.74 million t, Colombia with 0.52 million t and Thailand with 0.44 million t. Papua New Guinea produced 285 000 t and the Philippines 54 000 t palm oil. Areas planted to oil palm in South-East Asia are: Malaysia 2.91 million ha, Indonesia 2.01 million ha, Thailand 0.17 million ha, Papua New Guinea 70 000 ha and the Philippines 20 000 ha. World trade in palm oil amounted to 14.6 million t in 2000 or 70% of the total production. Malaysia and Papua New Guinea exported more than 90% of their production, Indonesia 50%, Colombia and Thailand each about 20%, while practically all of Nigeria's palm oil was consumed domestically. Oil palm still takes second place in world production after soya bean (24% against 28%), but in 2000 palm oil was the most important commodity (42%) in the world trade of vegetable oils and fats.
In 2000, world palm-kernel oil production was 2.6 million t with Malaysia (1.42 million t), Indonesia (0.67 million t) and Nigeria (0.18 million t) being the leading producers. Palm-kernel meal production in 2000 was 3.2 million t and Malaysia was the biggest producer (1.72 million t) followed by Indonesia with 0.83 million t and Nigeria with 0.21 million t. Fifty percent of the oil and 85% of the meal were traded internationally.

Properties Industrially extracted fresh fruit bunches of the most commonly planted *E. guineensis* cultivars (Dura × Pisifera hybrids producing thin-shelled Tenera fruits) yield per 100 kg: palm oil 20–28 kg and kernels 4–8 kg (2–4 kg kernel oil). Per 100 g, the mesocarp of mature fruit contains: water 30–40 g, oil 40–55 g and fibre (crude fibre and cell walls) 15–18 g. Per 100 g the endosperm of the kernel contains: water 6–8 g, protein 7–9 g, oil 48–52 g, carbohydrates 32–30 g and crude fibre 4–5 g.
Palm oil varies in colour from pale yellow to dark red; its melting point ranges from 25–40°C and it has an energy value of 3700 kJ per 100 g. It consists of triglycerides with the following fatty acids: myristic acid 1–2%, palmitic acid 45–52%, stearic acid 2–4%, oleic acid 34–41% and linoleic acid 4–9%. Palm oil for edible purposes should contain less than 3% free fatty acids. Crude palm oil also contains nutritionally valuable carotenoids (provitamin A), 800–2000 mg/kg in the orange-red palm oil from West Africa and 400–600 mg/kg in the lighter coloured palm oil from Malaysia and Indonesia. Tocopherol (vitamin E) is present in quantities of up to 850 mg/kg. Carotenoid content is reduced to zero and the tocopherol content to half during the refining of the oil. High quality palm oil should have the following characteristics: <2% free fatty acid (FFA), <0.1% moisture and <0.002% dirt content; iodine value of >53; carotene 500 ppm; tocopherol 800 ppm; good bleachability and consistency of all other properties.
Kernel oil is light yellow, but almost white when solid. Its melting point range is 23–30°C. The fatty acid composition of palm-kernel oil is similar to that of coconut oil: lauric acid 45–52%, myristic acid 15–17%, palmitic acid 6–10%, stearic acid 1–3%, oleic acid 13–19% and linoleic acid 1–2%. However, there is less caprylic acid (3–4%) and capric acid (3–7%). Per 100 g palm-kernel cake contains: water 8–11 g, crude protein 19–22 g, carbohydrates 42–49 g, crude fibre 11–15 g and some other minor components such as calcium, phosphorous and iron.
The weight of 1000 'seeds' (kernel with endocarp) is 4–12 kg for Dura (thick shelled) and 2–3 kg for Tenera (thin shelled).

Description An armed, unbranched, pleonanthic, monoecious palm up to 15–30 m tall, with a terminal crown of 40–50 leaves. Root system adventitious, forming a dense mat with a radius of 3–5 m in the upper 40–60 cm of the soil; some primary roots directly below the base of the trunk descending vertically for anchorage for more than 1.5 m; the roots also develop pneumatodes, particularly under very moist conditions. Stem erect, cylindrical, 30–75 cm in diameter but thicker at the swollen, often inverted cone-like basal part,



Elaeis guineensis Jacq. – 1, habit fruiting tree; 2, male inflorescence; 3, detail of male flowers; 4, detail of female inflorescence; 5, female flower; 6, infructescence; 7, fruit; 8, fruit (tenera) in longitudinal section.

rough and stout due to adhering petiole bases during the first 12–15 years, slender and smooth in older palms. Leaves spirally arranged, sheathing; sheath tubular at first, later disintegrating into an interwoven mass of fibres, those fibres attached to the base of the petiole remaining as regularly spaced, broad, flattened spines; petiole conspicuous, adaxially channeled, abaxially angled, 1–2 m long, bearing spines, upper spines are modified small pinnae; juvenile leaves lanceolate, entire to gradually becoming pinnate; mature leaf paripinnate, up to 8 m long; leaflets 250–350 per leaf, irregularly inserted on the rachis and giving the oil-palm crown a shaggy appearance, linear but single fold, 35–65 cm × 2–4 cm, pulvinus at base, with thick cuticular wax layer on upper surface and semi-xeromorphic stomata on lower side. Inflorescence axillary, solitary, looking like a short and condensed compound spike or spadix, unisexual, several adjacent axils producing inflorescences of one sex followed by several producing the other sex, branching to 1 order; peduncle 30–45 cm long; inflorescence tightly enclosed in 2 fusiform or ovate spathes before anthesis; central rachis with 100–200 spirally arranged spikes; male inflorescence ovoid, 20–25 cm long and spineless, with cylindrical spikes 10–20 cm long, each with 700–1200 closely packed flowers; male flower 3–4 mm long, perianth consists of 6 small segments, androecium tubular with 6 anthers and rudimentary gynoecium; female inflorescence subglobose, 25–35 cm long, with thick rachis, spikes thick and fleshy, each in the axil of a spiny bract, with 10–25 spirally arranged flowers and a terminal spine; female flower in shallow cavity accompanied by two rudimentary male flowers and subtended by a spiny bract, with 2 bracteoles, 6 sepaloid tepals 2 cm long, a rudimentary androecium, a tricarpellate ovary and a sessile, 3-lobed, creamy-white stigma. Infructescence with 500–3000 fruits together in tightly packed subspherical bunches up to 50 cm long and 35 cm wide, weighing 4–60(–90) kg; fruit a globose to elongated or ovoid, sessile drupe, 2–5 cm long, weighing 3–30 g, apex with persistent woody stigma and usually violet-black pigmented; exocarp smooth, shiny, orange-red when ripe; mesocarp fibrous, yellow-orange, oleiferous, comprising 20–90% of the fruit; endocarp (shell) stony, dark brown, very variable in thickness, with longitudinal fibres drawn out into a tuft at base and 3 germ pores at apex; innermost fruits are smaller, irregularly shaped and have a less pigmented apex. Seed (kernel) usually 1, sometimes 2 or 3, with dark brown testa; endosperm solid, oleiferous, grey-white, embedding an embryo opposite one of the endocarp germ pores. Embryo about 3 mm long.

Growth and development After harvesting, oil-palm seeds are dormant. Germination starts with the appearance of a white button, which develops within 4 weeks into a seedling consisting of a plumule with first green leaf, a radicle and adventitious roots, but still connected to the seed endosperm by a petioled haustorium. Subsequent leaves gradually change from lanceolate to pinnate over a period of 12–14 months, when the seedling has 18–24 leaves. Pinnate leaves on seedlings have no spines and are less xeromorphic than adult leaves. The base of the stem becomes like a swollen bulb from where adventitious primary roots develop. In the first 3–4 years, lateral growth of the stem dominates, giving a broad base up to 60 cm in diameter. After that, the stem starts growing in height, 20–75 cm per year, at somewhat reduced diameter. The rate of height increment and rate of leaf production appear to be independent. A leaf primordium develops about every second week from the single growing point. Succeeding primordia are separated by a divergence angle of 137.5°, causing leaf bases to be arranged in apparent spirals, of which a spiral of 8 leaves per tour is the most obvious one. This facilitates identification of leaf 17 (standard leaf sampled for foliar diagnosis of the palm's nutrient status), as being in a straight line down from the youngest opened leaf and 9th leaf. The rate of leaf production is up to 40 per year in the first 3 years, dropping to 20–24 per year from year 8 onwards. Development from leaf primordium to fully expanded leaf (2–10 m^2) takes 2 years and a leaf remains photosynthetically active for about 2 years. An adult palm has a crown of 36–48 green leaves, but 40 leaves per palm are usually maintained in plantations. The economic lifetime is about 25 years.

All leaf bases contain inflorescence primordia, but the first fully developed inflorescence does not appear before leaf 20 and usually much later, some three years after germination. Differentiation into male or female inflorescence takes place on adult palms at 20–24 months before anthesis, but this can be as short as 12–16 months in young palms. The physiological basis of this sex differentiation is not yet well understood, except that there is empirical evidence for drought and other stress conditions to increase maleness. This appears to be an effective mechanism for the oil palm to survive under adverse climatic conditions by reducing the crop load of fruit bunches. Generally, environmental, age and genetic factors determine the ratio of female to total number of inflorescences over time (sex ratio) of individual palms.

The female flower remains receptive for 36–48 hours after initial opening. Pollination is primarily by insects. One of the insect vectors, *Elaeidobius kamerunicus*, was successfully introduced from Africa into Malaysia in 1981 and subsequently to Indonesia and Papua New Guinea. Before then, oil palms in South-East Asia required artificial pollination for adequate fruit set, particularly during the first years of production. Male inflorescences spread a strong aniseed-like fragrance during anthesis. Fruits ripen within 4.5–6 months after anthesis. Fruit ripening on the bunch proceeds simultaneously from top to bottom and from outer to inner fruits. Ripe fruits become detached. Oil formation in the seed takes place from 2.5–3.5 months after pollination, but in the mesocarp it starts only in the 4th month and does not reach its peak until the fruit is fully ripe.

Other botanical information *Elaeis* Jacq. comprises only two species: the African *E. guineensis* and the tropical American *E. oleifera* (Kunth) Cortes (synonyms *Corozo oleifera* (Kunth) L. H. Bailey, *E. melanococca* Gaertn.). *E. oleifera* is distributed from southern Mexico to the central Amazonian region (Brazil, Colombia and Ecuador) and grows in poorly drained, sandy, often open habitats along river banks, in swamps and freshwater mangrove communities. Due to low oil yield, *E. oleifera* is of little economic importance, except in its natural area of distribution. However, it has a range of other characters that are potentially useful in oil-palm breeding, including resistance to some important pests and diseases, slow stem growth and high unsaturated fatty acid content of the mesocarp oil. *E. oleifera* and *E. guineensis* are inter-fertile and hybridization to transfer such characters is in progress.

Barcella odora (Trail) Trail ex Drude (syn. *Elaeis odora* Trail), is another palm closely related to the oil palm. It occurs along the Rio Negro in Brazil, has no petiole spines, a long peduncle and male and female flowers in the same inflorescence.

E. guineensis is very variable and many classifications exist to describe the variation, but no classification into cultivars and cultivar groups exists. Agricultural classifications are primarily based on variation in fruit characteristics. One with considerable economic consequences is the distinction between three forms based on shell thickness, which is determined by a single major gene:

- Dura: homozygous (sh+sh+) for the presence of a relatively thick endocarp (2–8 mm at cross-section of fruit);
- Tenera: heterozygous (sh+ sh–) with a relatively thin endocarp (0.5–4 mm);
- Pisifera: homozygous (sh–sh–) for the absence of a lignified endocarp.

Within the Dura and Tenera forms, there is considerable variation in shell thickness which is apparently under polygenic control. Tenera is preferred as planting material because it has more oil-bearing mesocarp (60–90% per fruit weight) than Dura (20–65% per fruit weight). The original Bogor oil palms and the material derived from them were of the Dura form and as a population, it is generally referred to as Deli Dura. Pisifera is usually unproductive because the female inflorescences abort before developing fruit bunches, but it is used as male parent in crosses with Duras to produce pure stands of Tenera palms.

Other classifications based on fruit characteristics (also controlled by one gene) are:

- anthocyanin in the upper fruit exocarp: absent in virescens form, present in nigrescens form (recessive);
- carotene in the mesocarp: absent in albescens form (recessive);
- additional carpels in the fruit: present in poissoni (mantled) form (recessive).

The so called 'idolatrica' oil palm has entire leaves because the leaflets do not separate (recessive character).

For some time an oil palm with smaller fruits found in Madagascar was considered a separate species (*E. madagascariensis* Becc.), but is now thought to fall within the normal variability range of *E. guineensis*. In Madagascar *E. guineensis* has probably been introduced.

Ecology Oil palm is a heliophile crop of the humid tropical lowlands, with maximum photosynthetic activity only under bright sunshine and unrestricted water availability. Such palms show one unopened leaf at any time, while several such spear leaves can be observed on palms suffering from drought or other abiotic stress factors. High correlations have been found between number of hours of effective sunshine (i.e. sunshine hours when the palms are not water stressed) and bunch yields of mature oil-palm fields 2.5 years later. Generally, climatic requirements for high production are: well distributed rainfall of 1800–2000 mm and water deficit of less than 250 mm per year, high air humidity, and at least 1900 hours of sunshine per year. Optimum mean minimum and maximum monthly temperatures are 22–24°C and 29–33°C, respectively. Under conditions of higher annual water deficits (prolonged dry season) or mean minimum monthly temperatures below 18°C (in elevations exceeding 400 m or latitudes above 10°), growth and productivity are severely reduced. The oil palm is also affected by excessively high temperatures, as photochemical efficiency becomes progressively lower above 35°C.

Oil palm can grow on various soils like latosols developed over different parent rocks, young volcanic soils, alluvial clays and peat soils, and is tolerant of relatively high soil acidity (pH 4.2–5.5). Major criteria for suitability are soil depth (>1.5 m), soil water availability at field capacity (1–1.5 mm/cm soil depth), organic carbon (>1.5% in the topsoil) and cation exchange capacity (>100 mmol/kg). Soils should be well drained with no signs of permanent waterlogging, but the oil palm is fairly tolerant of short periods of water stagnation.

Propagation and planting Freshly harvested, cleaned and dried (14–17% moisture content) 'seeds' of oil palm lose viability within 9–12 months at tropical ambient temperatures (27°C). High seed viability (>85% germination) can be maintained for about 24–30 months in air-conditioned stores at 18–20°C and seed moisture content of 21–22%. Longer storage of valuable oil-palm germplasm by cryopreservation of seeds, excised embryos or somatic tissues is now also possible. Seeds of the oil palm require a heat treatment at 39–40°C for 60–80 days, followed by cooling and rehydration, to break dormancy and induce rapid germination, but in vitro grown excised embryos start elongating within 24 hours.

Practically all planted oil palms are Dura × Pisifera hybrids which are produced by controlled pollination of female inflorescences on selected Dura palms with pollen from selected Pisiferas. The fruits are of the Dura type, but the palms raised from them will produce thin-shelled Tenera fruits. The multiplication factor in oil palm can be in excess of 10 000, since one mature Dura seed parent may produce 6–9 hand-pollinated fruit bunches per year, each yielding 1000–2500 seeds. Seed production, storage and heat treatment with subsequent flush of germination require considerable technological and logistic expertise and facilities, generally available only in public or private oil-palm research centres.

Newly germinated seeds can be transported over long distances (300 in a polythene bag and several bags carefully packed in a box) before planting in a mini polybag (8 cm × 20 cm lay-flat, 200 gauge, black polythene) pre-nursery. Transplanting takes place at the 2-leaf stage into a large polybag (40 cm × 60 cm lay-flat, 500 gauge, black polythene) nursery. Total duration of both nursery stages before transplanting to the field is 10–14 months. Under favourable climatic conditions and ample availability of space and irrigation facilities, a single-stage nursery system can be applied by planting germinated seeds directly in large polybags. Shading has to be provided to young seedlings during the first 2–3 months.

In-vitro methods of clonal propagation in the oil palm through somatic embryogenesis, starting from young root or leaf explants, were first developed in the late 1970s. Vegetative reproduction offers by far the quickest and most efficient means of fixing genetic improvements in a cross-pollinated species. However, the occurrence of epigenetic abnormalities in clonal offsprings, such as various degrees of androgynous inflorescences and mantled fruits, make further research efforts necessary before widespread application of clonal propagation in the oil palm can become feasible.

Field planting is preceded by land preparation, which may include underbrushing, tree felling and clearing followed by the layout of roads and planting blocks, lining and holing. In non-forest areas, disc ploughing followed by several harrowings can clear the land of strong growing weeds and other vegetation. Oil-palm plantations are usually established on flat or gently undulating land. Where soil permeability is poor, the construction of a drainage system may be necessary. Planting on steep hills requires terracing or construction of individual platforms. A leguminous cover crop is often sown after land preparation or soon after planting to protect the soil, provide humus, add to the nitrogen supply and suppress weeds. The main cover crops used are *Calopogonium muconoides* Desv., *Centrosema pubescens* Benth. and *Pueraria phaseoloides* (Roxb.) Benth., often in a mixture of two or all three. Except in regions with no distinct dry season, the best time for transplanting into the field is at the beginning of the main rainy season to give the young palm time to form a good root system before the next dry season arrives.

Planting density is a major issue as it determines competition between palms for light in particular, but also for water and nutrients. There is experimental evidence for a progressive reduction of dry matter production with higher density, but also that fruit yield is more affected than vegetative growth. Hence, maximum plant densities for oil yield (140–160 palms per ha) are lower than those for maximum total dry matter production. Planting palms 9 m apart in a triangular pattern gives 143 plants/ha.

Husbandry The inter-rows in oil-palm fields have to be slashed regularly, especially in fields with young palms. Weeding is practised around palms, manually or by applying herbicides, to prevent competition from the cover crop. Clean ring-weeding also facilitates the detection of loose fruits from ripe bunches. Harvesting paths are kept open. During harvesting of bunches, leaves are usually removed as well. If the number of leaves per palm drops below 35, yield declines. Hence the aim is to maintain the number of leaves close to 40. Pruned leaves are generally stacked between palms within or between the rows and provide mulch together with ground cover. As the canopies close in mature plantations, the legume cover is gradually replaced by natural vegetation, often consisting of a mixture dominated by various grasses and ferns. Increased use of herbicides instead of hand weeding leads to replacement of the less competitive grass-fern cover by more noxious broad-leaved weeds (*Asystasia* spp., *Diodia* spp., *Mikania* spp.). Intercropping oil palms with annual food crops during the first few years after planting is a common practice among small farmers, mainly in Africa.

Considering the importance of moisture supply, oil palms will undoubtedly benefit from irrigation, depending on the severity and length of dry periods. Substantial areas of oil palm are under irrigation in southern India and Colombia where water deficits during the dry period are compensated for by high numbers of sunshine hours and good yield results.

The root system of young palms is not sufficiently developed to exploit a large volume of soil. Regular complete (NPKMg) fertilizer applications are therefore recommended during the first three years after planting to boost vegetative growth. Nutrient requirements of adult palms vary considerably with soil and climatic conditions, as well as with yield levels. The gross annual uptake of nutrients by adult oil palms grown on a marine clay in Malaysia and yielding 25 t/ha of fruit bunches was: 1.4 kg N, 0.2 kg P, 1.8 kg K, 0.4 kg Mg and 0.6 kg Ca per palm. About 30–40% of that is removed by the harvested bunches, 25–35% is returned to the soil as dead leaves and male inflorescences and the rest is immobilized in the trunk. Foliar analysis (sampling a few leaflets from leaf 17) in oil palm in combination with the results of local fertilizer trials, is a reliable diagnostic tool to determine types and rates of fertilizer applications for mature oil palms long before deficiency symptoms on leaves become apparent. Generally nitrogen and potassium are the most important nutrients for maintaining growth and yield. Significant responses to phosphorus and magnesium are less common, but these are often included in fertilizer application as a precautionary measure. In plantations in Malaysia, 2–4 kg N fertilizer and 1.5–3 kg K fertilizer per palm are commonly applied annually. On the other hand, fertilizer requirements of palms on the nutrient-rich volcanic soils in parts of Sumatra are much lower. The need for micro-nutrients is less well established for oil palm. Well-documented cases of boron deficiency and suspected incidents of copper deficiency on peat soils have been reported.

The oil palm is a fairly labour-intensive crop. Optimum management requires about one field worker per 4 ha, but in Malaysia this has been decreased to approximately one per 10–12 ha. The need for increased mechanization of field operations becomes evident in a number of regions with a labour shortage. Most field maintenance operations can be mechanized, but there are no economically viable methods available for mechanically removing the ripe bunches from the palms.

Diseases and pests In the nursery, oil palm seedlings are affected by a number of fungal diseases, which however can be controlled by cultural and fungicidal treatments. The most important are anthracnose (caused by *Botryodiplodia* spp., *Glomerella* spp. and *Melanconium* spp.), seedling blight (caused by *Curvularia* spp.), Cercospora leaf spot (caused by *Cercospora elaeidis*) which is restricted to Africa and blast (a root disease caused by *Rhizoctonia lamellifera* and *Pythium* spp.). Crown disease is a physiological disorder causing leaf distortion in 2–4-year old palms, particularly of the Deli origin, and having a severe effect on early development and yield. Breeding for crown disease-free palms is possible, as susceptibility is inherited by a single recessive gene.

The most important disease in adult palms in South-East Asia is basal stem rot caused by *Ganoderma* sp., which may cause high losses, especially when replanting on land previously under coconut, but also after oil palm. Infection takes place through root contact with decaying stems and roots. Control is limited to sanitary measures, such as complete removal of all stumps and roots before new planting and removal of diseased palms in plantations.

Vascular wilt (caused by *Fusarium oxysporum* f.sp. *elaeidis*) occurs only in Africa, mostly in areas marginal to oil-palm cultivation. Breeding for resistance has resulted in some degree of success. Lethal bud rot (often with few leaf symptoms) and sudden wither are two serious diseases of oil palms in Central and South America. The causes are unknown or uncertain. A promising method of control is planting resistant *E. oleifera* × *E. guineensis* hybrids.

Strict plant quarantine measures (e.g. seed treatment) are taken to prevent the inadvertent introduction of such diseases as Fusarium wilt and Cercospora leaf spot into South-East Asia.

Most insect pests in South-East Asia are controlled by integrated pest management. Techniques include close monitoring, biological control and spraying with narrow-spectrum insecticides to prevent major epidemics. Occasional outbreaks of bagworms (*Psychidae*, e.g. *Cremastopsyche pendula, Mahasena corbetti* and *Metisa plana*), nettle and slug caterpillars (*Limacodidae*, e.g. *Darna trima* and *Setora nitens*) occur notably in Sabah and Sumatra. The rhinoceros beetle (*Oryctes rhinoceros*) has readily adapted to the oil palm. Good ground cover and the destruction of breeding sites generally ensure adequate control. Other insects occasionally cause some damage like oil-palm bunch moth (*Tirathaba mundella*), root-feeding cockchafers (*Adoretes* and *Apogonia* spp.) and grasshoppers (e.g. *Valanga nigricornis*). The leaf miner (*Coelaenomenodera elaeidis*) and the weevil *Rhynchophorus phoenicis* are serious oil-palm pests of West Africa, while leaf eating caterpillars (e.g. *Darna metaleuca* and *Sibine fusca*), root miner caterpillars (*Sagalassa valida*) and the beetle *Strategus aloeus* are damaging insect pests in the American continent.

Rats are sources of problems in many plantations. Control is carried out by rat baiting. The barn owl (*Tyto alba*) is also used to prey on rats and nest boxes are placed in the plantation.

Harvesting Under normal plantation conditions, harvesting of bunches of oil palm starts about 2.5 years after field planting in South-East Asia and after 3–3.5 years in West Africa. It is common practice to remove the first series of unopened female inflorescences from the young palm, by one round of so-called ablation with a special tool, to promote vegetative growth. The first bunches are small and have a low oil content anyway. Bunches ripen throughout the year and harvesting rounds are usually made at intervals of 7–10 days when they reach the optimum degree of ripeness. A practical indicator of ripeness is the number of loose or detached fruits per bunch, which should be 5 during the first three years of fruiting when bunches are still relatively small, to 10 for older palms. In young oil palms bunches are cut from the stalk with a chisel; in old palms with a Malayan knife that consists of a sickle attached to a long bamboo or aluminium pole. Loose fruits must be gathered from the ground because they also yield oil. So far, high costs have discouraged the use of mechanized forms of harvesting. Bunches are transported to collection sites along the road and from there, direct to the mill by road or rail track.

Yield World average yields per ha in the year 2000 were 3.3 t palm oil and 0.8 t palm kernels (45% oil and 55% meal). National averages for palm-oil yields per ha are 4.1 t in Papua New Guinea, 3.8 t in Colombia and Malaysia, 3.3 t in Indonesia, 2.9 t in Ivory Coast and 1.3 t in the Democratic Republic of Congo. Oil palm is extremely responsive to environmental conditions and yields therefore vary greatly. Over time, however, yields show a clear trend of rising to a maximum in the first four years of production and usually declining slowly thereafter. In well-managed mature plantations in Malaysia, Indonesia and Papua New Guinea, annual bunch yields of 24–32 t/ha are common. At a factory oil extraction rate of 22% (Tenera fruit type), this represents palm-oil yields of 5.3–7.01 t/ha. In West Africa with less favourable climatic conditions (substantial dry season), annual bunch yields of 12–16 t are obtained or 2.6–3.5 t of oil per ha, which is nevertheless still much higher than for any other vegetable oil crop.

Handling after harvest Palm-oil mills process fruit bunches to oil and kernels through the following stages:

- sterilizing bunches with steam under pressure to loosen the fruits, destroy the lipolytic enzyme lipase to arrest free fatty acid formation and kill all micro-organisms;
- stripping of the fruits from the bunches;
- digesting the fruits and reheating the macerated mix of pulp and nuts;
- extracting oil by hydraulic or (double) screw presses;
- clarifying to remove water and sludge from the oil in continuous clarification tanks or by centrifugal separation and drying;
- storing of the crude palm oil in large tanks before transport for further processing.

Nuts are separated from the presscake, dried, graded and fed into centrifugal crackers to remove the shell. Kernels are extracted for oil in separate mills, locally or abroad, by methods similar to that for copra.

Genetic resources Almost all present oil-palm planting materials in Malaysia, Indonesia and elsewhere in South-East Asia have been developed from the genetically very narrow Deli Dura population and one source of Pisifera (the Djongo Tenera palm from Yangambi in the Democratic Republic of Congo). Oil-palm research centres in West Africa had easier access to germplasm, but except at the Nigerian Institute for Oil Palm Research (NIFOR), most breeding programmes started from genetically restricted base populations. Increasing awareness of the importance of oil-palm genetic resources for future breeding progress led NIFOR to mount collecting expeditions in 1956 and 1964 and a very large one in collaboration with the Malaysian Palm Oil Board (MPOB, formerly PORIM and MARDI) in 1973, all in south-eastern Nigeria, the centre of highest genetic diversity. MPOB organized another 9 expeditions in the oil-palm belt from Angola to Senegal and even in Tanzania and Madagascar during the period 1984–1994. It also collected *E. oleifera* germplasm from Central and South America in 1982. The MPOB has the largest oil-palm germplasm collection in the world with 1780 accessions (61% from Nigeria and 21% from the Democratic Republic of Congo maintained on 400 ha of field trials at the research station near Kluang, Johore. Another large field collection of more than 1000 accessions is maintained by NIFOR near Benin city, Nigeria. The National Centre for Agricultural Research (CNRA) in Ivory Coast maintains a collection of more than 200 accessions. Other public and private oil-palm research centres in Asia, Africa and America also try to enlarge their genetic resources. Free exchange of germplasm by seed or pollen is general practice among research centres, and strict quarantine rules are followed to avoid inadvertent introduction of new diseases and pests.

Breeding Oil-palm breeding has progressed from simple mass selection (families and individual palms within the best families) to various forms of (reciprocal) recurrent selection for Dura and Pisifera palms as parents for higher-yielding Tenera planting material. Estimates of selection progress for oil yield in the Deli Dura populations of Indonesia and Malaysia are 50–60% over 3–4 generations of mass selection (1910–1960). The change to Tenera planting material in the early 1960s resulted in an instant yield increase of another 20% because of the jump in oil extraction rates from 18% in Dura to 22% in Tenera fruit bunches. Similar developments took place in Africa.

Extensive quantitative genetic studies in the 1960s and 1970s carried out in large breeding programmes of NIFOR in Nigeria and Ghana, CNRA (formerly IRHO) in Ivory Coast and the Oil Palm Genetics Laboratory (OPGL, now MPOB) in Malaysia confirmed the largely additive inheritance of all yield components. This allows breeders to make estimates of genotypic (breeding) values for these components for a large number of parents by a minimum number of crosses and so reduce the costs of progeny testing. Another observation relevant to selection progress in the oil palm is the generally insignificant genotype × environment interaction effects for yield and its components. Selection progress for yield is maximized by combining parents with contrasting yield components, such as the Deli × African 'interorigin' crosses, which combine a relatively low number of heavy bunches with a high number of smaller bunches. Further selection progress requires the development of new contrasting subpopulations, more particularly to increase the genetic variability of the Deli Dura population (and also the source population of Pisiferas in Asia) by introgression with other 'African' germplasm. In the Malaysian and some other breeding programmes, considerable selection efforts are being directed to vegetative growth components to improve harvest index and to reduce height increment for the further increase of oil yields and reduction of production costs. Germplasm evaluation in Malaysia has revealed highly productive (up to 10 t/ha of oil) and short-stemmed (height increment of 20–25 cm/year against 45–75 cm/year for present planting material) families of south-east Nigerian origin. The heritability of height increment is high, as is that of fruit quality components (mesocarp, shell and kernel content) and fatty acid composition of the palm oil, thus allowing effective phenotypic selection of parents.

Conventional plant breeding that exploits genetic diversity within the genus still offers considerable opportunities for improvement. Further development of high density genetic linkage maps for the oil palm, using advanced marker technology (e.g. microsatellites) will enable the identification of significant QTLs (quantitative trait loci) for yield and growth components to increase efficiency of selection, such as preselection at the nursery stage. The Malaysian Oil Palm Board has initiated research projects on genetic transformation in the oil palm. Objectives include resistance to herbicides and diseases (e.g. *Ganoderma*) and changing the fatty acid composition of the palm oil (e.g. high oleic acid content). Increased understanding at the molecular level may help to control flower abnormalities in clonal offspring after in-vitro embryogenesis and so make large-scale clonal propagation possible in the oil palm.

Prospects The prospects for the oil palm appear bright. The demand for vegetable oils is rising as the standard of living increases in parts of the Third World. As a crop, it is better suited than annual food crops to most soils in the humid tropics, which are prone to leaching. It provides continuous ground cover and ecological conditions similar to the original forest vegetation. Further increases in yield may also be expected. Extrapolations from crop-growth models suggest that the physiological potential for oil yield of the oil palm may well be 12–14 t/ha against present maximum yields of 7 t/ha. The new possibility of clonal propagation is an important factor in this respect.

In most countries with a suitable climate, oil-palm cultivation is expanding. The main drawback of the oil palm is the difficulty of cost-effective mechanization, notably of harvesting operations. Hence, availability and cost of labour may well become the main limiting factors in countries with improving standards of living.

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Garcinia L.

Sp. pl.: 443 (1753), Gen. Pl. ed. 5: 202 (1754).
GUTTIFERAE (Clusiaceae)
$x = 8, 16$; *G. indica*: $2n = 48$

Major species and synonyms

- *Garcinia indica* (Thouars) Choisy in DC., Prodr. 1: 561 (1824), synonyms: *Brindonia indica* Thouars (1804), *Garcinia microstigma* Kurz (1877).
- *Garcinia morella* (Gaertn.) Desr. in Lamk, Encycl. 3: 701, t. 405, f. 2 (1792), synonyms: *Mangostana morella* Gaertn. (1790), *Garcinia lateriflora* Blume (1825), *G. gaudichaudii* Planch. & Triana (1860).

Vernacular names

- *G. indica*: kokam butter tree, Goa butter, mangosteen oil tree (En). Brindonnier (Fr).
- *G. morella*: tamal, Indian gamboge tree, Mysore gamboge tree (En). Indonesia: kemenjing kebo (Javanese), jawura, manggu leuweung (Sundanese). Malaysia: kandis (Peninsular). Philippines: maladambo (Tagalog), ugau (Bikol), kandis (Manobo).

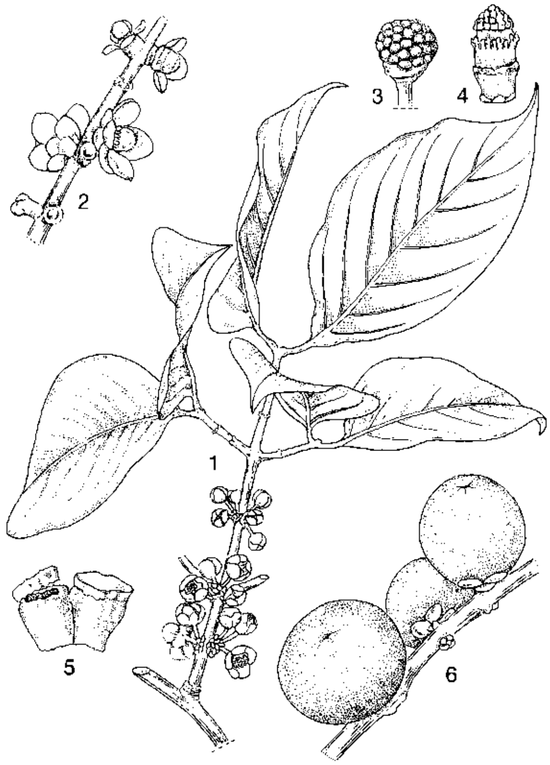
Origin and geographic distribution *Garcinia* is a large genus that occurs mainly in the Old World tropics. South-East Asia hosts about half the total number of species and is the major centre of diversity. *G. indica* probably originates from India (Western Ghats). It is also cultivated in India (lower slopes of the Nilgiri hills, West Bengal and Assam) and many other tropical Asian countries, including islands in the Indian Ocean. *G. morella* is widespread, from Sri Lanka, India, Bangladesh and southern China throughout northern South-East Asia, but is not cultivated.

Uses *G. indica* and *G. morella* both have multifarious uses. Their seeds are sources of edible fat known as 'kokam butter' or 'kokam fat' for *G. indica* and 'tamal' for *G. morella*. Kokam butter is used as a confectionery butter but because it solidifies with a rough surface it is often mixed with other fats. Kokam butter is also used as an adulterant of ghee (Indian clarified butter) and as an extender of or alternative for cocoa butter. Medicinally and in cosmetics, kokam butter is made into creams that are applied to ulcers, cracked lips and hands. Low-quality, non-edible grades of kokam butter are used to make candles and soap. The sweet and sour dried rind of the fruit of *G. indica*, also called kokam, is added to curries as a condiment and is processed into juices and syrups. In medicine, the fruit of *G. indica* is used as an anthelmintic and to treat piles, dysentery, tumours, pains, heart problems, gall bladder problems and age- related diseases such as diabetes.
Tamal fat is mainly used in cooking as a substitute for ghee. It is somewhat softer than kokam butter and less suitable for confectionery. It is also a source of stearin and is made into soap with fairly good lathering and detergent properties. The fruit pulp of *G. morella* is eaten. After wounding, the bark of *G. morella* exudes a brilliant golden-yellow resinous sap, called 'gamboge', which is used for dyeing and as a colouring agent for varnish, lacquer, paints and ink. It can be used in watercolours as it emulsifies well in water. In Burma (Myanmar) robes of monks are dyed with it. Gamboge is rarely used medicinally at present but it has purgative, emetic and vermifuge properties. Sap from the root is applied to heal cuts.
The seed cake of both species remaining after oil extraction is a very good and cheap cattle feed and a fertilizer. Cake of kokam seed is added to feed concentrates for lactating cows. The greyish-white wood of *G. indica* is suited for paper pulp, that of *G. morella* is made into boxes and temporary structures. In South- East Asia, *G. morella* is also used as vigorous rootstock for mangosteen (*G. mangostana* L.). When kokam seed cake was combined with urea and applied to a dry-season rice crop in India, the recovery of N increased by 25%. The seed cake can also be recycled through anaerobic fermentation to produce biogas and enriched manure. It can be used to substitute cowdung for up to 33% without reducing biogas production.

Production and international trade Annual kokam seed production in India (Western Ghats) has been estimated at about 500 t, producing about 200 t kokam butter. Some export of the condiment kokam (dried rind) from India to Zanzibar is reported, but kokam butter hardly enters international trade. No statistics are available for tamal or Indian gamboge.

Properties Total lipid content of dry seed of *G. indica* is about 50% and comprises about 88% neutral lipids, 4 % glycolipids and 3% phospholipids. The neutral lipids consist of 85% triglycerides, 8% free fatty acids and 3% diglycerides. The fatty acid composition is approximately stearic acid (38–56%), oleic acid (30–53%) and lesser amounts of palmitic and linoleic acids. The glycolipids are primarily digalactosyl diglyceride (40%) and monogalactosyl diglyceride (20%), while the main phospholipid is phosphatidyl ethanolamine (75%). The fat has a very distinct melting point (39.5–40°C) which is near the melting point of pure oleodistearine. At room temperature, the fat is solid, hard and greyish. Kokam butter is traded as light grey or yellowish, egg-shaped balls with a greasy feel and bland oil taste. Refined and deodorized kokam butter is white and compares favourably with other fats. When kokam butter is combined with a smaller amount of 'phulwara butter' obtained from seed of *Diploknema butyracea* (Roxb.) H.J. Lam (synonym *Madhuca butyracea* (Roxb.) J.F. Macbride) or with 'mowra butter' obtained from seed of *Madhuca longifolia* (Koenig) Mcbride, the resulting blend has properties similar to cocoa butter but is somewhat harder and more suitable for hot climates. Kokam butter has also been modified by lipase-catalyzed ester interchange to produce an interesterified fat that is similar to cocoa butter in solid fat content and melting temperature. The sweet and sour dried rind of the fruit of *G. indica* used as a condiment contains 10–30% (–)hydroxy-citric acid (HCA), the source of its sour taste. The acid may have a regulatory effect on obesity and appetite. Garcinol, one of the components of the fruit rind of *G. indica*, has anti-oxidative and anti-glycation activities, possibly accounting for positive results in treating age-related diseases such as diabetes. Fat-soluble yellow pigments such as cyanidin-3-sambudioside and cyanidin-3-glucoside have also been identified in the fruit rind. The seed cake remaining after oil extraction has 70% digestible nutrients, including 9–17% crude protein and 4% crude fibre.

Tamal fat from *G. morella* is brownish-yellow. The fatty acids are mainly stearic acid (46%) and oleic acid (50%). Its melting point is only 33°C and its consistency is more plastic than kokam butter, not breaking with a sharp crack at ambient temperatures. All parts of *G. morella* contain gamboge, a red-yellow or brown-orange, odourless, tasteless or slightly acidic resin, with a smooth, uniform conchoidal fracture. Gamboge forms a yellow emulsion with water and a clear, dark orange one with weak ammonia. It can be dissolved by adding alcohol and water and this solution can be transformed into solid form by adding acid. Commercial gamboge has the following characteristics: specific gravity 1.22, acid value 65–90, ester value 45–65, saponification value 125–145, ash content 1% and water content 3–5%. One constituent of gamboge is gamboge acid which has shown anticancer activity in experiments. The pericarp, stem bark and leaves of *G. morella* show antibacterial activity against *Staphylococcus aureus* and this action is primarily attributed to the yellow pigment morellin.



Garcinia morella (Gaertn.) Desr. – 1, leafy branch with male flowers; 2, branch with female flowers; 3, androecium (male flower); 4, gynoecium with staminodes (female flower); 5, transversal opening of anthers; 6, branch with fruits.

Description Dioecious evergreen trees. Trunk straight, tapering to the top of the conical crown. Branches arranged in alternating pairs, arising from the trunk at an acute angle, later becoming horizontal or pendent. In the forest branches are restricted to the upper part of the trunk, remnants of lower branches persist for a long time as woody knobs. White or yellow, thick, sticky latex is present in all parts. Leaves decussate, successive pairs at maturity in one plane by torsion of the twigs, the petiole with a basal foveola. Flowers axillary, polygamous-dioecious, regular, sepals and petals 4–5; male flowers with various numbers of stamens, filaments connate into one central column or into 4–5 bundles, pistil rudimentary or lacking; female flowers usually larger than male ones, usually solitary, staminodes with filaments connate into a ring at the base or into 4–5 short bundles; ovary 2–12-celled with 1 ovule per cell, style short or absent, stigma peltate, 2–12-lobed or incised, usually papillate. Fruit a berry with 1–12 seeds. Seeds large, usually enveloped in a juicy arillode; embryo a solid mass representing the hypocotyl, cotyledons absent.

- *G. indica*. Tree 10(–15) m tall, trunk blackish, usually buttressed. Leaves red when young, turning shiny dark green above and pale beneath; petiole 5–12 mm long; blade lanceolate or ovate-oblong, 6.5–11 cm × 1.5–5 cm, apex acuminate. Flowers solitary or in fascicles, unisexual per tree, small, 4–8 mm in diameter, white; bracts scale-like, caducous; sepals 4, ovate-rotundate, 3–5 mm long, the outer two smaller than the inner ones, thick, fleshy, yellowish to pink-orange; petals 4, 5–6 mm long, thick; male flowers with 10–20 stamens joined into a central column; female flower on pedicel 3 mm long, staminodes 1–3 mm long, ovary subglobose, 4–8-locular, stigma sessile. Fruit a globose berry, 2.5–4 cm in diameter, dark purple to pink when ripe, surrounded by persistent sepals. Seeds 5–8 per fruit, compressed.
- *G. morella*. Tree, up to 20 m tall; trunk diameter 50 cm but usually much smaller, glabrous in all parts. Inner bark up to 1 cm thick, white to pale yellow, containing plenty of brilliant yellow, sticky latex. Leaves coriaceous, entire; petiole up to 2 cm long, foveola conspicuous with prominent margins; blade obovate to oblanceolate, 9–24 cm × 5–10 cm, base tapering, apex usually obscurely acuminate, lateral veins on lower surface prominent, parallel, 8–14 mm apart, in 7–8 pairs. Flowers subsessile, solitary (female) or 2–3 together (male), per tree unisexual; sepals 4, 5 mm long; petals 4, elliptical, 5–8 mm long, fleshy, white to pink; stamens in male flowers in a monadelphous central column with free red anthers; female flowers with sessile peltate stigma, base of ovary surrounded by about 15 free staminodes. Fruit a globose berry, up to 3.5 cm in diameter, at base surrounded by the persistent sepals, at apex crowned by the flat tuberculate stigma, smooth, yellowish; exocarp thin; fruit pulp edible, acid-sweet, containing 2–3 seeds. Seed kidney-shaped, laterally compressed.

Growth and development In India, *G. indica* flowers from November to February and fruits from April to May; anthesis is in the early morning from 06.00–08.00 h, anther dehiscence occurs 15–20 minutes before anthesis. Flowering and fruiting of *G. morella* in southern India is from November to July; fruiting can persist until December. In Indonesia, flowering is in August, fruiting in November. Agamospermy (seed apomixis) is common in *Garcinia*: many species can produce seed asexually as well as sexually, but the reproductive biology of the genus is still not well-understood. Many wild species flower at night and have a characteristic strong odour.

Other botanical information As long as no taxonomic revision of *Garcinia* is available, confusion in the literature about correct names and synonyms will continue. Estimates of the total number of species vary between 100 and 400. *G. hanburyi* Hook.f. (syn. *G. morella* (Gaertn.) Desr. var. *pedicellata* Hanbury) is closely related to *G. morella* and information cannot always be accurately assigned to one of them. *G. hanburyi* occurs in Thailand and Indo-China and is the major source of gamboge. In Sri Lanka and possibly also in southwestern India, *G. echinocarpa* Thwaites also has seed rich in fat (60%). The fat is known as 'madol' and can be used in the same way as kokam butter. The tree can easily be recognized because it grows in wet places, always bearing stilt roots. *Garcinia* is polygamous-dioecious (bisexual, male and female flowers in certain combinations in the same and in different trees) but it is unclear whether *G. indica* and *G. morella* also have bisexual flowers.

Ecology *G. indica* prefers a per-humid tropical climate with 6–10 rainy months per year and a total annual rainfall of 2500–5000 mm. It thrives under mean maximum temperatures of 20–30°C, in partial shade, at altitudes up to 800 m, but it also occurs naturally at higher altitudes. *G. morella* grows both in dry and in humid forest in the tropics and subtropics. Trees in dry zones are often stunted, stiff with divaricate branches and thick nodes and the leaves are less fleshy. It occurs from sea-level up to 1100 m elevation.

Propagation and planting *G. indica* is usually propagated by seed. It can also be propagated vegetatively by softwood grafting. High-yielding cultivars that flower early and are short in stature exist. In India, preferably in October, mature scions (5–6 months old) and rootstock (more than 5 months old) are used. Grafted seedlings can be planted in the field in June–July for optimal establishment and a spacing of 6 m × 6 m is recommended for planting 1-year old grafted kokam.

Husbandry No information is available on the husbandry of *G. indica*. *G. morella* only occurs in the wild.

Diseases and pests In Java (Indonesia), sooty moulds (caused by *Clypeolum vulgare*) and leaf spot disease (caused by *Gloeosporium garciniae*) have been observed in *G. morella*. However, no serious diseases or pests are recorded.

Harvesting No information on fruit collection is available. For the harvest of gamboge, *G. morella* trees can be tapped when 10 years old by making a spiral incision in the bark and collecting the latex in a small container (e.g. of bamboo).

Yield For *G. indica*, the kokam butter yield and the number of fruits per tree vary with the cultivar. A maximum yield of nearly 50 kg/tree has been recorded in India. For G. *morella*, no information on the yield of tamal butter or gamboge is available.

Handling after harvest Newly harvested fruits of *G. indica* are reddish-green and turn full red-purple after about two days. Kokam butter extraction is mostly a cottage industry, where the seeds are crushed, boiled in water and the fat skimmed off. The fat is made into egg-shaped balls and is mostly sold without further cleaning or processing. The normal shelf life of fresh *G. indica* fruits is about five days. To produce the dried rind, fruits are dried in the sun immediately after harvesting. The fruit is cut in half and the fleshy portion and the seeds are removed. During preparation the rind, which constitutes 50–55% of the fruit, is soaked several times in the juice of the pulp and dried again. About 6–8 days are required for complete drying. The resulting product is the condiment kokam of commerce.

Genetic resources *G. indica* is included in the list of endangered plants of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), but not enough information is available to specify how seriously it is endangered. Germplasm collections for *G. indica* or for *G. morella* are not known to exist.

Breeding Some initial selection work on *G. indica* has been done in India and a clone with high yield, short harvesting period and large fruits with a long shelf life has been selected.

Prospects *G. indica* and *G. morella* are multipurpose trees which have not been fully exploited and are poorly known. The use of kokam butter of *G. indica* as an alternative or additive for cocoa butter deserves research attention in South-East Asia. The pharmaceutical value of both *Garcinia* spp. also deserves further investigation.

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S. Gopakumar

Guizotia abyssinica (L.f.) Cass.

Dict. Sci. Nat. 59: 248 (1829).

COMPOSITAE

$2n = 30$

Synonyms *Polymnia abyssinica* L.f. (1781), *Ramtilla oleifera* DC. (1834), *Guizotia oleifera* (DC.) DC. (1836).

Vernacular names Niger seed, niger, ramtil (En). Nigèr, guizotia oléifère (Fr).

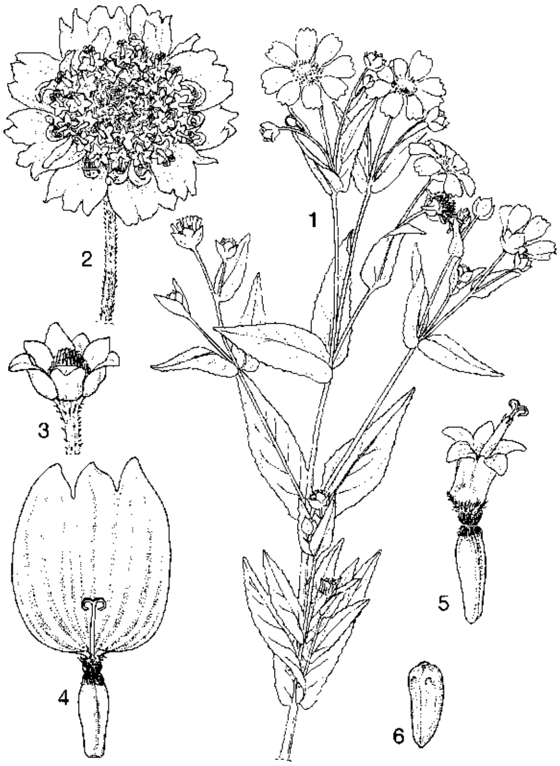
Origin and geographic distribution Niger seed originated from *G. schimperi* Sch. Bip. (synonym *G. scabra* (Vis.) Chiov. subsp. *schimperi* (Sch. Bip.) J. Baagøe) through selection and cultivation. Niger seed was probably domesticated before 3000 BC in the highlands of Ethiopia where it is cultivated as an oilseed crop and still grows wild. From there, traders brought it to India before the Christian era. It is now grown extensively in Ethiopia, India and Nepal and on a smaller scale in parts of montane eastern and southern Africa, the West Indies, Bangladesh, Bhutan, and possibly Pakistan. In the 19th Century it was also grown in Europe. Niger seed has been tested in Bogor (Indonesia), but this did not lead to its cultivation in Indonesia.

Uses Niger seed (a popular name for the fruits of *G. abyssinica*, but also used for the whole plant) is a valued source of edible oil. In Ethiopia, half of the total production of edible oil comes from niger seed and the oil is used in many dishes. In India it is mainly a substitute for or extender of sesame oil and contributes only 3% in the national edible oil production. Niger seed is eaten fried, prepared into chutneys, condiments and porridge, mixed with pulses to make snack foods and ground to produce flour and beverages. The seed is also an important component of birdseed mixtures. Aside from cooking, the oil is utilized in illumination, medicine and cosmetics, as well as in making paint and soap and to a limited extent in lubrication. In traditional medicine the oil is used in birth control and to treat syphilis. A medical test for the identification of the fungus *Cryptococcus neoformans*, which causes a serious brain disease, is carried out on a niger seed-based agar medium. Niger seed sprouts mixed with garlic and honey are taken to treat cough. The whole plant is grown as a fodder for sheep. Cattle refuse to eat the green plant but accept it as silage. Niger seed is also grown as a green manure. Niger seed cake is fed to animals and is used as a fuel. The roots have a suppressant effect on weeds, also in subsequent crops.

Production and international trade Statistical data on the production of niger seed vary greatly and should be interpreted with care. Its production is concentrated in India and Ethiopia which have a total annual production of 350 000–375 000 t. Ethiopia harvests 200 000–250 000 t yearly while India produces 80 000–180 000 t, probably excluding seed used for home consumption. Annual niger seed oil produced by India reaches 40 000–50 000 t. In recent years there have been wide variations in the production of niger seed in Ethiopia and this accounts for its fluctuating exports (from nil to 20 000 t annually) to Europe (especially Italy) and Japan.

Properties Per 100 g, the 'seed' (botanically an achene) of niger contains: water 6–8 g, protein 17–19 g, fat 30–50(–60) g, carbohydrates 34–40 g, fibre 13.5 g, ash 2–8 g, Ca 50–470 mg, P 180–800 mg, niacin 3 mg, riboflavin 0.6 mg and thiamine 0.4 mg. The oil content of unimproved traditional cultivars is about 25–45%, in improved cultivars it reaches 60%. In Ethiopia, the average oil content of niger seed is 45%. The oil consists of 20% saturated fatty acids, 80% unsaturated fatty acids, 0.4–3% free fatty acids and 0.5–1.0% unsaponifiable matter. The major fatty acids are: palmitic acid about 10%, stearic acid about 8%, oleic acid 5–8% and linoleic acid 65–85%. Palmitoleic acid, linolenic acid, arachidic acid, eicosenoic acid, behenic acid, erucic acid and lignoceric acid make up the remaining 2–3% of the oil. The oil has a solidification point between −9 and −15°C, and iodine value of 126–139. It is slow-drying, clear, pale yellow, odourless or with faint sweet fragrance and has a nutty taste. Oil from Indian cultivars has a higher oleic acid (30%) and a lower linoleic acid (50%) content than oil from Ethiopian cultivars.
Niger seed cake contains per 100 g: protein 24–34 g, fat 4–14 g, carbohydrates 20–28 g, fibre 8–24 g, ash 8–12 g, N 5 g, P 0.9 g and K 1.3 g. Seed cake from India tends to have a higher protein and a lower fibre content than that from Ethiopia. The amino acid composition of the protein is fairly balanced although different tests show different amino acids to be deficient. Niger seed roots contain a water-soluble compound that has an allelopathic effect on monocotyledons thereby reducing weed incidence in the following crops. The weight of 1000 seeds (achenes) is 2–5 g.

Description A stout, erect, well-branched, variable annual herb, up to 2 m tall, smooth to slightly scabrid. Root system well-developed, with taproot and many laterals, particularly in upper 5 cm. Stem terete, hollow, up to 2 cm in diameter, light green, often purplish stained or dotted, becoming yellow with age, puberulous to pilose with multicellular white hairs. Leaves opposite, uppermost ones sometimes alternate, sessile and clasping half the stem; blade lanceolate to narrowly ovate or obovate, 3–23 cm × 1–6 cm, base truncate to cordate, margin entire to serrate, ciliate, apex tapering, softly hairy on both surfaces, usually dark green but lower leaves show distinct yellow tinge. Inflorescence a cup-shaped head (capitulum), 1–3 cm in diameter, axillary or terminal, grouped like corymbose cymes, surrounded by leafy involucral bracts arranged in various rows; peduncle up to 14 cm long, densely pilose near the head; outer involucral bracts usually 5, broadly ovate to obovate-elliptical, up to 3 cm long, margin ciliate, 5–9-veined; inner bracts scarious (thin, not green), obovate, up to 1 cm long, 7–9-veined, progressively smaller and finally merging into the flattened, 5-



Guizotia abyssinica (L.f.) Cass. – 1, flowering branch; 2, flowering head (top view); 3, flowering head (side view); 4, ray floret (female); 5, disk floret (bisexual); 6, fruit (achene).

veined paleae of the receptacle; flowers of two types, 6–15 female ray florets at the outer part of the receptacle and 40–60 bisexual disk florets which are arranged in 3 whorls in the central part; ray floret with tube 2 mm long, ligule obovate to rectangular with 3 teeth, 14–21 mm × 5–6 mm, bright yellow, becoming more golden with age, ovary 4–4.5 mm long, with 4 longitudinal ribs, style up to 7 mm long, stigma with 2 branches 2 mm long; disk floret with lower part of tube up to 1.5 mm long, upper part slightly campanulate, 2–3 mm long with 5 acute lobes, yellow to orange; stamens 5, inserted at the base of the limb, filaments flattened, 2 mm long, bent twice near the anthers, anthers orange, cohering, with apically an acute appendage; ovary 3.5–4.5 mm long, 4-ribbed, style about 5 mm long, stigma 2-branched; florets at the outer part opening first, followed progressively by the next in line to the centre of the head. Fruit (often called seed) an achene, obovoid, club-shaped, 3–5 mm × 1.5 mm, 4-angled in transverse section, without pappus, glossy black but sometimes mottled; usually a head contains 15–30 mature achenes and a varying number of immature ones at the centre. Seedling with epigeal germination.

Growth and development The seed of *Guizotia abyssinica* germinates in a few days and the young plant grows immediately to an erect habit. The first side-shoots are formed when plants have 6–8 leaves and are about 30 cm tall. Most forms of niger seed are short-day plants with only few day-length-insensitive individual plants. The critical day length is about 12 h. Under short days flowering starts about 60 days after germination. Photoperiodic sensitivity is stronger in Ethiopian than in Indian cultivars. Another difference between Indian and Ethiopian cultivars is that induction of flowering in Indian plants probably takes place at an earlier stage of development. Short days 1 month after sowing gave full induction in Indian material but no induction in Ethiopian plants. In the latter, induction took place 55–75 days after sowing. In Ethiopian cultivars high temperatures delay flowering; this was not found in Indian cultivars. Flowers are pollinated by insects, mostly by bees. Although the style of the disk floret is covered with pollen when emerging, self fertilization is rare as the pollen does not cover the receptive part of the stigma and because plants are self incompatible. In Ethiopia a single head flowers for about 8 days; a field takes about 6 weeks to complete flowering. From flowering to maturity takes 45–55 days. Niger seed matures in 120–180 days after emergence in Ethiopia and in 75–120 days in India depending on the cultivar or landrace. Individual plants that are early maturing shed seeds even before others are mature.

Other botanical information *Guizotia* Cass. is genus of about 7 species classified in the tribe *Heliantoidae* of the *Compositae*. *G. abyssinica* is closely related to, partly sympatric and fully interfertile with *G. schimperi*; it could possibly be considered a cultivar group within *G. schimperi*. Distinguishing characters for *G. abyssinica* are the combination of its annual habit, its heads arranged like corymbose cymes, its 5 outer ovate to obovate-elliptical involucral bracts, its plane 5-veined paleae and its 3–5 mm long achenes. The Ethiopian and Indian gene pools of *G. abyssinica* differ as a result of long-term geographical isolation, the former being more variable. Indian niger seed flowers and matures earlier and has higher seed weight. Forms grown in Ethiopia mature later, are taller and higher yielding. Three different types of niger seed are recognized in Ethiopia:

'abat nough' (grown during the rainy season in well-drained soil), 'mesno noug' (grown in September to January in high rainfall, waterlogged areas) and 'benenge noug' (grown in July to October in more dry lowland). In north-eastern India 3 growing seasons per year for niger seed are also recognized: 'kharif', early 'rabi' and late 'rabi'. Well-known improved cultivars in India are: 'Ootacamund', 'Gaudaguda', 'No. 71' and 'RCR-317'. A few of the niger seed varieties in Ethiopia are 'Sendafa', 'Esete-1', 'Fogera-1' and 'Kuyu'.

Ecology While niger seed originated in the tropical highlands of eastern Africa, it has adapted to the tropical and sub-tropical lowlands in India and to temperate conditions in Europe. Optimum yields are obtained in Kenya at altitudes of 2000–3000 m and in Ethiopia at 1600–2200 m, where average maximum temperatures during the growing season are 22–24°C. In India best yields are obtained below 1000 m altitude, with temperatures of 18–23°C. Rainfall of 1000–1300 mm is optimum and more than 2000 mm rainfall may result in depressed yield. Niger seed is adapted to a wide range of soils but grows best in clay loams or sandy loams with a pH of 5.2–7.3. It is often cultivated on poor sandy soils, but also on heavy, black cotton soils. During vegetative growth, niger seed may withstand waterlogging. It is extremely resistant to poor oxygen supply in the soil, explained by the development of aerenchyma and the ability to form respiratory roots. Some niger seed selections are moderately salt tolerant but flowering may be delayed by rising soil salinity.

Propagation and planting Well-dried niger seed can be stored dry without special requirements for at least 4 years without losing its viability. In India niger seed is planted in June–August as a rainy season crop and in September–mid-November as a winter crop. In Ethiopia the main planting season is May–July. Land preparation is similar to that applied when planting other small-seeded crops. Traditionally seed is broadcast at a rate of 6–12 kg/ha and covered 1–3 cm deep. For sowing, seeds are sometimes mixed with sand for even distribution. Seed drills and mechanical planters are occasionally used. The land is then harrowed to cover the seed. In sole cropping, row widths vary from 30–50 cm depending on soil conditions. In intercropping, sowing rate depends on the area allocated to niger seed which is usually 20–25%. It is commonly strip-cropped with pulses, millet, sorghum, castor, sunflower and sesame.

For micro-propagation hypocotyls, cotyledons and leaves have been cultured in vitro and survival rates of regenerated plantlets range from 70–98%.

Husbandry Weeding in niger seed fields is important. It should be sown in a clean field and weeded twice when seedlings are 10 cm tall and before flower bud development. Both hand weeding and herbicide application can control weeds. Chemical fertilizer is rarely applied. In India, application of 10–20 kg N and 10–20 kg P per hectare at sowing is recommended, followed by a N top dressing of 10–20 kg/ha, 30–35 days after sowing. Yield increases of 60% and 40% have been obtained for niger seed after application of N and P both at a rate of 40 kg/ha. Potassium has either no or a non-significant effect. Manure (4–5 t/ha) is also used sometimes combined with 10–20 kg N/ha. Incorporation of cowpea biomass gave positive results on niger seed in India. Niger seed is usually grown in rotation with cereals.

Diseases and pests Niger seed blight caused by *Alternaria* sp. and leaf spot caused by *Cercospora* sp. are the most serious diseases of niger seed. Other diseases recorded are leaf spot caused by *Macrophomina phaseolina* and *Phytophthora* root rot on young seedlings in India and bacterial blight (due to *Pseudomonas* spp.) in Africa and India.

The most serious insect pests are niger fly (*Dioxyna sororcula* and *Eutretosoma* spp.) and black pollen beetle (*Meligethes* spp.). Niger fly lays eggs in the disk florets and later, the larvae destroy the flowers. The black pollen beetle eats pollen grains and adversely affects pollination. In India control measures of niger caterpillar, semi-looper and other insect pests have been developed.

The parasitic weed 'dodder' (*Cuscuta campestris*) causes serious losses in Ethiopia and India. Hand-weeding and the application of herbicides (e.g. chloropropham, propyzamide) provide effective control. Other major weeds are *Solanum elaeagnifolium* Willd. ex Steud., *Oxalis latifolia* H.B.K., *Avena fatua* L. and *Imperata cylindrica* (L.) Raeuschel.

Harvesting As niger seed ripens over a period of several weeks it is harvested when plants are still yellow to reduce shattering. In India, the practice is to harvest when leaves are dry and heads turn black. The optimum stage to harvest is when seeds are yellow-brown and their moisture content is 45–50%. Harvesting is done manually; cut plants are stacked in the field to dry and taken to a threshing place for further drying and threshing.

Yield Seed yields of 250–400 kg/ha are common in India but these increase to 500–600 kg/ha when niger seed is grown in moderately fertile soils. In Ethiopia yields of 300–700 kg/ha are normal but yields of 1000 kg/ha have also been obtained. Improved cultivars in combination with improved agronomic practices can attain yields of 1000 kg seeds/ha.

Handling after harvest Threshing is mostly done by hand in India. In Ethiopia, oxen are used to either tread on the harvested plants or to pull a small threshing sledge. To keep seeds clean, tarpaulin or plastic sheets are used and threshing is done on special threshing floors. Small pedal-operated threshers for rice may be adjusted to suit niger seed. Seeds are stored in sacks and other containers, should be protected from storage pests and transported to bulk storage facilities as soon as possible. In Ethiopia, home processing of oil is done by grinding the dry seeds into fine powder, adding hot water to it, stirring it until the oil floats to the surface and then scooping the oil off. However, most oil is now processed in small, mechanized expeller mills. In India, the oil is extracted by traditional bullock-driven 'ghanis', in small rotary mills or in hydraulic or screw presses. Usually, locally-extracted oil has a poor storage life but heating and storing in airtight containers can prolong it.

Genetic resources The most important niger seed germplasm collections are in the Biodiversity Institute (formerly the Plant Genetic Resources Centre), Addis Ababa (Ethiopia) (about 1000 accessions), in the All India Coordinated Research Project on Oilseeds, Jabalpur (about 560 accessions) and the Indian National Bureau of Plant Genetic Resources, Akola (200 accessions). In India, the niger seed base collection is held at –20°C for long storage and at 4°C for medium-term storage. In vitro and in situ conservation of the working collections are not done in India; instead, they are maintained and regenerated by sibbing (during multiplication, plants of an accession are bagged as a group to avoid intercrossing with other accessions) to produce viable seed stocks. The adoption of improved cultivars at the expense of landraces is not widespread in Ethiopia.

Breeding Niger seed populations in Ethiopia and India are very heterogeneous, indicating the great potential for yield increases through breeding, and breeding programmes exist in both countries. Breeding objectives for niger seed are to increase seed yield and oil content. To achieve the first objective, single-headed, dwarf types with uniform maturity must be developed. An increase in oil content appears feasible because of existing genetic variability for oil content which can be used in breeding research.

Prospects Although niger seed is mainly produced in India, Ethiopia and other African countries, it can potentially be grown in cooler places in South-East Asia.

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B.E. Umali & K. Yantasath

Helianthus annuus L.

Sp. pl.: 904 (1753).
COMPOSITAE
$2n = 34$

Vernacular names Sunflower (En). Tournesol (Fr). Indonesia: bunga matahari (Indonesian), kembang sarengenge (Sundanese), purba negara

(Javanese). Malaysia: bunga matahari. Philippines: mirasol (Pilipino, Tagalog), lampao (Ifugao), ak-aklit (Bontok), takin-takin (Hanunuo). Thailand: thantawan (general), bua-thong (northern). Vietnam: h[uw][ows]ng d[uw][ow]ng.

Origin and geographic distribution Wild *H. annuus* spread from its origin in the south-western United States to most regions of North America, partly naturally and partly in association with human migration in prehistoric times. According to archaeological evidence modern single-headed sunflowers are derived from similar types first domesticated in central North America more than 5000 years ago. European explorers of the 16th Century found very tall and large-headed sunflowers widely used as food and a source of oil. Sunflower became popular in Europe as a novel ornamental soon after its first arrival in the botanic garden of Madrid around 1510 from Mexico. Its potential as an oilseed crop for higher latitudes became apparent in 18th Century Russia, and by 1880 sunflower was grown on some 150 000 ha mainly in the Ukraine and Caucasus regions for the manufacture of edible vegetable oil. In the Soviet Union of the 1930s, more than 3 million ha of sunflower were harvested annually against 0.5 million ha in the remainder of Europe, particularly Hungary and the Balkan Peninsula. Breeding programmes in Russia developed high-yielding and oil-rich sunflower cultivars, which played a crucial role in the expansion of sunflower production in Europe and elsewhere in the world between 1920 and 1970. Modern sunflower production in North and South America (mainly United States, Canada and Argentina) developed from sunflower types re-introduced by immigrants from Eastern Europe and Russia at the end of the 19th Century and from Russian cultivars brought in after 1960. The application of F_1 hybrid seed technology in combination with dwarf and semi-dwarf plant habits, high oil content of the seed and resistance to diseases and pests have been major factors leading to the spectacular increase of sunflower production since 1980 in Argentina, India, China, Turkey and the European Union (e.g. France, Spain and Italy). Sunflower production in South-East Asia is a recent development with Burma (Myanmar) and Thailand being the main producers.

Uses Sunflower seed yields an edible oil of excellent quality due to a high concentration of unsaturated fatty acids, near absence of toxic substances, attractive light colour, good taste and flavour. It is used mainly as cooking and salad oil and in the manufacture of margarine, sometimes as a pure sunflower product but more often in blends with soya bean and other vegetable oils. Inferior grades of sunflower oil find application as drying oils for paints and varnishes, and in the manufacture of soap. The main by-product of sunflower is a protein-rich meal used as livestock feed. For this purpose, it is commonly blended with soya bean meal. Defatted sunflower meal is also suitable for human consumption and has been used as a partial substitute for wheat flour in baking bread and cakes. The indigenous people of North America have had a long tradition of preparing bread-like products from ground sunflower seeds.

The seeds (achenes) of non-oil cultivars which are large and often black and white-striped, are consumed directly. Generally, the largest 25% of the seeds are consumed as salted and roasted snacks, the medium 30–50% fraction is used as hulled seeds in confectionery and bakery products and the smallest seeds as birdseed and pet food.

Sunflower is sometimes cultivated as a forage crop. It requires a shorter growing season, is more drought tolerant and produces a silage only slightly inferior to maize (*Zea mays* L.). In Russia and Canada, sunflower is occasionally grown as a hedge crop in fields of wheat to accumulate snow and to protect against desiccating winds. Sunflower is also grown as an ornamental garden and pot plant.

Formerly, yellow and purple dyes were extracted from the florets.

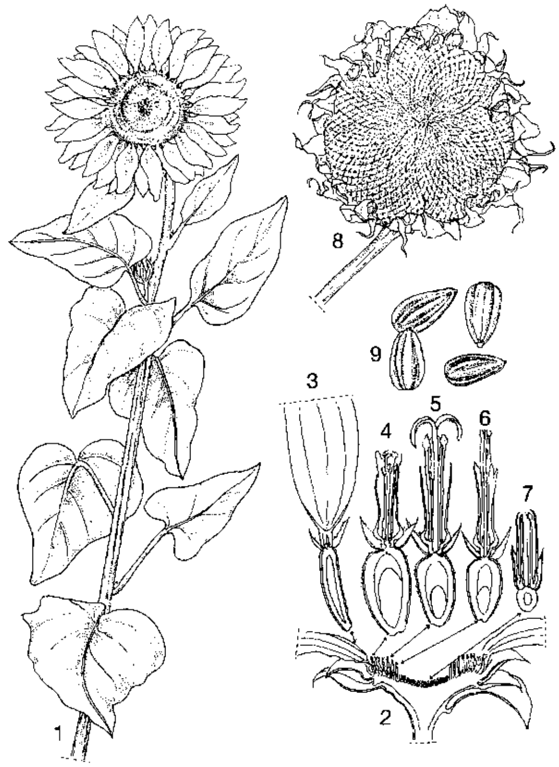
Production and international trade Average annual world production of sunflower seed over the period 1994–1998 was about 24 million t, equivalent to 9 million t oil, from 21 million ha in 58 countries. Argentina is the largest producer (5.5 million t), followed by the Russian Federation (3 million t), Ukraine (2.2 million t), United States (2 million t), France (1.9 million t), India (1.5 million t), China (1.2 million t), Spain (1.1 million t), Romania (1 million t), Turkey (850000 t) and Hungary (700 000 t). Countries in South-East Asia with sizable sunflower production are Burma (Myanmar) (130 000 t) and Thailand (20 000 t).

Most sunflower oil is consumed in the countries of origin and only 30% reaches the international market; the European Union absorbs about two-thirds of it. Important exporting countries are Argentina, United States and Hungary. The 9–10 million t of sunflower presscake are also of considerable commercial value. The oil represents about 75% and the meal 25% of the total value of oilseed sunflower production. Most of it is traded in the domestic markets, except for 1.0–1.5 million t imported annually into the European Union from Argentina. Non-oilseed production of sunflower represents only 5–10% of the total production.

Properties The composition of 100 g dry sunflower seeds (achenes) is approximately: water 5–7 g, protein 14–25 g, oil 20–60 g, other lipids 1–2 g, carbohydrates 18–27 g and ash 2–4 g. Oilseed sunflower cultivars have a high oil content (more than 50%) and low hull fraction (20–25%), against the low oil content (25–30%) and high hull fraction (43–52%) of non-oilseed sunflower cultivars. About 97–98% of the oil is contained in the seed (kernel) and 1–2% in the hull. The fatty acids of traditional sunflower oil are: palmitic acid 5–7%, stearic acid 3–6%, oleic acid 16–36%, linoleic acid 61–73% and only traces of linolenic acid. The composition of recently developed 'high-oleic' sunflower cultivars is different: palmitic acid 3–4%, stearic acid 4–5%, oleic acid 80–90%, linoleic acid 3–9%. Such oil is less susceptible to oxidative degradation than oil with a high polyunsaturated linoleic acid content. Unrefined sunflower oil contains 1–2 mg/kg carotenoids (provitamin A) and 630–700 mg/kg tocopherols (fat-soluble vitamin E).

Sunflower meal has a protein content of 28–45% depending on cultivar and method of oil extraction and is a good source of Ca, P, K and vitamin B complex. Sunflower proteins are easily digestible and have a high biological value, but are somewhat deficient in the essential amino acid lysine. The 1000-seed (achene) weight is 40–60 g for oilseed and 80–110 g for non-oilseed cultivars.

Description A variable, erect, hirsute, annual herb, usually 2–4 m tall. Taproot strong, up to 2–3 m deep with numerous lateral roots 60–150 cm long, in the top 40–60 cm of the soil. Stem erect but slightly to sharply curved below the head in mature plants, (0.5–)1.6–1.8(–5) m tall, round with ridges, 3–6 cm in diameter, branched in many wild forms, unbranched in most cultivated forms, woody and angular at maturity and often becoming hollow. Leaves cordate and opposite below, higher ones soon becoming ovate and alternate in spiral with two-fifths phyllotaxis, 20–40 per plant; petiole long; blade cordate to ovate, 10–30 cm × 5–20 cm, margin serrate, apex acute or acuminate, hispid on both sides with glandular and non-glandular trichomes, veins prominent and forming a reticulate pattern. Inflorescence a terminal head (capitulum), 10–50 cm in diameter, sometimes drooping; receptacle flat to concave or convex, 1–4 cm thick; involucral bracts arranged



Helianthus annuus L. – 1, habit flowering plant; 2, schematic cross section through flower head; 3, ray floret; 4,5,6,7, disk florets in different stages of development; 8, fruiting head; 9, seeds.

in 3 rows, ovate to ovate-lanceolate, ciliate; outer ring of flowers are sterile but showy ray florets, deciduous, corolla ligulate, elliptical, about 6 cm × 2 cm, strongly 2-veined, yellow, sometimes white, lemon, orange or red; inner flowers are bisexual disc florets, arranged in spiral whorls from the centre of the head, 700–3000 in oilseed types, up to 8000 in non-oilseed types per head, about 2 cm long, subtended by a pointed bract; pappus scales 2, chaff-like, deciduous; corolla tubular, 5-lobed, brown or purplish; stamens 5, filaments flattened, free, anthers long, fused into a tube; ovary inferior, pubescent, with single basal ovule, style long with nectaries at its base, stigma with 2 curved lobes. Fruit an achene (in sunflower commonly called 'seed'), obovoid, flattened, slightly 4-angled with truncated tip and rounded base, variable in size and colour, 7–25 mm × 4–15 mm × 3–8 mm, white, cream, brown, purple, black, or white-grey with black stripes, sometimes with phytomelanin layer. Seed (kernel) with thin seed coat adnate to the fruit wall (hull), a single layer of endosperm and a large straight embryo which for the major part consists of the 2 cotyledons. Seedling with epigeal germination.

Growth and development Sunflower seeds show dormancy until 30–50 days after harvesting, but this is easily overcome by rinsing them in water or exposure to ethylene prior to sowing. Dry seeds stored below 10°C at 50% relative humidity will retain their viability for several years. The growth cycle is usually about 4 months but it ranges from 75–180 days depending on the environment and genotype. Sowing to seedling emergence takes 5–10 days, emergence to floral initiation 15–20 days, floral initiation to first flowering 20–90 days, flowering 5–15 days and flowering to seed maturity 30–45 days. Floral initiation occurs around the 8th leaf stage. Pronounced heliotropism is a characteristic of sunflower. Heads and leaves face east in the morning and follow the movement of the sun to face west in the evening. This heliotropism decreases gradually during flowering with most mature heads eventually facing east. Anthesis progresses from the periphery of the head inwards at 1–4 rows of florets per day. Anthesis of a floret starts early in the morning and is protandrous; the style extends through the anther tube, pushing the pollen outside; the stigma becomes fully extended and receptive the following morning. Pollination is mainly by honeybees and bumble-bees. Fertilization is complete by the evening of the second day. Sunflower is allogamous with a rather complex system of sporophytic self-incompatibility controlled by at least 2 multi-allelic S loci. However, artificial self-pollination generally results in some degree of seed set and certain genotypes show a high degree of natural self-fertility.

At physiological maturity the head becomes yellow, the bracts brown and about 75% of the leaves are desiccated. During the following 10 days, the seeds will dry to 10–12% moisture content and start shattering, while the receptacle may still contain more than 30% water.

Other botanical information At present, the genus *Helianthus* L. comprises about 50 species, including annual and perennial, diploid as well as polyploid species, all endemic to North America. *H. annuus* L. is one of the 13 annual species. It is a complex species, comprising wild and cultivated sunflowers, formerly classified as subsp. *lenticularis* (Dougl.) Cockerell and subsp. *annuus* respectively. Within subsp. *annuus* two groups were distinguished, a weedy group (var. *annuus)* and the cultivated sunflowers group (var. *macrocarpum* (DC.) Cockerell). Cultivated sunflowers, however, can better be classified into cultivar groups and cultivars, but such a classification does not yet exist. Four groups of sunflower cultivars can be distinguished according to plant height:

- Tall (Giant) cultivars: 2–4 m, late maturing; heads 30–50 cm in diameter; seeds large, white or grey or with black stripes; oil content rather low; representative: 'Mammoth Russian', an old, very tall cultivar;
- Standard cultivars: 1.5–2.1 m; representatives: 'Peredovik', 'VNIIMK 8931' and 'Progress', of Russian origin with high oil content;
- Semi-dwarf cultivars: 1.2–1.5 m, early maturing; shorter internodes but the same number of leaves as standard cultivars; heads 17–22 cm in diameter, seeds black, grey or striped; oil content higher than in tall cultivars; representatives: 'Pole Star', 'Jupiter', most modern hybrid cultivars;
- Dwarf cultivars: 0.8–1.2 m, early maturing; fewer nodes and leaves than standard cultivars but normal internode length; flower heads 13–17 cm in diameter; seeds small; highest oil content; representatives: 'Advance', 'Sunrise'.

Ecology Sunflower is cultivated mainly between 20–50°N and 20–40°S, in relatively cool temperate to warm subtropical climates. In the tropics, it can be grown in drier regions, up to 1500(–2500) m altitude, but sunflower is unsuitable for humid climates. Temperatures for optimum growth are 23–27°C. When grown in hotter climates, oil content is lower and composition changes with less linoleic acid and more oleic acid. Temperatures for germination should not be below 4–6°C and maximum temperatures during growth not above 40°C. Young sunflower plants with 4–6 leaves may withstand short periods of frost down to –5°C. Most sunflower cultivars show day-neutral or quantitative long-day responses to photoperiod, but there is at least one short-day cultivar. Long photoperiods increase plant height. Water requirement is 300–700 mm during the main growing period, depending on cultivar, soil type and climate. More than 1000 mm rain increases the risk of lodging and disease incidence. Sunflower is capable of extracting more soil moisture than most other field crops. Dry weather after seed set is important for adequate ripening of the crop. A wide range of soils from sandy to clayey are suitable for sunflower cultivation, provided they are deep, free-draining and neither acid nor saline; suitable pH ranges from 5.7 to 8.1.

Propagation and planting Sunflower is sown directly in the field at a depth of 3–8 cm. It requires a medium fine seed-bed that is free from weeds. With mechanical planting, seed rates are 3–8 kg/ha depending on seed size and spacing. Commonly used spacings are 60–75 cm between rows and 20–30 cm within the row. Optimum final plant densities vary with environment and cultivar: 15 000–30 000 plants/ha under rainfed and 40 000–60 000 for irrigated sunflower crops. With good seed quality, seedling emergence of more than 80% can be attained. Sunflower has some ability to compensate for lower densities or irregular crop stands by increasing total biomass, seed size and number of seeds per plant, provided other growth factors such as moisture and nutrients are not limiting.

Smallholders often intercrop sunflower with groundnuts, pulses and millets, plant it on banks around irrigated fields, or use it as living support for beans and gourds.

Husbandry Sunflower seedlings compete poorly with weeds. Control is effected by interrow cultivation and herbicides. Pre-plant, pre-emergence and post-emergence herbicides are used, but they should be selected carefully as sunflower is extremely susceptible to hormone-based herbicides. Mechanical cultivation should also be done carefully to avoid damage to the extensive superficial network of roots. Irrigation to supplement rainfall to 600–750 mm can result in considerably higher yields in sunflower, but may also increase the risk of lodging, especially for tall cultivars and in areas where strong winds are common. For this reason too, surface irrigation is the preferred method of application.

Fertilizer requirements depend on yields and nutrient status of the soil. Plant nutrient status can be monitored through foliar analysis by sampling the youngest expanded leaf. Macro-nutrients removed by 1 t harvested seed are about 25 kg N, 4 kg P, 17 kg K, 2 kg Ca, 3 kg Mg and 2 kg S. Considerable amounts of these elements, K particularly, are also immobilized in the plant stover, resulting in a rather low fertilizer use efficiency. Recommended applications of fertilizer to sunflower crops with expected yields of 1.5–2.5 t seeds per ha vary: 50–120 kg N, 20–30 kg P and 40–80 kg K. Sunflower is particularly susceptible to boron deficiency, which can be rectified by soil or foliar application. Soil application of 1–4 kg B per ha is normally adequate. Sunflower should not be grown in 2 consecutive crops to avoid a build-up of diseases and pests. Crop rotation with cereals and pulses is common.

Diseases and pests Sunflower is affected by some 15 pathogens of worldwide importance, regularly causing considerable economic losses. Probably the most serious disease is Sclerotinia wilt or white rot caused by *Sclerotinia sclerotiorum* which affects roots, stems, buds and heads. Wide host range and longevity of the sclerotia complicate control, but clean seed, wide crop rotation (3–4 years) with non-host crops and the use of less susceptible cultivars help to reduce disease incidence. Other major fungal diseases and pathogens are: downy mildew (*Plasmopara halstedii*) causing damping-off in seedlings and yellowing of the leaves that spreads from the midribs, downy growth underneath the leaves and a characteristic upright orientation of the head; sunflower rust (*Puccinia helianthi*) forming small dark brown pustules on the underside of the leaves, eventually causing the leaves to turn brown and in severe cases the death of the plant; Alternaria blight (*Alternaria helianthi* and related species) causing seedling blight, leaf and stem spots and head rot; and Septoria leaf spot (*Septoria helianthi*) causing lesions in the leaves. Sunflower can be a host of the cucumber mosaic virus (CMV) and *Mormor astrictum* which infect tobacco crops in East Java, Indonesia. Sunflower is also attacked by nematodes, e.g. *Meloidogyne* and *Rotylenchus* species. There are numerous insect pests, many of them specific to a continent, but the most damaging are those that attack buds, flower heads and developing seeds. A major cause of poor emergence and plant stands are the larvae of various cutworms (*Agrotis* spp.), wireworms (*Gonocaephalum* spp.) and crickets (*Gryllotalpa* spp.). Other important sunflower pests in Asia are: *Chrotogonus* spp., *Diacrisia* spp., *Spilosoma* spp., *Spodoptera* spp., the leaf miner *Phytomyza atricornis* and sucking insects like *Aphis gossypii* and *Bemisia tabaci* on foliage; stem borer *Ostrinia damoalis*; and *Helicoverpa armigera*, *Homoeosoma nebulella*, *Oxycertonia* spp. and *Dolycoris indicus* on the head and developing seeds. Insecticides to control pests in sunflower should not be toxic to pollinating bees during the flowering period. Cultivars with seeds that have a phytomelanin layer in the pericarp are less attacked by seed-damaging insect pests. Birds and rodents can cause major losses to the maturing sunflower crop and can be controlled by measures such as scaring, chemical repellents and early harvesting. Broomrape (*Orobanche cernua* Loefl.) is a plant parasite that feeds on the roots and may cause considerable damage also in Asia. Crop rotation, catch crops, biological control and resistant cultivars are means of control. Sunflower affects germination of witchweed *(Striga* spp.), but is not a host and may contribute to its control. In some states of the United States, weedy sunflower forms are considered noxious weeds.

Harvesting Sunflower is ready for harvesting when the heads have turned yellow-brown and seed moisture content is 10–12% at about 120–160 days after planting for tall and 80–110 days for dwarf cultivars. Manual harvesting by smallholders involves cutting the heads and drying them on platforms or threshing floors for 6–7 days in the sun before manual or mechanical threshing and winnowing. Cleaned seeds are dried in the sun again for a few days before storage. The highly uniform ripening of short-stature hybrids allows mechanized harvesting by adapted combine harvesters. Time of harvesting is then usually earlier, when seed moisture is about 20%, to avoid yield losses due to shattering. Before storage, harvested seeds are cleaned and dried to 8% moisture content in open sacks under a shelter in warm and dry weather, or otherwise by artificial dryers.

Yield World average seed yield is 1.2 t per ha. National averages range from 0.5 t–2.5 t, e.g. India 0.7 t, Burma (Myanmar) 0.8 t and China 1.5 t per ha. High yields of 2–4 t per ha are obtained in France and the United States from modern hybrid cultivars and with high inputs. Maximum yields of 5–6 t seed per ha have been obtained in field experiments.

Handling after harvest Small quantities of dried seeds can be stored in moisture-proof and insect- proof containers placed in a cool place. Large-scale storage of sunflower seeds requires well-aerated bins or silos maintained at low relative humidity. Regular inspection prior to and during storage is necessary to avoid storage pests similar to those in other grain crops. Infestations may be controlled by fumigation.

The extraction and processing of oil takes place in oilseed crushing plants. The seed is first cleaned and dried to 7% moisture content before cracking and separating the pericarp from the seeds. Three methods of oil extraction are available: expulsion by mechanical screw press, organic solvent extraction e.g. with hexane, or a combination of mechanical and solvent extraction. Mechanical pressing leaves a meal residue with 5–6% oil while solvent extraction forms residues with only 0.5–1.5 % oil. The crude oil is subsequently cleaned by filtration, refined to reduce its free fatty acid content, bleached to remove carotenoids and other pigments and finally deodorized to produce a colourless cooking and salad oil. Oil stability is improved by adding anti-oxidants. The manufacturing of margarine requires an additional process of partial hydrogenation of the sunflower oil and usually blending with other vegetable oils to produce the right hardness and mouthfeel.

Genetic resources Most wild *Helianthus* species are potentially useful genetic resources for the improvement of the cultivated sunflower because of the relative ease of introgression by interspecific hybridization. Embryo-rescue and in-vitro culture is quite a successful method for achieving difficult interspecific hybridization in sunflower. Wild *H. annuus* and several other species have been important sources of resistance to several diseases and some pests, cytoplasmic male sterility and other agronomic characters such as drought and salt tolerance. The USDA's North Central Regional Plant Introduction Station at Ames, Iowa, has the largest germplasm collection with 3300 accessions of which 2245 are wild species. Other research centres with important *Helianthus* germplasm collections are the N.I. Vavilov Institute (VIR) at St. Petersburg and the Research Institute for Oil-bearing Crops (VNIIMK) at Krasnodar, both in Russia; the Plant Breeding Station in Clermont-Ferrand, France; the Research Institute for Field and Vegetable crops in Novi Sad, Yugoslavia; and the Research Institute for Cereals and Industrial Crops in Fundulea, Romania.

Breeding Uniform F_1 hybrids have almost completely replaced the open-pollinated cultivars developed by mass and family selection such as 'Peredovik' in Russia. The early hybrid cultivars based on self-incompatibility like 'Advance' in Canada or on genetic male sterility like 'INRA 651' in France still had 30–50% selfed plants. The discovery of cytoplasmic male sterility in offspring of an interspecific cross of *H. petiolaris* × *H. annuus* together with maintainer and restorer genes in France in 1968–1970 quickly led to a new generation of sunflower F_1 hybrids. Potential yields are 100–150% higher than those of open- pollinated cultivars. In the meantime more than 40 new sources of CMS have been detected within the *Helianthus* gene pool, but most of the F_1 hybrids grown at present are still based on the first CMS source, partly because introgression into inbred lines and finding matching restorer genes takes time. Selection against self-incompatibility during inbred line development leads to self-fertile F_1 hybrids capable of producing good seed when pollinating insects are less abundant. Multi-branched male lines are used to enhance pollination and

seed set in large-scale seed production. This character is conditioned by one recessive gene and the F_1 hybrids will be unbranched.
Breeding objectives include higher yield and oil content, precocity, reduced plant height and higher harvest index. Generally, seed yield is positively correlated with plant height, head diameter and single seed weight, while oil content is negatively correlated with pericarp thickness. Other objectives are resistance to diseases and pests, drought, low temperatures, salinity and lodging. Many sunflower hybrids are resistant to downy mildew (*Plasmopora halstedii*) and rust (*Puccinia helianthi*) which are both conditioned by dominant major genes, but the resistances are race-specific and breakdowns due to new virulent races of the pathogen have occurred. Resistance to sclerotinia wilt and rot are difficult to achieve due to its complexity and polygenic inheritance. Broomrape resistance exists, but virulent races may overcome it. Bird damage appears to be less in cultivars with concave-shaped heads which hang parallel to the soil at maturity.

Prospects There is still considerable scope for increasing yields in sunflower, although the upper limits of selection for higher oil content may not be far above 60%. Further exploitation of the wild *Helianthus* gene pool should contribute to higher crop security by improved host resistance to diseases and pests, which at present still account for the destruction of 40–50% of the world sunflower crop. In recent years sufficient progress in molecular marker-assisted selection and genetic transformation has been made in sunflower to expect substantial contributions to more efficient improvement from these advanced technologies.
Sunflower produces an excellent vegetable oil, but possibilities for expansion in South-East Asia are limited to drier parts. Numerous diseases and pests, as well as serious risks of damage by birds and rodents are also factors limiting the possibilities for small-scale and low-input cultivation of this crop.

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Olea europaea L.

Sp. pl.: 8 (1753).
OLEACEAE
$2n = 46$

Vernacular names Olive (En). Olivier (Fr). Indonesia: zaitun. Malaysia: zeitun. Philippines: oliva.

Origin and geographic distribution The olive is a characteristic fruit tree of the Mediterranean. Wild olive (oleaster) is a typical component of the Mediterranean shrub vegetation and the most likely progenitor of the cultivated olive trees. First domestication is associated with early civilizations in the eastern Mediterranean. Archaeological evidence of olive cultivation dates back to the fourth millennium BC. The Phoenicians and Greeks in particular contributed to the expansion of olive cultivation around the Mediterranean Sea during the last millennium BC. In the Roman empire of the 2nd Century AD, olive oil became one of the most economically important commodities. Eastwards, olive cultivation spread up to north-western India and the Caucasus. Olive cultivation was introduced to the new world (Peru, Chile, Argentina, Mexico and United States (California)) in the 16–18th Centuries by the Spanish, to Australia and South Africa by Italian and Greek immigrants and to Japan and China from France in the 19th Century. Nevertheless, about 97% of the world's 800 million olive trees are still grown in the Mediterranean region.

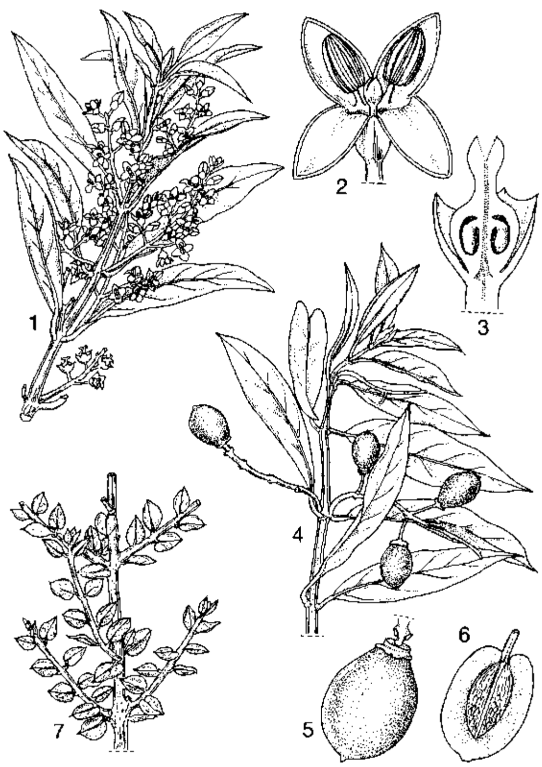
Uses The main product of the olive tree is the edible oil extracted from the fruit's mesocarp and

commonly used as a cooking and salad oil and in the preservation of various foods. It is much appreciated for its specific flavour and supposedly beneficial effects on health due to the high concentration of monounsaturated fatty acids and polyphenolic anti-oxidants. Lower grade olive oils are used in the manufacturing of soap, cosmetics and lubricants. Traditionally, olive oil also has various pharmaceutical applications and has served as lamp oil.
Fruits are processed into green and black table olives (whole, sliced, minced or paste). The presscake is not a very suitable livestock feed, but can be used as fuel or fertilizer. Other useful products from the olive tree include the leaves as cattle feed, valuable timber from the stem, and firewood from the branches. Olive trees are planted for ornamental purposes, as firebreaks and to control soil erosion.

Production and international trade Average world production of olive oil during the period 1995–2000 was 2.3 million t/year, almost all from the Mediterranean region. The biennial bearing habit of the olive tree and variable weather conditions cause considerable fluctuations in annual world production (1.6–2.8 million t). The total area planted with olive trees is estimated at 9.1 million ha in 21 countries. The principal olive oil producing countries are: Spain (32%), Italy (21%), Greece (17%), Tunisia (8%), Syria (4%), Turkey (4%), Morocco (3%) and Algeria (1%), which together account for 90% of the world supply. About 400 000 t per year reach the international vegetable oil market; the European Union and United States are the main importers of olive oil.
The 1.1 million t of table olives produced annually represent about 8% of total olive fruit yields. Spain is the largest producer of table olives (25%) followed by the United States (14%), Turkey, Morocco, Syria, Greece and Italy (6–9% each).

Properties Mature olive fruits consist of mesocarp (pulp) 70–90%, endocarp (stone) 9–29% and seed 1–3%. Per 100 g fresh edible portion, the mesocarp contains: water 60–70 g, oil 15–30 g, carbohydrates 3–6 g, crude protein 1–2 g, cellulose 1–4 g, phenolic compounds 1–3 g, ash and other substances 1–3 g. The fatty acid composition of the oil is: palmitic acid 7.5–20%, palmitoleic acid 0.3–3.5%, stearic acid 0.5–5%, oleic acid 55–83%, linoleic acid 3.5–20%, linolenic acid 0–1.5%, arachidic acid 0.1–0.6% and traces of gadoleic, behenic and lignoceric acids. The anti-oxidant effect of the phenolic compounds (50–400 ppm) and the high oleic content combine to give an oil of exceptional stability even during deep frying. Olive oil is classified into two main quality classes: cold-pressed or virgin oil and refined olive oil. Virgin olive oil is one of the few vegetable oils that is traded and consumed without any refinement and contains its full complement of secondary compounds. Mainly oleuropein but also other phenolic compounds are responsible for the intense bitterness of olive fruits, as well as for fruit blackening and inhibition of microorganisms during processing. The bitterness in table olives is largely removed in the early stages of processing. The weight of a fresh fruit is 1–12 g.

Description Evergreen tree, up to 10–(15) m tall, with broad multibranched crown, trunk thick, up to 1–2 m in diameter, often gnarled, or densely branched shrub, up to 2(–5) m tall. Root system extensive with main roots thickened due to fasciation, up to 6 m deep in porous soils and spreading laterally with dense mat of feeder roots; protuberances (spheroblasts) at the base of trunk



Olea europaea L. – 1, flowering branch; 2, flower; 3, longitudinal section through pistil and calyx; 4, fruiting branch; 5, fruit; 6, section through fruit to show endocarp; 7, leafy branch of the wild form of olive.

with additional lateral roots. Twigs grey, subterete and thornless in cultivars, 4-angled and thorny in wild forms. Leaves opposite, simple, entire, coriaceous, subsessile; blade elliptical to lanceolate, 1–8 cm × 0.5–2.5 cm, mucronate at apex, dark grey-green and glabrous above, densely silvery lepidote beneath. Inflorescence an axillary panicle, shorter than the leaves, 3–5 cm long with 10–40 bisexual, white, fragrant flowers 3–4 mm long; pedicel short; calyx cup-shaped with 4 teeth, persisting in fruit; corolla with short tube and 4 valvate lobes; stamens 2, filaments short, anthers large; pistil with superior, 2-loculed ovary, a short style and a 2-lobed stigma. Fruit a subglobose to ellipsoid drupe, 0.5–4 cm × 0.5–2.5 cm, bright green, turning purple-black, brown-green or ivory-white at maturity; mesocarp rich in oil; endocarp stony, usually containing 1 seed. Seed ellipsoid, 9–11 mm long with straight embryo and copious endosperm. Seedling with epigeal germination.

Growth and development Practically all olive trees in the world are grown from clonal cultivars. Seeds germinate within 25–50 days after sowing, but seed viability of cultivated olives is generally low. Olive seedlings have a distinct juvenile phase lasting 4–9 years and characterized by strong vegetative growth and profuse branching. Plants raised from cuttings have a more adult growth habit with monopodial branching and may start flowering within 3–7 years after field planting. The life of leaves is 2–3 years. Flowering occurs annually in spring on branch segments formed during the previous season, with 50–80% of the leaf axils developing inflorescences. Wind pollination and cross-fertilization are the rule due to self-incompatibility. Even under optimum conditions of pollination and initial fruit set, generally only 1–5% of the flowers will develop into mature fruits due to severe early (up to 50%) and late physiological fruit abscission, water stress, diseases and pests. In a year of profuse flowering, such low fruit set still represents a large crop. Olive is a strongly biennial bearer, because a heavy fruit load in one year inhibits adequate shoot extension necessary for the following year's bearing wood and vice versa. Olive fruit development takes 6.5–7 months from anthesis to harvesting, the last 20–40 days being essential for oil formation in the mesocarp.

The commercial life span of an olive tree is about 50 years, but individual trees can become very old (hundreds of years). Very often, old trees are hollow, usually because during its history, fungus diseased wood has been cut away repeatedly. Such old, gnarled trees are often also twisted and slanting, giving the tree a peculiar appearance: abundant, fresh, lively, young, green sprouts on an old, grey, twisted, gnarled and slanting, hollow cylinder.

Other botanical information The *O. europaea* taxonomy is confusing and many names and classifications exist. Usually, 2 groups are distinguished: cultivated and wild, and a selection of scientific names encountered for each group is listed:

- the cultivated olive: *O. europaea* L. var. *europaea*, *O. europaea* L. subsp. *europaea*, *O. gallica* Miller, *O. hispanica* Miller, *O. lancifolia* Moench, *O. sativa* Gaterau, *O. europaea* L. var. *sativa* Lehr., *O. europaea* L. var. *sativa* Loud., *O. europaea* L. subsp. *sativa* Arcang.
- the wild olive: *O. europaea* L. var. *sylvestris* (Miller) Lehr., *O. sylvestris* Miller, *O. europaea* L. subsp. *sylvestris* (Miller) Rouy, *O. europaea* L. subsp. *sylvestris* (Miller) Hegi, *O. europaea* L. var. *sylvestris* Brot., *O. oleaster* Hoffmannsegg & Link, *O. europaea* L. subsp. *oleaster* (Hoffmannsegg & Link) Negodi.

Instead of classifying the cultivated olive into a system developed for wild plants, it is better to distinguish cultivars and cultivar groups. More than 2500 cultivars are known, but an overall cultivar classification system has not yet been developed. According to their use, three groups of cultivars can be distinguished:

- Cultivars for oil extraction, e.g. 'Picual', 'Arbequina' and 'Blanqueta' in Spain; 'Frantoio' and 'Leccino' in Italy and 'Koroneiki' in Greece.
- Cultivars for fruit consumption, e.g. 'Gordal Sevillana' and 'Manzanilla de Sevilla' in Spain, 'Conservolea', 'Kalamata' and 'Chaldiki' in Greece, 'Picholine du Languedoc' in France, 'Manzanillo' and 'Mission' in the United States and 'Oliva di Spagna' and 'Oliva di Cerignola' in Italy.
- Dual-purpose cultivars (for oil extraction and fruit consumption), e.g. 'Hojiblanca', 'Manzanilla Cacereña' and 'Aloreña' in Spain, 'Tanche' in France, 'Picholine marocaine' in Morocco, 'Dan' in Syria and 'Arauco' in Argentina.

It is generally believed that the cultivated olive originates from the wild form of *O. europaea* (often called 'oleaster') by selection of high oil yielding genotypes and their vegetative propagation. Oleaster is distributed similarly to the cultivated olive in the Mediterranean. It can be distinguished by its obovate leaves (shorter than 4 cm), its thorny, quadrangular lower twigs and its small fruits (up to 1.5 cm long). Oleaster fruits have always been used for their edible oil. Sometimes, it is difficult to decide to which group a plant belongs: in disturbed habitats (e.g. near the edge of olive plantations), intermediate forms exist because the two are interfertile. Many cultivars are genetically heterozygous and they have often been grafted on wild oleaster stock.

Olea L. comprises about 35 species but in the Mediterranean only *O. europaea* occurs. Several non- Mediterranean wild *Olea* species, however, are closely related to and sometimes interfertile with *O. europaea*. Some examples are: *O. chrysophylla* Lamk (synonyms: *O. cuspidita* Wall ex G. Don, *O. africana* Miller, *O. verrucosa* Link) occurring in southern Iran, southern Arabia and eastern Africa; *O. ferruginea* Royle, occurring in South Asia; *O. laperrini* Battand. & Trab., occurring in the mountains of the Sahara; and *O. cerasiformis* Webb & Berth., occurring in the Canary Islands and Madeira. These taxa are so closely related to *O. europaea* that they have also been classified as its subspecies (subsp. *cuspidata* (Wall. ex G. Don) Cif. and subsp. *cerasiformis* (Webb & Berth.) Kunkel & Sunding). Their geographic isolation from the location of early domestication of the olive makes them unlikely progenitors, but they could become useful genetic resources for the improvement of the cultivated olive, e.g. for disease and pest resistance and adaptation to new ecosystems.

Ecology The olive tree is well adapted to the seasonal and relatively dry climate of the Mediterranean region. Worldwide cultivation is concentrated between 30–45° latitudes in the northern and southern hemispheres (excluding the tropics), from sea level to 900 m altitude on south-facing slopes (higher than 1200 m in Argentina). Frost in spring can damage young shoots and flowers, and the ripening fruits in late autumn. Olive trees are fairly frost-hardy during winter, tolerating –8°C to –12°C. For flower initiation, most olive cultivars require a vernalization period of 6–11 weeks below 9°C which ends 40–60 days before anthesis. Optimum temperatures for shoot growth and flowering are 18–22°C. Temperatures above 30°C in spring can damage flowers, but the tree can withstand much higher temperatures in summer. The xerophytic physiology of olive trees makes them highly tolerant of long period of water stress, but for economic yields, low and irregular rainfall (less than 300 mm) should be supplemented by irrigation during critical growth stages to 500–800 mm per year. Soils should be light-textured (less than 20% clay), well-drained and have a depth of at least 1.5 m. Olives can do well on very poor soils, except when these are waterlogged, saline or too alkaline (higher than pH 8.5).

Propagation and planting The main method of propagation of olive is based on rooting of semi-hardwood cuttings prepared from one-year old branches (10–12 cm long with 4–5 nodes and two pairs of leaves). Propagation by seed is possible but gives rather variable seedlings because of cross fertilization. It is mostly used for breeding purposes. In vitro micro-propagation of olive explants has not yet passed the experimental stage, partly because of large variation in rates of success between different cultivars. Somatic embryogenesis is very difficult to achieve from adult tissues and cannot be used for propagation purposes. Traditional methods of clonal propagation are: large hardwood cuttings, grafting on seedlings or mature trees, grafting on wild olive trees and rooting of fragments of protuberances with a shoot attached. Protuberances can also be used for in situ rejuvenation of very old and decaying olive trees.

Plants from rooted cuttings are raised in beds or polythene bags in nurseries for 1.5–2 years prior to planting in the field in spring. They are planted in large holes (40 cm × 40 cm × 60 cm) which are later refilled with topsoil, organic compost and fertilizers, especially P and K. Plant densities traditionally vary from 40–60 trees/ha in very dry areas to 300–400 trees/ha under optimum soil conditions and water availability (more than 600 mm) and using cultivars with more compact and erect growth habit. Field experiments with high density olive orchards (up to 2000 trees/ha planted in hedges) are in progress in Spain and France. The majority of olive orchards in the Mediterranean region have traditional densities of 100–250 trees/ha. Planting along contour lines or in terraces is necessary in sloping terrain to prevent soil erosion. Leguminous and cereal crops have been planted as intercrops in olive groves.

Husbandry The olive tree requires pruning to shape it into the desired main frame and crown, to maintain a proper balance between vegetative growth and fruit production and so reduce biennial bearing and to rejuvenate senescent trees. There is a long tradition of manual pruning methods and some are region specific. Mechanized maintenance pruning is done in modern olive orchards, but requires adaptation of tree shape and careful management to prevent excessive branch damage and subsequent disease problems.

Regular fertilizer application is needed for sustained fruit production, but type and rate vary with local climate, soil condition and agronomic practice. Foliar analysis provides information on the nutrient status of olive trees. Nutrients removed by 3 t of fruit amount to about 19 kg N, 9 kg P_2O_5 and 25 Kg K_2O. A general fertilizer recommendation would be: annual applications of 0.8 kg N (in 2–3 split applications), 0.3 kg P_2O_5 and 0.9 kg K_2O per tree at medium planting density (150 trees/ha). These correspond to 120 kg N, 45 kg P_2O_5 and 135 kg K_2O per ha. Occasional correction of calcium, magnesium and boron deficiencies may also be needed. Triennial application of organic manure or compost (50 kg/tree) is recommended to improve soil texture and fertility. It can also be done before planting.

Only 15% percent of areas planted with olive trees worldwide are actually irrigated but this is steadily increasing. Surface, sprinkler or drip irrigation are some of the methods applied to supplement deficient rainfall in intensive olive cultivation. Correctly timed and dosed irrigation is required to produce economic responses in yield and fruit quality. Irrigation combined with ground cover positively influence olive production and soil conservation.

Diseases and pests Leaf spot or peacock spot caused by *Spilocaea oleagina* (*Cycloconium oleaginum*) is the most common disease in olive cultivation. Methods of control include preventive copper-based fungicide sprays and host resistance. Copper sprays also have a tonic effect of promoting longer leaf retention. Other diseases are sooty mould caused by secondary infection of *Alternaria, Capnodium* and *Cladosporium* spp. following black scale infestation, Verticillium wilt caused by *Verticillium dahliae* and bacterial canker or olive knot caused by *Pseudomonas syringae* pv. *savastanoi*.

There are numerous pests, which generally cause much more economic harm to olive cultivation than diseases. The most damaging insect pests are the olive fly (*Bactrocera oleae*) and olive moth or kernel borer (*Prays oleae*, synonym *Prays oleellus*) on fruits, black scale (*Saissetia oleae*) on branches, jasmin moth (*Margaronia unionalis*) on young shoots, bark beetles (*Hylesinus oleiperda* and *Phloeotribus scarabaeoides*) on branches and trunk, psyllids (*Euphyllura olivina*) sucking on flowers, mites (*Aceria oleae*) on leaves and fruits and thrips (*Liothrips oleae*) on flowers and young leaves. Insect control in olive cultivation is increasingly based on systems of integrated pest management including monitoring, pheromone trapping, promoting or releasing natural enemies, *Bacillus thuringiensis*-based insecticides and cultural measures such as pruning and irrigation.

Harvesting Olives for oil are harvested at full maturity in late autumn or early winter, either mechanically or with the use of rakes, beating poles and collecting nets. Table olives are harvested by hand; mature green fruits in early autumn and black olives in late autumn. Manual fruit picking (capacity about 80 kg/person per day) accounts for 50–60% of field production costs. Machines developed to reduce harvesting costs include trunk and branch shakers in combination with inverted umbrellas or rolling canvas frames to catch the fruits. Self-propelled overhead harvesting machines in olive orchards planted in hedge rows and the application of chemicals (e.g. ethephon) to promote fruit abscission shortly before harvesting are still in the testing stage.

Yield World average yield in 1999 was 1.7 t of olive fruits per ha. Fruit yield per ha varies from less than 1–3 t in traditional olive groves to 4–10 t under irrigation and optimum agronomic practices (e.g. in Italy at 280 trees per ha). In well-managed plantings under rainfed conditions, fruit yield is 2–5 t/ha. There is always considerable year-to-year variation in productivity. About 5–6 kg of fruits are needed to produce 1 kg oil. The world's average oil production in 1999 reached about 300 kg/ha.

Handling after harvesting Oil extraction should start within 3–4 days after fruit harvesting to avoid a change in flavour and increase in free fatty acid content. The fruits are washed, crushed and mashed into a paste, from which the oil is cold-extracted by mechanical pressing. The 'margine', or mixture of water and oil, is allowed to settle and the oil is separated by decantation, centrifugation and filtration. Oil prepared exclusively by this process, i.e. by physical means only and without any heating, is called virgin olive oil. In the European Union, virgin olive oil is graded into 4 classes based on many characteristics of which the most important ones are free fatty acid content and organoleptic test score: extra virgin oil, virgin oil, standard and 'lampante' virgin oil. 'Lampante' virgin oil and oil obtained by heating or solvent extraction are either used industrially or have to be refined by neutralization, bleaching and deodorization to produce refined olive oil. Further solvent extraction may be done to produce an industrial grade oil from the cake.

Preservation of table olives starts with soaking fruits in an alkaline solution to reduce the bitterness before pickling in brine (Spanish-style and Californian-style). The Greek-style preservation of fully ripe, black olives involves pickling in brine without alkaline pre-treatment.

Genetic resources The numerous traditional olive cultivars (estimated at 2000) are gradually disappearing because of abandonment of marginal groves and urbanization or replacement by modern cultivars. Programmes to collect and preserve this valuable olive germplasm are in progress with the support of the International Olive Oil Council (COI) and the European Union. In addition to the Olive World Collection at Cordoba (Spain) with 310 accessions, there are 73 collections of olive germplasm in 23 countries and a project of a second world collection at Marrakech (Morocco).

Breeding Olive improvement has a long tradition of clonal selection. Breeding programmes based on inter-varietal crosses followed by selection within segregating seedling populations are of fairly recent date. The long juvenile phase of olive seedlings has been an impediment to breeding, but forcing methods and existing genetic variation in length of juvenile phase have contributed to shorter breeding cycles. Main criteria of selection in the olive are fruit yield, regular production, cold tolerance, early first bearing, compact growth, oil content of the fruit mesocarp, quality of the oil and resistance to diseases and pests. Quality of olive oil is determined by standard physical and chemical analyses and sensory assessment of taste and flavour. Host resistance to *Spilocaea oleagina* has been reported in Israel and to *Pseudomonas syringae* pv. *savastanoi* in Portugal. Progress is also being made with the application of molecular biology in the olive, including molecular markers for cultivar identification, the construction of a linkage genome map and marker assisted selection. There are no crossing barriers for introgression of desired characters from the oleaster olive and some related species.

Prospects Increasing interest in the olive as a source of high quality and healthy vegetable oil may have a positive effect on world production, notwithstanding its high production costs in relation to other vegetable oils. The olive also contributes considerably to environmental protection (soils, flora and fauna) in dry and hilly areas, particularly of the Mediterranean region. There are prospects for olive cultivation in Australia, India, China and possibly northern Thailand but possibilities in South-East Asia are very limited.

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N. Moutier & H.A.M. van der Vossen

Reutealis trisperma (Blanco) Airy Shaw

Kew Bull. 20: 395 (1967).

EUPHORBIACEAE

$2n = 22$

Synonyms *Aleurites trisperma* Blanco (1837), *A. saponaria* Blanco (1845).

Vernacular names Philippine tung, soft lumbang, banucalag nut (En). Indonesia: kemiri cina (Java), muncang cina (Sundanese), minyak pakal (oil). Philippines: baguilumbang, lumbang balukalad, balokanad (Pilipino), balukanag, lumbang (Bikolano).

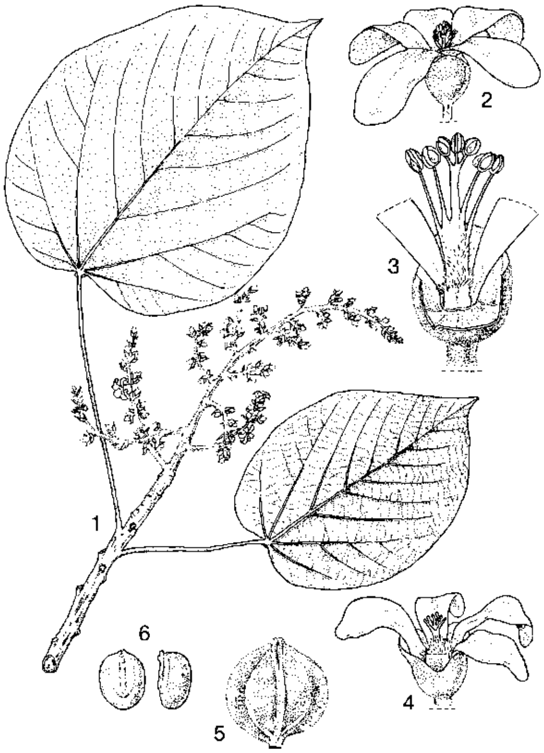
Origin and geographic distribution *R. trisperma* is native to the Philippines (Luzon, Negros, Mindanao), where it is also occasionally cultivated. It has been planted in Java (Indonesia), where it also became naturalized.

Uses A drying oil is obtained from the seed of *R. trisperma*. It was formerly made into a weak soap which was popular with sailors as it lathered with sea water. The oil has been widely utilized in the Philippines for illumination, for lubrication and to caulk ships. The oil is said to be an effective insecticide and can be applied as a wood preservative. It can be used as a drying oil in making paint and varnish when combined with kemiri oil (from seed of *Aleurites moluccana* (L.) Willd.) or tung oil (from the seed of *Vernicia fordii* (Hemsl.) Airy Shaw). The wood can be made into tea boxes, matches, wooden shoes and light construction material. Medicinally, sap from the bark has been used to cure scurf and the seed as a strong purgative.

Production and international trade *R. trisperma* products are only produced and used locally and production statistics are not available. In the Philippines, it is said to be a major source of drying oil.

Properties The seed of *R. trisperma* is made up of a shell or seed coat (35–45%) and a kernel (55–65%). The kernel contains about 55% dark orange oil (dry matter based). The approximate composition of the fatty acids is, according to one analysis: palmitic acid 13%, palmitoleic acid 5%, stearic acid 6%, oleic acid 18%, linoleic acid 23%, linolenic acid 5% and unidentified 30%. Another analysis indicated the following composition: palmitic acid 10%, stearic acid 9%, oleic acid 12%, linoleic acid 19% and α-eleostearic acid 51%. The presence of α-eleostearic acid is characteristic of *Aleuritinae* and explains the toxicity of the oil. Some physical characteristics of the oil are: specific density 0.89 (25°C), iodine value 160 g/100g, acid value 1.7 mg K per g oil, saponification value 192–200, melting point 2–4°C and solidifying point −6.5°C. The oil turns rancid very quickly unless stored in airtight containers. Although the oil is a drying one, it is not suitable by itself for paint manufacturing. Paint made with *R. trisperma* oil quickly forms a surface foil that effectively seals the paint from the air and prevents further drying. Mixing the oil with at least an equal amount of the less drying kemiri oil or tung oil overcomes this problem. After oil extraction, the remaining cake can be used as a fertilizer, containing about 6% nitrogen, 1.7% potassium and 0.5% phosphorus. The fresh kernel of the seed has a pleasant, nutty taste, but may cause a burning sensation in the mouth and throat. Consuming even part of a single seed causes violent vomiting within half an hour and diarrhoea within a few hours. The oil may irritate the skin and cause eruptions. The latex from the bark is known to cause dermatitis.

Description Evergreen tree, up to 15 m tall with stem 60 cm in diameter, bark grey to brown. Young twigs distinctly 5-ribbed, with simple indumentum, soon glabrescent. Leaves alternate, simple; stipules triangular, 4–6 mm × 2–4 mm, early caducous; petiole terete, 0.5–3 cm long, striate, with a conspicuous adaxial groove and at apex 2 sessile, cup-shaped glands 1–2 mm in diameter, exuding sweet sap; blade ovate, (4–)8–16(–28) cm × (2.5–)7–15(–22.5) cm, never lobed, base truncate, cordate or reniform, margin entire, apex acuminate, ending in a sessile, discoid gland; venation pinnate with 4–9 pairs of veins, at base 3–7 veins



Reutealis trisperma (Blanco) Airy Shaw – 1, habit flowering branch; 2, male flower; 3, male flower showing staminal column and disk glands (calyx and petals partly removed); 4, female flower (one petal partly removed); 5, fruit; 6, seeds, ventral and side views.

palmately arranged; lower surface stellate-pubescent, prominently in vein axils. Inflorescence a terminal, numerous-flowered, woolly panicle (pyramidal thyrse), 4–30 cm × 4–21 cm, with simple and stellate hairs; flowers unisexual, in bracteate clusters, protogynous, each major axis terminated by a solitary female flower, lateral cymules male; bracts oblong-triangular, 2–7 mm × 1–3 mm, conspicuously hooded after anthesis; pedicel up to 5 mm long, densely puberulous; flowers regular, small, about 1 cm in diameter, yellow-white, often flushed with pink; calyx bell-shaped, valvately rupturing for half to two thirds its length into 2 or 3 lobes, densely pubescent outside, glabrous inside; petals 5, free, imbricate, clawed, narrowly obovate-spatulate, rounded at the apex, veins not distinct, glabrous on the inside except for the claw, sericeous outside; disk with 5 fleshy glands (large in male, small in female flowers), and 5 free lobes bearing apically a conspicuous tuft of upwardly directed hairs; male flowers 6–10 mm × 10–13 mm, calyx lobes about 5 mm long and wide, petals 7–13 mm × 2–4 mm, claw 2–3 mm long and basal part adnate to the staminal column; stamens (7–)8(–10), in 2 whorls, filaments united into a column, the 5 outer ones up to 3 mm long, free for about half their length, the 2–5 inner ones up to 5 mm long, united for nearly their entire length; female flowers 7–8 mm × 8–10 mm, calyx lobes about 4 mm long and wide, petals 6–14 mm × 3–5 mm, claw 2–3 mm long, ovary superior, ovoid-subglobose-trigonous, 2–4 mm in diameter, 3–4-locular, densely hairy, styles 3–4, 2 mm long, 2–3-lobed with spatulately flattened stigmas. Fruit capsular, subglobose, 3–5 cm in diameter, velutinous, with 3 or 4 distinct longitudinal ridges, light brown. Seed without caruncula, flattened subglobose, 2–3 cm × 1.5–2 cm, surface smooth; hilum large, brown to maroon with faint dark brown variegations; embryo straight, embedded in copious endosperm; cotyledons flat, broad.

Growth and development Germination of the seed of *R. trisperma* takes about 3 weeks and early growth is fairly rapid. On fertile soils, seedlings may grow to a height of 50 cm in 1 year, while trees reach 5 m in 5 years and develop a dense crown with dark green foliage. On poor soils with minimal husbandry in Indonesia, however, most trees only reach a height of 4 m in 10 years. First fruits are collected 8 years after planting, but only some trees older than 10 years produce in quantity. In the Philippines, the fruiting season is from January to July.

Other botanical information *Reutealis* Airy Shaw is closely related to *Aleurites* J.R. Forst. & G. Forst. and *Vernicia* Lour., together constituting subtribe *Aleuritinae* (of the tribe *Aleuritideae*, subfamily *Crotonoideae*, family *Euphorbiaceae*). These three genera were separated from the former single genus *Aleurites*. *R. trisperma* is the only species in *Reutealis*. In contrast to *Aleurites*, *Reutealis* has truncate to cordate, never cuneate leaf bases, flowers with 7–10 stamens (*Aleurites* 17–32), ovary 3–4-locular (*Aleurites* 2–3) and a dehiscent, capsular fruit (*Aleurites* drupaceous). *Reutealis* can be distinguished from *Vernicia* by its stellate hairs on the leaf underside (hairs simple or bifurcate in *Vernicia*), 5-angular twigs (terete in *Vernicia*) and a woolly, pyramidal thyrse with flowers about 1 cm in diameter (*Vernicia* has a tomentose, corymbiform thyrse with flowers 2–4 cm in diameter).

Ecology *R. trisperma* is a rare tree in forests at low to medium altitudes in the Philippines. In western Java, where the tree has been introduced, it is locally naturalized at sea level on poor soils.

Agronomy *R. trisperma* is propagated by seed which is recalcitrant. In the Philippines, a planting experiment showed a germination rate of 98% in only 19 days. In the early 1900s in West Java, *R. trisperma* was sown directly in the field, intercropped with food crops during the first 2–3 years and then left almost untended. In the Philippines, sowing in a nursery and transplanting bare-rooted seedlings into the field gave mixed results. After 4 months, untreated seedlings had a survival rate of only 30%, covering the roots with mud increased the rate to 50%, while treatment with the surfactant Agricol resulted in 75% survival. Diseases and pests are not known to cause serious damage. Fruits are normally collected from the ground, where they may be left for 7–10 days. Alternatively, a light pole with an attached hook may be used to detach fruits from the tree. After collection, the seeds should be processed rapidly as the thin seed coat does not protect the kernel against oxidation of the oil. Usually whole seeds are ground, although removing the seed coat before grinding gives a better quality oil. The seed coat can be easily removed manually after drying the seed. The ground seeds are warm-pressed to extract the oil. The oil should be stored in airtight containers as its quality deteriorates rapidly through oxidation.

Genetic resources and breeding No germplasm collections or breeding programmes of *R. trisperma* are known to exist.

Prospects In spite of the high oil content of its seeds, it seems unlikely that *R. trisperma* will become an important source of drying oil as several alternative sources are available. The moderate growth rate of the tender seedlings does not favour the inclusion of R. triperma in reforestation programmes.

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N.O. Aguilar & L.P.A. Oyen

Ricinus communis L.

Sp. pl.: 1007 (1753), Gen pl. ed. 5: 437 (1754).

EUPHORBIACEAE

$2n = 20$

Vernacular names Castor (En). Ricin (Fr). Indonesia: jarak (general), kaliki (Sundanese), balacai (Moluccas). Malaysia: jarak. Papua New Guinea: kaswel. Philippines: sina, lingang-sina (Pilipino, Tagalog), tangan-tangan, tang-tangan (Bilokano), taua-taua (Ilokano), tangan-tangan, lansinan (Tagalog), tangan-tangan-hawa (Sulu). Cambodia: lohông khvâ:ng, lohông pré:ng. Laos: hungx saa, hungx hna:n. Thailand: lahung (general), hin (northern), lahung daeng (central). Vietnam: th[aaf]u d[aaf]u.

Origin and geographic distribution Castor is indigenous to East Africa and probably originated in Ethiopia. It was already grown for its oil in Egypt some 6000 years ago and spread through the Mediterranean, the Middle East and India at an early date. In Chinese and European literature, it is not mentioned until the 9th and 15th Centuries AD, respectively. Castor is now grown in most drier areas of the tropics and subtropics and in many temperate areas with a hot summer. It naturalizes easily and grows in many areas as a ruderal plant.

Uses The main product of castor is the oil extracted from the seed. The oil which consists mainly of triglycerides of ricinoleic acid is non-drying and non-edible. Traditionally, it is used for illumination and in medicine. As a lamp oil, it is now only used in rural areas and even then often mixed with kerosene. Currently, castor oil is primarily used as a high-quality lubricant and a versatile raw material in the chemical industry. As a lubricant it is characterized by its high lubricity, high viscosity remaining constant over a wide range of temperatures and its insolubility in aliphatic petrochemical fuels and solvents, making it suitable for equipment operating under extreme conditions such as in arctic zones and in aviation. Another specialized use of castor oil is in crumb rubber manufacturing, where it prevents rubber crumbs from coagulating. Highly purified, food-grade castor oil is used as an anti-stick agent for candy-moulds and as a lubricant for machinery in industrial food processing. Castor oil is further employed as a plasticizer in the coating industry, as a disperser for dyes and as a filler in cosmetics such as lipsticks, nail varnishes and shampoos. Saponification of castor oil yields a clear, transparent soap.

Partial oxidation of castor oil in air at about 100°C yields 'blown oil', which remains fluid at low temperatures and is a major component of hydraulic and brake fluids and is used as a plasticizer for inks, lacquers and leather. Dehydration of castor oil turns it into a very pale, odourless, quick-drying oil used in manufacturing alkyd resins, epoxy resins and acryl resins used in heavy-duty paints and varnishes e.g. for refrigerators and other kitchen equipment. Hydrogenated castor oil yields a hard and brittle, odourless wax, mainly applied to modify the qualities of other waxes. Its main component hydroxystearic acid, is used in lubricants, insulators and surfactants and in the production of non-drip paints. Treating castor oil with sulphuric acid yields 'Turkey-red oil', a wetting agent used in dyeing cotton and linen fabrics and in leather and fur manufacturing.

Cracking of ricinoleic acid yields a number of compounds, particularly suitable for the manufacture of high quality lubricants and synthetic polymers such as the polyamides nylon 11, nylon 6.10 and more recently developed polyurethanes. Other components derived from cracked ricinoleic acid include aroma chemicals, sebacic acid used in manufacturing jet-engine lubricants, synthetic detergents and additives for insecticides. Castor oil is so important in chemistry and also in military applications that the United States has declared castor oil a 'strategic material' of which adequate stocks have to be maintained at all time.

In medicine, castor oil is used primarily as a purgative. It stimulates peristalsis by irritating the intestinal mucosa but causes little griping. The oil is also applied as an emollient in the treatment of sores and as a solvent for antibiotic eyedrops. Neutral sulphated castor oil can replace soap in certain cases of contact dermatitis. Castor oil has been used as an abortifacient and in preparations inducing labour in pregnant women. Ricinoleic acid prepared from the oil is a component of contraceptive creams and jellies.

The presscake of castor beans is poisonous and allergenic and is mainly used as fertilizer or as fuel. Methods to detoxify the presscake to make it suitable as an animal feed have been developed but some toxicity may remain even after treatment, to which horses are particularly sensitive. Another product extracted from the presscake is a lipase used in the industrial processing of fats.

In China, South and South-East Asia, the leaves of castor are used to treat skin diseases. They are also fed to the eri silkworm (*Philosamia ricini*, syn. *Samia cynthia-ricini*). Although they are somewhat toxic, mature leaves are occasionally used as a fodder, but care must be taken to avoid the more toxic young leaves. In Korea, mature leaves are dried and stored until winter when they are eaten as a vegetable; in Bengal (India) the young fruits are eaten. Castor is also an ornamental.

Production and international trade Between 1985 and 1998 the annual world production of castor bean averaged 1.2 million t, while the harvested area declined gradually from 1.6 million ha to 1.2 million ha. India and China are by far the most important producers, accounting together for almost 80% of the production. Brazil has long been the second largest producer, but a dramatic decline in production has occurred since 1985. In South-East Asia, Thailand and the Philippines have a notable annual production of 5000–25 000 t and 500–7000 t, respectively. Production is tending to decline in the Philippines and to a lesser extent also in Thailand. Most castor beans are now processed to castor bean oil in the countries of production. India dominates the export market of castor bean oil (199 000 t of total world exports of 236 000 t in 1997). Production in China seems to be mostly used locally. Major importers of castor seed or oil are France (about 60 000 t oil), the United States (40 000 t oil), Germany (25 000 t oil + 22 000 t beans) and Japan (25 000 t oil). In South-East Asia, Thailand is an important importer. Programmes are in place to promote local production of castor in both the United States and the European Union.

Data on cultivated acreage and yield per ha do not present a fair indication of the actual production in a country since much castor is collected from the wild and because sole cropping of castor by peasant farmers is the exception.

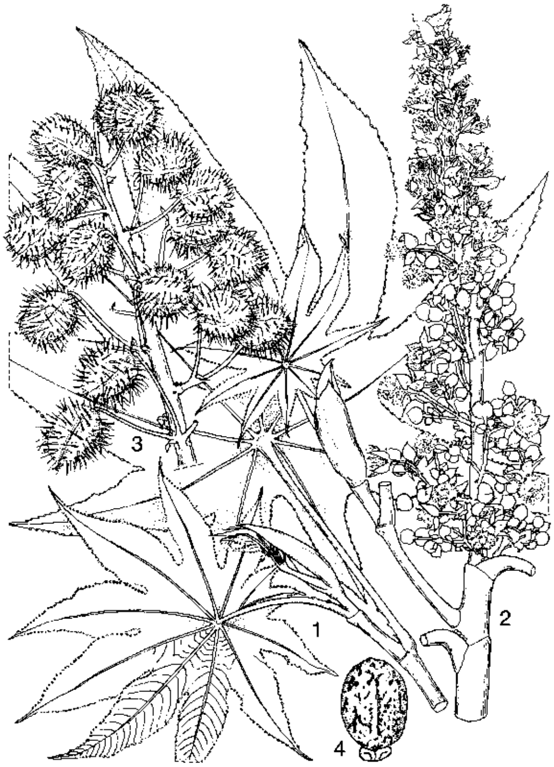
Properties Per 100 g, castor seeds contain approximately: water 5 g, protein 15–30 g, oil 43–53 g, carbohydrates 7–10 g, crude fibre 15–25 g, ash 2–3.8 g. The seed, and to a minor extent other plant parts as well, contain extremely toxic proteins, the toxic alkaloid ricinine, and allergens.

The oil is non-drying, viscous, nearly colourless, transparent and with a characteristic odour and taste. It has the highest viscosity of all vegetable oils; ricinoleic acid (about 90%) renders the special properties to the oil. Other fatty acids include: palmitic acid (2%), stearic acid (1%), oleic acid (about 7%), linoleic acid (3%).

Ricinoleic acid (12-hydroxy-9-octadecenoic acid) has a single double bond and is further characterized by a hydroxyl group. Dehydration of castor oil in which part of the ricinoleic acid is converted to a polyunsaturated acid yields a quick-drying oil with properties that compare favourably with those of tung oil and linseed oil. It is used in paints, varnishes, waxes and epoxy resins. Hydrogenation of castor oil in which the ricinoleic acid is partly or completely converted to 12-hydroxystearic acid yields a hard and brittle wax. Blown oil, i.e. oil that is oxidized and partially polymerized by bubbling finely dispersed air through it at 80–130°C, is a major component of hydraulic flu-

ids. In inks, it is used to reduce water pick-up and improve drying characteristics.
When the oil is pressed or extracted from the seed, the poisonous proteins remain in the presscake. The main toxic proteins are 'ricin' a potent cytotoxin and 'RCA' (Ricinus communis agglutinin), a powerful haemagglutinin. Poisoning by ingestion of castor seed is due to ricin, as RCA does not penetrate the walls of the intestines. Ricin is extremely poisonous when injected into the bloodstream; as little as 1 mg can kill an adult. It irreversably inhibits ribosome activity; a single molecule that has entered a cell can inactivate over 1500 ribosomes per minute. It was probably used in the infamous 'umbrella' murder of a Bulgarian journalist in London in 1978. Because of its extreme toxicity, ricin is included in Schedule 1 of the Convention on Chemical Weapons (1994) imposing the most stringent restrictions and control on its production, transportation and use. The ricin molecule consists of 2 parts, one responsible for its transport through the cell wall, the other the toxin proper. Pharmacological research is going on to combine the toxic part of ricin with monoclonal and polyclonal antibodies in the development of immunotoxins for the treatment of cancer and Aids.
The alkaloid ricinine ($C_8H_8N_2O_2$) is a convulsant agent; it causes respiratory depression. Castor seeds are allergenic. They may cause asthmatic reactions in sensitive persons, but others may work in castor processing facilities for years without developing any sensitivity.
As a flavouring, castor oil has been accorded the generally recognized as safe (GRAS) status in the United Sates. The weight of 1000 seeds is between 100–1000 g.

Description An evergreen, glabrous, soft-woody shrub or small tree, often grown as annual, 1–5 m tall. Taproot strong and with prominent lateral roots. Stem and branches with conspicuous nodes and ringlike scars of the bracts; shoots usually glaucous, variously green or red; glands often present at nodes, petioles and main axes of inflorescences. Leaves arranged spirally, dark green when old; stipules 1–3 cm long, united to a sheathing bud, deciduous; petiole round, 3.5–50 cm long; blade peltate, 10–70 cm across, membranous, palmately lobed with 5–11 acuminate, serrate lobes. Inflorescence an erect terminal panicle, later somewhat lateral by overtopping, up to 40 cm long, usually glaucous, with cymes of unisexual flowers, male flowers towards the base, female ones towards the top; flower with short pedicel,



Ricinus communis L. – 1, branch with leaves; 2, inflorescence; 3, infructescence; 4, seed.

1–1.5 cm in diameter, with 3–5 acute calyx lobes; corolla absent; male flowers with many stamens in branched bundles; female flowers with early caducous sepals, ovary superior with three 1-ovule cells, usually soft spiny, styles 3, red or green, 2-cleft. Fruit an ellipsoid to subglobose capsule, 15–25 mm long, brown, spiny or smooth. Seed ellipsoid, 9–17 mm long, compressed, with a brittle, mottled, shining seedcoat and with a caruncle at the base; endosperm copious, white; cotyledons thin. Seedling with epigeal germination; cotyledons petioled, broadly oblong, up to 7 cm long, flat, with entire margin; first leaves opposite.

Growth and development Seedlings of castor emerge 10–20 days after sowing. Later development of the plant is in accordance with Leeuwenberg's growth model and with sympodial branching. The successive formation of branches and inflorescences continues throughout the plant's life. The node at which the first inflorescence originates is a cultivar characteristic. In annual cultivars, the first inflorescence is the largest one and may account for up to 80% of the seed yield. In perennial forms flowering is more diffuse. Flower-

ing starts early in the life of castor and continues for a long time. The first flowers may open 40–70 days after sowing. Pollen is mainly shed in the morning and pollination is by wind. As growth is indeterminate, one plant may bear infructescences in different stages of development. Ripening of fruits within an infructescence is uneven, the lower fruits maturing before the upper ones. In wild types, the period of maturation between the first and the last fruits within a given infructescence may be several weeks. In cultivars grown as annuals, the period from emergence to maturation varies from 140–170 days; however, perennial forms are common in peasant agriculture.
Under favourable conditions, castor has a high rate of photosynthesis which has been attributed to a high chlorophyll content in the leaves.

Other botanical information *Ricinus* L. comprises only one species (*R. communis*). Previously described species have been transferred to other genera or grouped within *R. communis*. Some castors are large perennials, others behave as short-lived dwarf annuals and every gradation between them can be found. Colour differences in leaves, stems and inflorescences have resulted in selection of these variants as horticultural plants. However, attempts to classify such selections as subspecies or varieties are botanically inaccurate; a classification into cultivar groups would be more appropriate. In most countries red and white types (cv. groups) are distinguished based on the colour of young shoots. Within these groups, cultivars are recognized based on seed characteristics. Numerous cultivars exist; 'Hale' and 'Lynn' are dwarf cultivars in the United States, now mainly used as pollen parents in the production of hybrids. Other well-known cultivars include: 'Conner' and 'Kansas' in the United States, 'Rica' and 'Venda' in France and 'T-3', 'GCH-3', 'DCS-9' and 'SKI-7' in India.
Castor is used extensively in physiological studies to elucidate mechanisms involved in phloem transport.

Ecology Castor is a long-day plant but is adaptable to a fairly wide photoperiodic range. At a daylength of 9 hours, growth and development are reduced, but at 12–18 hours, development is normal. Castor grows throughout the warm-temperate and tropical regions. It has been commercially cultivated from 40°S to 52°N, from sea level to 2000 m altitude at the equator, with an optimum between 300–1500 m, the limiting factor being frost. Suitable soil temperatures for germination are between 10–18°C. Castor requires average day temperatures of 20–26°C with a minimum of 15°C and a maximum of 38°C. It prefers clear, sunny days, with low humidity. Temperatures of 40°C or higher at flowering are detrimental.
In regions with an average annual rainfall of 750 mm or less, sowing should be carried out on such a date that 400–500 mm rainfall up to the time of main flowering is assured for the crop. Castor can tolerate water stress because of its deep root system, but is sensitive to excess of water and humidity.
Castor will grow on almost any soil type as long as it is well-drained and reasonably fertile. It prefers deep, sandy loams with pH 5–6.5. Plants with the best tolerance to salinity or alkalinity tend to be large bushy ones with little commercial value.

Propagation and planting Castor is propagated by seed. Per hole, 2–3 seeds are planted at a depth of 3–8 cm; alternatively it is sown in rows. Crop management varies widely when castor is grown as a cash crop. For mechanized cropping under rainfed conditions, field preparation starts by ploughing deep enough to break up any compact layers. Castor requires a moist topsoil for germination and early growth for a longer period than maize or cotton. In dry regions where total rainfall is low, ridging is a suitable method. Smallholders usually intercrop castor with annual crops or plant it along the edges of fields. Short-cycle cultivars may be grown in sole cropping as a second crop. In intercropping, plant distances may be as much as 4–5 m and castor will receive the treatment of the main crop. With dwarf cultivars in sole cropping, planting may be at 1 m row distance. Closer spacing can result in considerable damage to branches and to shallow lateral roots during weeding. Recommendations for in-row spacing range from 25–30 cm for dwarf to 30–40 cm for larger cultivars, or about 25 000–30 000 plants/ha for crops grown in locations with 750–900 mm rainfall. Under irrigation, row width may be determined by the system of water delivery, and where water is not limiting, 30 000–40 000 plants/ha is feasible, depending on cultivar.

Husbandry Castor seedlings are poor competitors and weed control is essential. Two weeding rounds are normally sufficient. Where practical, application of a pre-emergence herbicide followed by handweeding is probably most effective. The first weeding is about 6 weeks after sowing. It is often combined with thinning, earthing up and topping. Since the young crop is very susceptible to mechanical damage, weeding should be carried out carefully. Effective weed control often results in a relatively bare soil surface thus offering little protection against erosion. This, combined with the low soil-binding ability of castor, often makes it necessary to include conservation measures in the cropping system and to exercise care in selecting sites for large plantings of castor.

Peasant farmers do not usually irrigate or manure castor, although both are often beneficial for yield. It has been calculated that 3.3 t fruit (2 t seed and 1.3 t hulls) remove 80 kg N, 8 kg P, 26.5 kg K, 8.5 kg Ca and 6 kg Mg.

Diseases and pests Few diseases are of economic importance. Normally, serious attacks only occur in badly-growing crops and under humid conditions. The most damaging diseases that attack seedlings are various rots ('damping-off' caused by *Fusarium*, *Phytophthora*, *Rhizoctonia*, *Sclerotium* spp.). The most common foliar disease is rust caused by *Melampsora ricini* which is now probably of worldwide occurrence; symptoms are the presence of uredopustules on the lower surface of the leaves. In severe cases leaves may be covered completely and dry up. A high degree of resistance is found in e.g. the Indian cultivars 'Raichur Dwarf', 'VH-701/5' and '837/1'. *Cercospora ricinella*, causing a leaf-spot disease, can become locally damaging in Indonesia. Among the capsule diseases, those caused by *Alternaria* and *Botrytis* are the most serious ones. *Alternaria ricini* causes damage worldwide. Symptoms are the appearance of brown lesions on the leaves surrounded by a yellow halo. Affected capsules may suddenly wilt and turn dark brown or purple; also sunken areas may develop which gradually enlarge to cover the whole capsule. Under very humid conditions inflorescences may become covered by black sooty spore deposits. Seed treatment with a fungicide may control the disease. In later stages foliar application of carbamates or copper-based fungicides may be effective.

Probably the most damaging pests are those attacking the inflorescence, such as mirids (*Helopeltis* spp.). Peach moth or castor shoot and capsule borer (*Dichocrocis punctiferalis*) is a most important pest in India and throughout South-East Asia. Young caterpillars feed on the green capsules and bore their way inside at the apical or basal end. At the point of entry a silken gallery is formed. As a single caterpillar may affect several fruits, they may become webbed together by these galleries. As the caterpillars feed inside the fruits, control is difficult. Many other pests have been observed but damage is mostly minor and localized. Tall, perennial forms can often outgrow the effects of insect attack. However, because of their tall stature and long duration, they are more susceptible to damage caused by stem borers than short-term ones.

Harvesting Castor is harvested in the dry season. The whole infructescence is reaped when about half of its fruits are mature. Harvesting is done every 2 weeks. Simple tools in the form of a tin with a notch for manual harvesting have been developed. Where castor seeds are merely collected from wild or volunteer plants, their harvesting sometimes involves no more than collecting the scattered seeds. Under intensive cropping, harvesting and hulling are the most time-consuming operations. However, suitable machines and cultivars which are adapted to large-scale cultivation have been developed. Mechanical harvesting consists basically of removing fruits from standing plants. Commercial plantings of dwarf cultivars are usually fully mechanized. Important problems still to be solved are the uneven ripening and the varying thickness of the fruit wall, both producing a large proportion of unhulled or broken seeds.

Yield Average seed yield of castor is about 1000 kg/ha, with a maximum of about 3000 kg/ha. In China and India, average seed yields are about 1000 kg/ha while those in the Philippines fluctuate from 800–1000 kg/ha. Thailand's seed yields declined from 800 kg/ha in 1985 to 500 kg/ha at present. Statistics on yield are very difficult to compile as castor is often intercropped or grown along field borders.

Handling after harvest The fruits of traditional cultivars are mostly semi-shattering. After harvesting, the panicles are dried and spread on a floor. They lose most of their seeds in 4–6 days. Unopened fruits are threshed. After separation of the healthy seeds from the trash, the product is ready for storage or for sale. Fruits of modern cultivars are often non-shattering. Such cultivars should only be grown if mechanical dehullers are available, because traditional threshing results in a large proportion of damaged seeds. Castor seed can only be stored in the open for short periods, as both heat and sunlight reduce its oil content and quality. Seed should be handled with care since the thin and often brittle testa is easily damaged.

Genetic resources Local populations are commonly the best resources for breeding. Large collections are maintained in the Russian Federation (N.I. Vavilov Institute of Plant Industry, St. Petersburg) and in China (Institute of Crop Germplasm Resources, Beijing and Institute of Oil Crops Research, Wuhan), while smaller collections are kept in e.g. the United States, Ukraine, Brazil and India. In Ethiopia (Biodiversity Conservation and Research Institute, Addis Ababa), a collection of local castor is available.

Breeding All natural forms of castor are diploid; they cross freely and are fully fertile. The frequency of natural out-crossing is commonly between 5–50%, but in some dwarf cultivars it may be as high as 90–100%. Male-sterile and female-sterile lines have been identified and are of great value in breeding. Selection has mostly focused on problems associated with mechanical production such as annual life cycle, dwarf plant architecture, and indehiscent, thin-hulled and sparsely spiny fruits, maturing synchronously. The main aims of modern castor breeding are high seed yield, high oil and ricinoleic acid contents, easy harvesting and resistance to diseases and pests.

Prospects As a raw material for industry, castor oil has to compete with alternative raw materials. Demand depends on the price of the oil in relation to that of alternatives and the reliability of supply. Both supply and price have fluctuated considerably in the past. Currently, competition is strongest for dehydrated castor oil, as cheap alternatives prepared from soya bean oil are available. With increasing research efforts aiming at the development of new products based on the unique properties of ricinoleic acid, however, the demand for castor oil may increase in the future.

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C.J.P. Seegeler & L.P.A. Oyen

Salvia hispanica L.

Sp. pl.: 25 (1753).
LABIATAE
$2n = 12$

Synonyms *Kiosmina hispanica* (L.) Rafin. (1836), *Salvia chia* Sessé & Moc. (1893), *S. schiedeana* Stapf (1896).

Vernacular names Chia (En). Chia (Fr). Indonesia: cuwing, salasi huma (Sundanese).

Origin and geographic distribution *S. hispanica* originates from southern Mexico and northern Guatemala. Its earliest cultivation and utilization was by the Aztecs in Central America. It was introduced and naturalized in the West Indies, Spain and West Java. It is grown commercially in central Mexico, Guatemala, United States (southern California, south-eastern Texas), north-western Argentina and occasionally in West Java, Peninsular Malaysia and Singapore.

Uses The oil obtained from the seed of *S. hispanica* is used in cooking, cosmetic preparations and, as it is a drying oil, in the industrial production of paints, varnishes and lacquer work. Traditionally the oil is utilized in Mexican lacquer work and as overgloss protection for paintings. The presscake is suitable as human food and animal feed.

Since pre-Columbian times the people of Central America have consumed *S. hispanica* seeds as food and medicine. The seed is also a source of a mucilaginous polysaccharide gum. When water or juice is added to the seeds, a gel-like preparation is produced which is nutritious and filling. In Mexico parched ground seed sometimes mixed with maize flour is made into loaves. Ground seed is also mixed with orange juice to make a breakfast drink, while in West Java it is made into a drink that is used as a substitute for 'selasih', a drink made from *Ocimum basilicum* L. Seeds have also been used as thickening material e.g. in sauce preparation. The seeds are very nutritious and it is said that a teaspoonful would sustain a person on a forced march for 24 hours. The high content of anti-oxidants makes the seed a possible source for their commercial extraction. In herbal medicine chia seed is taken to adjust the secretion of bile particularly after emotional stress and as a remedy for constipation. Chia leaves contain an essential oil which is potentially useful in the production of flavours and perfumes and to reduce insect attack and damage in stored goods. *S. hispanica* has gained some importance as an ornamental in the United States. The seeds are placed on the surface of clay figurines. When wetted they germinate, covering the object with a coat of hairy sprouts.

Production and international trade Production and trade of chia seed is locally important in America but statistics are not available. In Mexico seeds are for sale in markets.

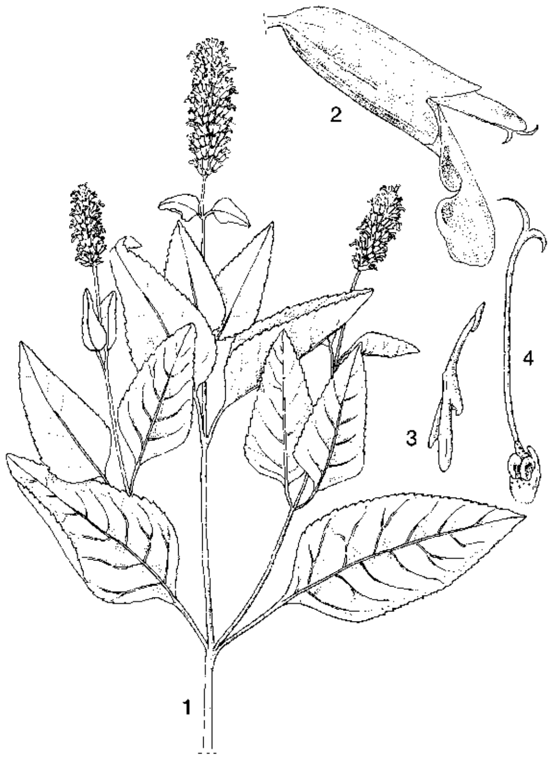
Properties Per 100 g, the seed of *S. hispanica* contains: protein 23 g and fat 25–39 g. The oil is clear, does not turn yellow with time; its iodine value is 198. Its lipid fraction is composed of neutral lipids 97%, glycolipids 2% and phospholipids 1%. The fatty acid components are linoleic acid 17–26%, linolenic acid 50–57%, and small amounts of palmitic acid and oleic acid. For the glycolipids and the phospholipids the dominant fatty acids are palmitic acid and linoleic acid.

As the content of unsaturated fatty acids in the seeds is high, they also contain a relatively large amount of anti-oxidants, including flavonols, caffeic acid and chlorogenic acid. Caffeic acid is a potential anti-oxidant for foodstuffs because it has no mutagenic effect.

The mucilaginous gum of chia is contained in large cells in the seed coat. When placed in water these cells swell rapidly absorbing 5–6 times the weight of the seed in 3 minutes. The gum consists of long polysaccharide chains that comprise β-D-xylose, α-D-glucose and 4-0-methyl-α-D-glucuronic acid in a ratio of 2:1:1.

In the essential oil from chia leaves, 52 components have been identified. Major components are β-caryophyllene, globulol, τ-muurolene, β-pinene, α-humulene, germacrene-B and widdrol. The composition of the essential oil varies with growing area, climate and post-harvest handling of the leaves.

Description Erect or ascending herb, 0.5–1 m tall or more; stem and branches quadrangular, villous and hispid. Leaves opposite, thin; petiole slender, 1–6 cm long; blade oblong-lanceolate to ovate, 3–8 cm × 1–4.5 cm, base obtuse and abruptly attenuate, margin entire at base and elsewhere serrate or serrulate, apex acute or acuminate, both surfaces pubescent. Inflorescence consisting of verticillasters of 6–10 zygomorphic flowers, these congested in a dense, terminal false spike 5–25 cm × 1.5 cm; internodes 2–5 mm long; bracts ovate-acuminate, 6–8 mm long, persistent; calyx tubular but 2-lipped, slightly inflated below, 6–8 mm long, in fruit 8–11 mm, densely pilose, upper lip strongly keeled, sharply pointed, lower lip 2-toothed; corolla tubular, 2-lipped, blue or purplish-blue, the lips shortly exposed, tube 4.5–5.5 mm long, upper lip rounded, 3 mm long, sericeous outside, lower lip 3-lobed; 3.5–5 mm long; stamens 4, didynamous, hardly exposed, lower pair fertile, lower connective branch swollen; disk prominent; ovary superior, style 2-branched, upper branch long and slender, 2.5 mm long, pointed, lower one short, club-shaped; the main style articulate above the base. Fruit consisting of 4 schizocarpous nutlets, each one ellipsoid, 1.8 mm long, mottled with black and grey.



Salvia hispanica L. – 1, flowering branch; 2, flower; 3, stamen; 4, pistil.

Growth and development The growing period of *S. hispanica* is 4–6 months. In the United States it is grown as a summer annual. It is sown and germinates during the warm days of late spring, flowers during the shorter days of September and produces seed that matures in the autumn. In West Java it bears flowers the whole year. The flowers are much visited by bees. When the seeds ripen, the plant loses its leaves and fields then look much like those of sesame.

Other botanical information *Salvia* L. comprises about 500 species, widely distributed in temperate and subtropical areas, but less so in the tropics. About 20 species occur in South-East Asia, of which 1 is truly native, 5 are naturalized and 14 others occur only in cultivation mainly as ornamentals. A small group of *Salvia* species and the closely related *Hyptis suaveolens* (L.) Poit. are known as 'chias'. They all occur in the drier parts of Mexico and include, in addition to *S. hispanica*, the summer annuals *H. suaveolens* ('chia grande', 'chan' or 'conivari') and *Salvia tiliaefolia* Vahl (mostly a weed, but seeds are occasionally collected), and the winter annuals *S. columbariae* Benth. ('California chia' or 'golden chia') and *S. carduacea* Benth. ('thistle sage'). In the United States the summer chias flower in late summer and produce seed in late autumn, the winter chias set seed in summer.

Ecology In its natural area, *S. hispanica* grows in moist or dry thickets, in open, often dry rocky slopes, sometimes on sandbars along streams and often as a weed, at altitudes 1150–2500 m. In West Java it can be found in open areas, road sides, fallow or weedy agricultural land and low brushwood at altitudes of 900–1700 m. In north-western Argentina it is grown at elevations of 300–1350 m, with maximum temperatures of about 30°C and minimum temperatures of 12.5°C. Rainfall in this region varies between 100–1000 mm per year. This is a species for the semi-arid areas.

Propagation and planting *S. hispanica* is grown from seeds. The germination rate of good seed averages 98%, declining to 75% after 1 year. The seed rate is about 6 kg/ha. The seeds are sown in rows that are 70–80 cm. apart.

Husbandry In commercial farms in north-western Argentina nitrogen fertilizer is applied at a rate of 25–50 kg/ha. *S. hispanica* is occasionally irrigated.

Diseases and pests Few diseases and pests seriously affect *S. hispanica*. Charcoal rot (*Macrophomina phaseolina*) occasionally causes damage.

Harvesting *S. hispanica* is harvested manually or with a modified combine harvester. In north-western Argentina, hand-harvesting gives higher yields than combine-harvesting.

Yield Commercially grown *S. hispanica* in north-western Argentina yields an average of 540–600 kg seed per ha, although it can be as high as 1600 kg/ha. In Mexico, 1000–3000 kg/ha are obtained.

Handling after harvest The oil of *S. hispanica* is obtained from the ground seed by heating and solvent extraction.

Genetic resources and breeding A few germplasm collections of *S. hispanica* exist, but the number of accessions is very limited. Breeding programmes are not known.

Prospects Interest in the oil of *S. hispanica* is growing both as a highly unsaturated food oil and as a non-yellowing, drying oil for varnishes and lacquer work. The current interest in traditional products and techniques is likely to strengthen this trend. Programmes have been established to expand production of *S. hispanica* in Argentina, while in the United States it is one of the crops promoted to diversify agriculture. There are no indications, however, that it will become more important in South-East Asia.

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B.E. Umali & L.P.A. Oyen

Sesamum orientale L.

Sp. pl.: 634 (1753).
PEDALIACEAE
$2n = 26$

Synonyms *Sesamum indicum* L. (1753), *S. luteum* Retz. (1791), *S. oleiferum* Moench (1802).

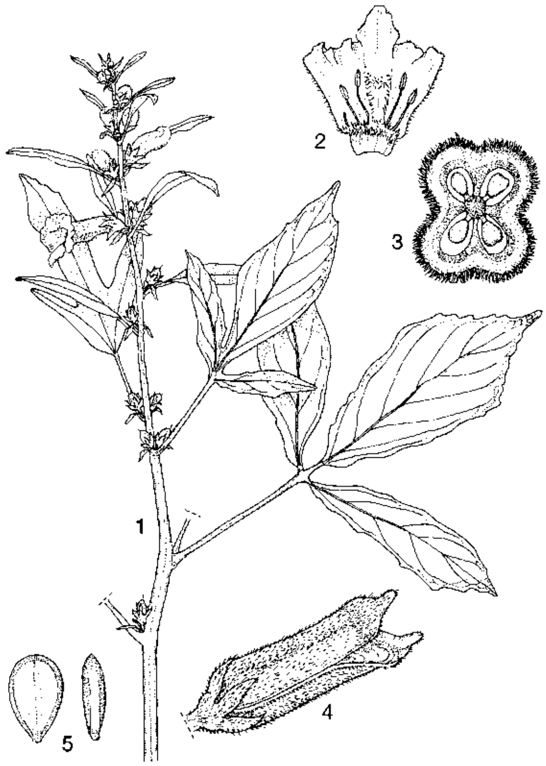
Vernacular names Sesame, gingelly, benniseed (En). Sésame (Fr). Indonesia: bijan, lenga (general), wijen (Javanese). Malaysia: bijan, lenga. Philippines: sesame, linga (Pilipino), langa (Ibanag), lunga, langa (Bisaya), lugna (Bikolano), linga (Ilokano), ahon-holi (Tagalog). Cambodia: longo. Laos: nga. Thailand: nga. Vietnam: c[aa]y v[uwf]ng, m[ef].

Origin and geographic distribution Sesame is probably the most ancient oilseed used by man, its domestication lost in the mists of antiquity. It is considered to have originated in Africa, most probably in Ethiopia, although there is also evidence supporting an Indian origin. As early as 2100–2000 BC sesame was an important crop in Mesopotamia, which became the main centre of distribution of sesame as a domesticated plant. King Sargon II (722–705 BC) considered the oil so important that he introduced price control measures which remained in place during the first millennium BC. Sesame found in excavations at Harappa (Pakistan) was dated at 2000 BC. The 'Medical Papyrus' of Thebes (Egypt), of about 1500 BC, lists herbal remedies that include sesame oil and seed. The Greeks and Romans spread sesame throughout the Mediterranean, but it was reported from Britain only in 1731. In the 6th Century BC, it achieved such prominence in China that it was used as currency. In Japan it was an established field crop by 1700 AD and now produces the most highly regarded edible oil. In Marco Polo's travels he noted excellent sesame oil in Afghanistan and a plentiful supply in Sri Lanka. India may have received sesame from Malaysia and Indonesia before 1500 BC, while it was mentioned in the Athavaveda of about 1000 BC as tila. It is now a major oilseed and the preferred edible oil. The earliest records from sub-Saharan Africa are those of early explorers; this region later became a major seed exporter. The Portuguese introduced sesame to South America, and slaves are credited as having introduced sesame to North America at the end of the 17th Century. Sesame is widely planted in Burma (Myanmar) and also cultivated elsewhere in South-East Asia, particularly in Thailand and Indonesia.

Uses Sesame seed, flour and oil are utilized in a very wide range of mostly edible products. Pure and crude sesame oil pressed from the seed can be used directly as a cooking oil while the refined oil is utilized as a salad oil or wherever an edible oil of high keeping quality is needed. In India sesame oil has to make up 5% of vegetable ghee, to facilitate detection of adulteration of ghee made from butter. The oil is also an important constituent in the production of pharmaceutical products, cosmetics, soap, and as a perfume fixative. In India, the oil is used for anointing and conditioning the skin. Whole seed may be eaten raw, roasted and dried. It is ground into a tasty paste known as 'tahini'. It is a major ingredient in various sweets and a garnish of breads and pastries. The minor components sesamin and sesamolin are effective synergists of pyrethrin, a natural insecticide. The presscake is a valuable stock feed. It is usually too expensive for general use but is utilized by growers for their domestic stock. In times of famine, the cake also provides a nutritious emergency food.

Production and international trade World production of sesame seed has grown only very gradually since the 1970s, despite an increasing demand for sesame oil in non-European countries, and amounted to 2.7 million t in 2000. International trade in sesame seed declined in favour of other more cheaply produced oilseeds. Africa, with an estimated 20% of total world production up to 1980, formerly contributed nearly 70% of world exports, with Sudan dominating and frequently accounting for half of the world exports; from 1970–2000 production in Sudan fluctuated around 200 000 t. In Burma (Myanmar) and China however, the area planted increased to supply local and regional demand, growing to 300 000 and 700 000 t, respectively. Annual production in India remained stable at about 500 000 t. Practically all world trade in sesame is as seed, and only minor quantities of oil and cake are shipped. Some 100 000–200 000 t of sesame seed is available annually for export; most movement is between neighbouring South-East Asian and African countries. Japan, Italy and China are major markets for international trade, with Israel, Saudi Arabia and Greece being substantial consumers.

Properties Sesame seed contains per 100 g edible portion: water 5 g, protein 20–25 g, fat 45–50 g, carbohydrates 16 g and fibres 5 g; it also contains vitamin A, thiamine, riboflavin, niacin and traces of ascorbic acid. The seed is rich in phytic and oxalic acid which on chelation with calcium create a slightly bitter taste. Crude sesame oil varies from dark to pale yellow while the refined oil is clear, pale yellow and has a nutty flavour. It consists of glycerides with as major fatty acids oleic acid (36–54%) and linoleic acid (38–49%). Other components are the saturated fatty acids: myristic acid (0.1% or less), palmitic acid (8–12%), stearic acid (3.5–7%) and arachidic acid (0.5–1%). The oil contains 1.2% unsaponifiable matter that includes tocopherols, and lignans including sesamin (0.1–0.6%), sesamolin (0.25–0.3%) and sesamol which give the oil its remarkable resistance to oxidation. Extracted sesame cake varies in colour from light yellow to greyish black depending on the dominant seed coat colour. Its chemical composition is also variable depending on seed type, method of oil extraction and whether it is hulled or unhulled. The protein content of Indian sesame cake ranges from 35% (expeller-pressed, unhulled) to 47% (hexane-extracted, hulled). It is high in calcium and phosphate but low in lysine, which must be supplemented by high lysine feeds. Crude fibre content in cake from unhulled seed is 5–6%, but only about 3% in cake from hulled seed.



Sesamum orientale L. – 1, flowering branch; 2, opened corolla; 3, cross section ovary; 4, mature fruit; 5, seed, front and side view.

Description Erect, stout, branched, aromatic, annual herb, 0.5–2 m tall. Root system well-developed with taproot strongly tapering, up to 90 cm long, bearing many laterals. Stem firm, square with ribs at each corner, less distinct when young, up to 1 cm in diameter at base, bright pale green, sparsely pilose, glabrescent or glabrous but characteristic hyaline glands present on all parts, except the oldest, glands composed of 4 globular cells and a basal one, becoming white with drying. Leaves very variable within and between plants, petiolate, lower ones decussate, higher ones subopposite, highest ones spirally arranged in 4 rows, all leaves densely pilose beneath on the veins and near margin, with a few globules, between veins sparsely pilose with many globules, sparsely pilose above; petiole hemicylindric, canaliculate, at least at base, up to 17 cm long, higher leaves gradually shorter petioled; lowest leaf blades entire to 2–3-lobed, in outline ovate to broadly ovate, 10–21 cm × 5–13 cm, margin usually entire or partly crenate to serrate; higher ones lobed to trifoliolate, lobes or leaflets narrowly elliptical, 9–17 cm × 3–7 cm, margin entire, crenate or serrate; highest ones bracteolar, narrowly elliptical, 5–15 cm × 1–3 cm, margin entire. Flowers single or 2 or more in the axil of upper leaves, early flowers larger than later ones; pedicel 2–5 mm long, pilose with globules, brownish to bluish dark green, with two small deciduous lateral bracteoles and in axil of each bracteole a yellowish, cup-shaped to disk-shaped, apically 5-lobed gland is present; calyx slender, 5-lobed, lobes oblong, 4–7 mm × 1–1.5 mm, base slightly connate, apex acute, pilose; corolla campanulate, 2–3.5 cm × 1.5–2.5 cm, horizontally flattened, base slightly bent and widened, rim undulate 5-lobed, variable in colour and markings (white in pale-seeded forms, violet in brown-black-seeded forms, often yellow-spotted), lobes about 1 mm long, lowest lobe widely ovate, revolute, apex acute to retuse; stamens 4, the upper 2 shorter than lower 2, implanted at base of corolla, filaments 8–9 mm or 12–13 mm long, white to slightly purplish, between the upper stamens, a staminode of variable length is present; ovary superior, about rectangular longitudinally, rounded to quadrangular in cross-section, 5 mm ×

2 mm, with greyish, velutinous to woolly hairs, bicarpellate, 4-locular by intrusive growth of parietal placentae; style 1 cm long, ending in 2-lobed stigma 3 mm long. Fruit a 4-locular, many-seeded capsule, 1.5–3 cm × 0.5–1 cm, 2.5–3 times as long as broad, rectangular in cross-section, with 4 deep grooves and a short triangular beak, grey-brown at maturity. Seed flattened ovoid, 2–3 mm in diameter, 0.5–1 mm thick, on one side mostly narrowly margined all round and with a longitudinal midrib, the opposite surface margined only at the base and without a midrib, surfaces moderately rough, yellow-white, greyish, brown or blackish, often with vein-like darker discolourations.

Growth and development In sesame seed germination is moderately slow and seedlings grow slowly until they reach a height of 10 cm; thereafter, growth is rapid. Branches develop when the plant is 25 cm tall. The degree of branching is cultivar specific and non-branching cultivars exist. Growth habit is generally indeterminate, but determinate cultivars have been selected. Flowers arise in leaf axils on the upper stem and branches, and the node number on the main shoot at which the first flower is produced is a cultivar characteristic and highly heritable. Most flowers open at 05.00–07.00 h., wilt after midday, and are shed at 16.00–18.00 h. Anthers release pollen shortly after the flowers open; the interval is a cultivar characteristic. The stigma is receptive one day before flower opening and remains receptive for a another day. Under natural conditions, pollen remains viable for about 24 hours. Flowers are mostly self-pollinated, but insect pollination is common. Up to 10% cross-pollination occurs, but this may reach 50% in specific cultivars. Sesame can be harvested 80–150 days after sowing. Capsules near the stem base normally ripen first, while those nearest the tip ripen last. The number of capsules per plant is directly related to the number of flowers, but climate can affect the percentage of fertilized flowers. Active dry matter accumulation and synthesis of oil occurs between 12–24 days afer fruit set, but continues at a reduced rate up to 27 days, with a slight fall in oil content before maturity. The free fatty acid percentage is highest at the beginning of synthesis, declines rapidly around 18–22 days and then more gradually until seed maturity. In most cultivars, dry mature fruits split open and seeds are shattered.

Other botanical information At present the genus *Sesamum* L. comprises about 36 species but an overall revision of the genus will probably reduce this number. Many species occur in Africa (18 exclusively), 8 in the India-Sri Lanka region (5 exclusively) and 4 in South-East Asia. Within *Sesamum* the basic chromosome numbers are x = 8 and x = 13 and $2n$ = 26, 32, or 64. Among the species with $2n$ = 26 are *S. capense* Burm.f., *S. malabaricum* Burm., *S. mulayanum* Nair and *S. orientale*. *S. radiatum* Thonn. ex Hornem., which is sometimes cultivated for its oil-rich seed (also in South-East Asia), has $2n$ = 64. From hybridization experiments it is clear that many species can be crossed successfully and many so-called species may turn out to be identical.

The scientific name of sesame remains contended, *S. orientale* or *S. indicum*, two names of Linnaeus published at the same time in Species Plantarum of 1753, for what later was correctly considered as being one species. In such cases either of the 2 names can be chosen as the correct name, but as soon as a choice is made, others have to respect that choice. Roxburgh was the first, and he chose *S. orientale* in 1832, which choice is followed here. Within *S. orientale* no cultivar groups have been formally recognized, but existing cultivars are numerous. Characters which may typify cultivars include branching habit (branched or unbranched), growth habit (indeterminate or determinate), fruit dehiscence (dehiscent, partially dehiscent or indehiscent), and seed colour (white, grey, yellow-white, brown, black). Existing botanical classifications of cultivated sesame into subspecies and varieties need revision and reclassification into cultivars and cv. groups.

Ecology Sesame is basically a crop of the tropics and subtropics, but newer cultivars have extended its range into more temperate regions. It occurs mainly between 25°S and 25°N, but up to 40°N in China, Russia and the United States, 30°S in Australia and 35°S in South America, generally below 1250 m altitude. Sesame is a short-day plant, but many cultivars have become adapted to various photoperiods. With 10-hour days it will normally flower in 42–45 days after sowing. Temperature and moisture have major modifying effects on the number of days to flowering. A short photoperiod can increase the number of capsules per plant in early and medium-late cultivars. High temperatures are required for optimal growth and production. Temperatures around 30°C encourage germination, initial growth and flower formation, but up to 40°C will be tolerated by specific cultivars. Temperatures below 20°C normally delay germination and seedling growth, and below 10°C inhibit both. Approximately 150 frost-free days are required and a hard frost at maturation reduces seed and oil quality, adversely affects the minor seed-oil constituents sesamolin and sesamin and kills plants. However, in Hubei (China) seed oil content was found to be higher in genotypes from the colder north than in those from the warmer south. It is also higher in genotypes with light-coloured seeds. Sesame is considered drought-resistant. Established plants can withstand high moisture stress, but seedlings are extremely susceptible. It will produce an excellent crop with a rainfall of 500–650 mm. Ideally, 35% of rain should fall during germination until first bud formation, 45% until main flowering and 20% at seed filling. Rain should cease as first pods begin to ripen. Heavy rain at flowering drastically reduces yield. Seedlings are susceptible to waterlogging. After stem elongation it is also susceptible to wind damage. Sesame thrives on moderately fertile and well-drained soils, but is sensitive to salinity. Soils with a neutral to slightly alkaline reaction are preferred and sesame does not thrive in acid soils.

Propagation and planting Land preparation for small grains such as wheat and sorghum is also suitable for sesame. Level land is important to ensure an even depth of planting but land may be ridged for better drainage in areas where high-intensity storms are common. Immediately before planting, the land should be harrowed to kill weeds since sesame seedlings have slow initial growth. Weed control while plants are small is difficult and the seedbed should be as weed-free as possible. Many types of sowing equipment are suitable. Depth of planting is usually 2–5 cm, but can be 10 cm in loose soil. Soil should not be compacted after sowing. Even depth of planting is important and ensures even crop emergence and growth which facilitates subsequent tillage operations and harvesting. Plant density depends on the prevailing environment, seed rates of 2–10 kg per ha are used in sole cropping. Plant populations directly influence the number of capsules per plant, and a high population or close in-row spacing tends to reduce both the number of capsules and number of seeds per capsule. Maximum yields have been obtained from crops planted 90 cm × 90 cm, while row spacings of 50–100 cm are recommended.

Husbandry In sesame early weed control is important. Two or three shallow weedings are usually adequate. Weeding implements should be set as shallow as possible to avoid damage to the roots. Growth is rapid once plants are 10 cm tall and few weedings are needed thereafter. Close row spacing can reduce late weed growth which may be troublesome at harvest. A wide range of pre-emergence herbicides has been successfully used, but none of them is safe post-emergence. Sesame is frequently intercropped in smallholders' fields. Strip cropping with maize and sorghum is common which gives it protection from strong winds. Sesame has also been planted with beans and cotton. Few data on fertilizer requirements of sesame are available. The amount of nutrients removed by a crop per t seed is estimated at 30 kg N, 14 kg P and 5.5 kg K. In Korea an application of 7 kg N, 1 kg P, and 6 kg K per ha has produced a seed yield of 1755 kg/ha. Where sesame is grown on a large scale, NPK mixtures of 5-10-5, 12-12-6, and 10-14-10 at a rate of 500–700 kg per ha are commonly applied at planting. Irrigated sesame requires the equivalent of 900–1000 mm rain for optimum yields. If more than 1000–1200 mm are required, sesame is usually replaced by other oilseeds better able to utilize large volumes of water. In Asia sesame is often grown as a second crop after rice, and is then sown in the rice stubble. In addition to residual soil moisture only a single irrigation is required.

Diseases and pests Many of the damaging fungal diseases that attack sesame are of restricted distribution. Some of the most important ones are known to be seed-borne so disinfection of seed should be routine, unless seed from disease-free areas is available. The most damaging diseases are bacterial leaf spot caused by *Pseudomonas sesami* and leaf spot caused by *Alternaria sesami*, and *Cercospora*. *P. sesami* causes light-brown, dryish, angular spots with a darker, more purple margin; spots coalesce to form large, necrotic areas on the leaves. *Alternaria sesami* is a seed-borne pathogen that infects stems, leaves and green capsules. Dark brown, water-soaked lesions mainly on the stem are major symptoms, although lesions may occur also in midribs and leaf veins without the spots. Cercospora leaf spots are irregular brown spots of 2.5–10 mm. Stem anthracnose is important in Asia and Africa. Infected stems become discoloured and dull green and turn brown or black later. Its cortical tissues crack, exposing the inner tissues and brown streaks or large spots may be seen along the stem, either along the whole stem or alternating with healthy tissues. Fusarium wilt can also be devastating to susceptible cultivars. The most damaging viral or mycoplasmal disease is phyllody, especially in India and Burma (Myanmar). The characteristic symp-

toms are deformed flowers that remain green and with the calyx and corolla sometimes stiff and forming a half-open hood. Chemical control of these diseases is difficult and sometimes not economical. Seed treatment, planting resistant cultivars, destruction of crop residues and alternate hosts and crop rotations that give a quarantine period should all be applied.
Sesame is attacked by many insects. In some regions, those attacking flower heads and young fruits assume greatest economic importance; in others, the foliage eaters cause major losses. The reduction caused by insects can reasonably be assumed to be 25% of potential yield worldwide. Estimated damage on smallholdings and commercial crops in Africa, Asia and Central America where no or minimum pesticides are used, is usually more than one-third of the yield. Cutworms, especially *Agrotis ipsilon* and *A. segretum* are widespread and common pests of sesame. *Holotrichia helleri* and *Valanga nigricornis* are common in Indonesia. Herbivorous insects *Antigastra catalaunalis* and *Acherontia styx* occur widely but *Diacrisia obliqua* and *Amsacta moorei* are important in Asia. The bug *Cyrtopeltis tenuis* is present in Asia (Indonesia and other growing areas). Chemical control of sesame pests is generally unprofitable, but the extent of potential yield loss must be realized and offset as far as possible by cultural techniques. High seed rates compensate for seedbed losses and branching cultivars produce more flowers. Timing of planting to avoid the main outbreak of a major insect pest, the destruction of crop residues, and the use of resistant cultivars reduce successive infestations.

Harvesting Sesame is harvested 80–150 days after sowing but most commonly in 100–110 days, some very short-season cultivars in 70–75 days. At maturity, leaves and stems change from green to a yellowish, finely reddish tint. Capsules ripen irregularly from the lowest to the highest, and plants must be harvested before all capsules are mature, since field losses from shattering cultivars can reach 75%, but even non-shattering types may lose about 25%. Smallholder crops are usually harvested by hand and allowed to dry in stooks. Non-shattering cultivars can be directly combined provided this is carefully done by specially modified machines, or cut by a mower to allow the plants to dry, followed by a combine fitted with a pick-up reel. Threshing equipment should be set to a low drum speed and a wide spacing between drum and concave to avoid damage to the seed.

Yield Seed yield is directly related to the number of branches, but the total number of capsules has the greatest direct effect on seed yield. The number of seeds per capsule, their weight, oil content and other constituents vary with capsule position, irrespective of cultivar, and are also directly affected by environment. Seed yields of smallholder crops seldom exceed 300–500 kg/ha when planted in pure stands. However, under intensive, high-input production yields reach 2000–2500 kg/ha with an oil content of about 50%.

Handling after harvest Sesame seed of less than 8% moisture content can be stored for up to 2 years in airtight containers. Bulk storage of clean and dry seed presents few problems but seed that is damaged or contaminated by extraneous material produces discoloured or rancid oil. Sesame seed is mostly processed with the seed coats although hulled seed produces higher quality oil and meal. Seed is crushed or pressed by methods ranging from the Indian 'ghani' to large, modern plants. Oil extraction in Europe and Asia is done in 3 consecutive phases. The first cold pressing produces high quality oil. The residue from this process is heated and pressed to yield coloured oil that must be refined first before edible use. Further extraction of the residue gives oil that is not used for human consumption. Crude oil is filtered to remove impurities such as suspended meal and free fatty acids. The oil is also bleached and deodorized to transform it to a light-coloured and bland oil.

Genetic resources Sesame is rich in genetic variability and much collection still needs to be done. The National Bureau of Plant Genetic Resources (New Delhi, India) now maintains about 10 000 sesame accessions, including 2500 exotic collections. Other large collections are found in the Russian Federation, the United States, Venezuela and China. These collections contain many duplicates and smaller core collections are being made of well-identified and evaluated material.

Breeding Among the breeding objectives for sesame are higher yields, improved plant architecture, length of growing season, resistance to diseases and pests and indehiscent capsules. The degree of dehiscence is a cultivar characteristic and of great importance for mechanized harvesting. The discovery in 1943 of an indehiscent mutant produced non-shattering cultivars that were, however, difficult to thresh. The introduction of paper-shell capsules into indehiscent plants helped to solve this problem. Plants with partially dehiscent fruits that open slightly but generally retain their seed have also been identified. Cultivars developed by SESACO (Texas, United States) are of this type. Plant height to the first capsule is another cultivar characteristic that is important for mechanical harvesting. The discovery of genetic male sterility in sesame eased the production of hybrid seed. Induced mutations play an important role in sesame breeding. One of the most widely grown cultivars of Korea named 'Ahnsankkae' has X-ray-induced disease resistance. A mutant named 'dt45', with determinate growth and capsules clustered near the top, was detected in Israel. The apical capsules are often quadricarpellate and have large seeds. The modified gene has been incorporated into several newly released cultivars.

Interspecific hybridization is possible, and crosses may produce viable seeds. The Indian *S. mulayanum* (sometimes considered a form of *S. orientale*) is similar to *S. orientale* and has the valuable characteristics of being resistant to phyllody and wilt. Hybrids are partially fertile. Polyploidy can be induced, but colchicin-treated plants tend to produce low yields, although the growth rate and general vigour of tetraploids can exceed those of diploids.

Prospects Although sesame is of ancient cultivation, there is ample scope for crop improvement. The oil with its characteristic taste and excellent cooking and keeping qualities is highly appreciated in many parts of the world from the Middle East to Japan. As an annual oilseed crop well adapted to dry tropical conditions its importance in South-East Asia may increase in drier areas.

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E.A. Weiss and Q.D. de la Cruz

Shorea Roxb. ex Gaertner f.

Fruct. 3:47 (1805).
DIPTEROCARPACEAE
$x = 7$; $2n = 14$

Major species and synonyms

- *Shorea macrophylla* (de Vriese) P. Ashton, Gard. Bull. Sing. 20: 278 (1963), synonyms: *Hopea macrophylla* de Vriese (1861), *Shorea gysbertsiana* Burck (1886), *Pachychlamys gysbertsiana* (Burck) Ridley (1922).
- *Shorea splendida* (de Vriese) P. Ashton, Gard. Bull. Sing. 20: 279 (1963), synonym: *S. martiniana* R. Scheffer (1873).
- *Shorea stenoptera* Burck, Meded.'s-Lands Plantent. 3:11 (1886).

Vernacular names General: tengkawang (En). Illipe (Fr). Indonesia: tenkawang. Brunei, Malaysia: engkabang, illipe, singkawang.

- *S. macrophylla*. Brunei: kawang jantong. Indonesia: awang katolok, tengkawang buah (East Kalimantan), tengkawang hantelok (Kalimantan). Malaysia: engkabang jantong, engkabang ringgit (Sarawak), kawang jantong (Sabah).
- *S. splendida*. Indonesia: tengkawang bani, tengkawang goncang, tengkawang rambai (West Kalimantan). Malaysia: engkabang bintang, melindang (Sarawak).
- *S. stenoptera*. Indonesia: tengkawang tayau, tengkawang tungkul (West Kalimantan). Malaysia: engkabang kerangas (Iban), engkabang rusa (Sarawak).

Note: in the literature the name illipe nut is sometimes used for *Shorea* nuts. Illipe nut however, is the fruit of *Madhuca* and other *Sapotaceae*; their fat is buttery while the fat of tengkawang fruit is more solid and has a higher melting point.

Origin and geographical distribution Many *Shorea* species including *S. macrophylla*, *S. splendida*, *S. stenoptera* and most other tengkawang species are endemic to Borneo where also the greatest diversity occurs. A few of the in total 200 species occur in India and Sri Lanka, the rest in South-East Asia (only some in continental South-East Asia, the majority in Borneo, several in Sumatra, Java, Moluccas and the Philippines).

Uses Several species of *Shorea* produce edible fruits (nuts) that are rich in fat, commonly known as tengkawang fat or butter, illipe butter, green butter or Borneo tallow. The extraction of fat from these nuts is an old tradition in Borneo. The indigenous people consider traditionally-extracted tengkawang fat as a delicacy and commonly add it to food such as rice. In Peninsular Malaysia and Sumatra, tengkawang fat is only used occasionally. Tengkawang fat is an excellent substitute for cocoa butter in the manufacture of chocolate. Its composition is very similar to cocoa butter so that its addition hardly alters the properties and taste and is difficult to detect. It can also be used in the confectionery industry and in the manufacture of cosmetics particularly creams and lipsticks. Medicinally, tengkawang fat is applied to treat thrush and sprue and as an ointment on wounds. The meal remaining after oil extraction can be used as a 10% feed supplement for pigs.

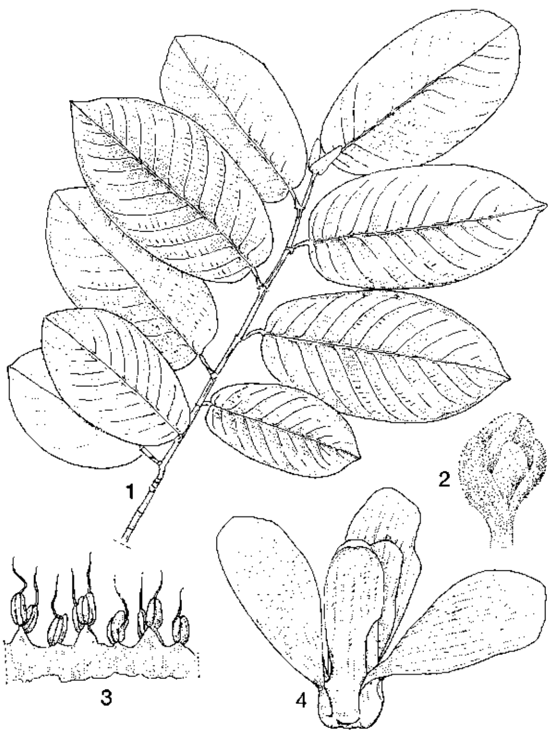
Shorea is the most important source of timber in South-East Asia and the species yielding tengkawang fat also yield timber, mostly classified in the trade groups 'balau' (e.g. some minor species mentioned in other botanical information) or 'red meranti' (e.g. the 3 major species mentioned). Some species grow into large trees with excellent boles that are in high demand by the plywood and veneer industry. All timber aspects of *Shorea* are given in PROSEA 5(1): Timber trees: major commercial timbers, and are not repeated here.

In Borneo, tengkawang trees play a role in religious tradition, land tenure and shifting agriculture and are therefore often regarded as family heirlooms and banned from logging. However, they are still cut for their valuable timber even where collection of tengkawang nuts is an economically important activity. In Indonesia and Sarawak, the main tengkawang species are protected and their logging is banned in most regions. Tengkawang species are used in reforestation, agroforestry activities and rehabilitation of land that has been subjected to shifting cultivation.

Production and international trade Production and trade volumes of *Shorea* vary widely from year to year, due to the gregarious flowering habit of many dipterocarp species with intervals of 2–7 years. During good years production is 20 000–30 000 t and 5000–20 000 t from main exporters Sarawak and West Kalimantan, respectively. Exports in 1968, 1970, 1973, 1977, 1980, 1983 and 1987 were good but they were nearly nil in other years. Prices also fluctuate and drop drastically in high-production years. As tengkawang fat is a substitute for cocoa butter, its price is further subject to the mechanisms of the cocoa market. This market, in turn, is dependent on world demand for cocoa products and the production in the major cocoa growing countries.

Properties Tengkawang nuts have a fat content of about 50% (on dry weight basis). The proximate fatty acid composition is: palmitic acid 18–21%, stearic acid 39–43% and oleic acid 37–38%. Tengkawang fat has an iodine value of 29–38. Its pronounced melting point is 33–36°C which is just below the temperature of the human body. It is slightly higher than that of cocoa butter and the consistency of tengkawang fat is consequently slightly harder. This is important in the manufacture of chocolate, particularly for warm and tropical countries. The high latent heat of both cocoa and tengkawang fat is freed when they melt and this creates the fresh and cool sensation associated with the taste of chocolate. This property also imparts a creamy, solid characteristic to cosmetics when applied on the skin. The fat keeps for a very long time without a change in properties and smell. Poorly prepared tengkawang fat with a free fatty acid content of over 5% is not suitable for human consumption.

Description Medium-sized to very large trees up to 75 m tall; bole straight, cylindrical, branchless for 10–40 m, diameter up to 3 m; buttresses usually prominent, up to 5 m tall; bark surface smooth, prominently fissured or becoming flaky, sometimes scaly, grey or brown; inner bark reddish, pink, orange or yellow, exuding a brown, reddish or yellowish resin; mature crown hemispherical or dome-shaped, sympodial. Leaves alternate, stipules and bracts persistent or fugacious, usually petiolate; blade simple, entire, glabrous, pinnately veined with scalariform tertiary venation, often glaucous on the lower surface. Inflorescences terminal or axillary, paniculate; flowers secund or distichous, usually rather crowded, hermaphrodite, 5-merous, actinomorphic, scented; calyx lobes free, hirsute; petals free or connate at base, cream suffused with pink, the outer surface hirsute; stamens usually 15, sometimes up to 70, usually



Shorea macrophylla (de Vriese) P. Ashton – 1, leafy branch; 2, flower bud; 3, stamens; 4, fruit.

strap-shaped, the anthers with 4 pollen sacs, linear-oblong to subglobose, with short to long, glabrous appendages; ovary with or without a stylopodium. Fruit a usually short stalked, subglobose to ovoid nut, sharply pointed, with the outer 3 or rarely all calyx lobes much elongated, these more or less thickened and saccate at the base. Seedling with epigeal germination; pericarp splitting irregularly; cotyledons reniform-sagittate, greenish-orange or red; first two leaves opposite, subsequent leaves arranged spirally, often larger than those on mature trees.

- *S. macrophylla*. Tree up to 50 m tall, bole up to 130 cm in diameter, buttresses up to 2 m tall. Leaves coriaceous; stipules persistent, broadly hastate, up to 5 cm × 1.3 cm; petiole 1.5–3 cm long; blade elliptical-oblong, 17–35 cm × 10–14 cm, base obtuse to subcordate, apex acuminate, secondary veins 11–20 pairs. Panicle up to 17 cm long; flower bud ellipsoid, up to 8 mm × 5 mm; petals pale pink; stamens 15, of which inner 5 long and outer 10 short, filaments adnate forming a tube around the ovary, tapering distally, becoming filiform below the anthers; anthers with long appendages, stylopodium pyriform; larger calyx lobes 3, in fruit up to 11 cm × 3 cm, 2 shorter lobes up to 8 cm × 1.5 cm. Nut obovoid, up to 6 cm × 4 cm, yellow-brown, soft pubescent.
- *S. splendida*. Tree up to 30 m tall, bole up to 65 cm in diameter, buttresses low. Leaves chartaceous, lustrous; stipules subpersistent, cordate, up to 2.5 cm long; petiole 1–2 cm long; blade oblong, 8–23 cm × 4–11 cm, base cordate, apex acuminate, secondary veins 9–12 pairs. Panicle up to 20 cm long; flower bud conical, up to 10 mm × 3 mm; petals lanceolate; stamens 15, inner 5 longer than outer 10, filaments adnate forming a tube around the ovary, anthers with long, slender appendages, stylopodium spindle-shaped; larger calyx lobes 3, oblong, in fruit up to 7.5 cm × 2.3 cm, 2 smaller lobes up to 6.5 cm × 1.2 cm. Nut ovoid, 5.5 cm × 3 cm, pale yellow-brown pubescent.
- *S. stenoptera*. Tree up to 25 m tall, bole up to 60 cm in diameter, buttresses small or absent. Leaves thickly coriaceous; stipules subpersistent, ovate, up to 2 cm × 1 cm; petiole 2–5 cm long; blade oblong, 18–40 cm × 8–22 cm, base cordate to cuneate, apex acuminate, secondary veins 10–14 pairs. Panicle up to 35 cm long; flower bud conical, up to 7 mm × 3 mm; petals deep pink, lanceolate; stamens 15, inner 5 somewhat longer than outer 10, filaments connate for 3/4 of their length, tapering abruptly below the anthers, anthers with long slender appendages, stylopodium spindle-shaped; larger calyx lobes 3, in fruit up to 7.5 cm × 2 cm, 2 shorter lobes 5.5 cm × 0.8 cm. Nut ovoid, up to 5 cm × 3 cm, pale yellow-brown pubescent.

Growth and development Seed dispersal in *Shorea* is usually only over short distances, generally not more than 30 m from the mother tree. Seed is recalcitrant and loses its viability within a month and on drying. Seedlings often grow faster in sunny than in shaded sites, but seedlings of many species suffer severe damage from prolonged exposure to full sunlight. Seedlings usually survive best in intermittent sunlight. Full sunlight causes the soil temperature near the seedlings to rise, inactivating the mycorrhizae which are essential for good growth of tengkawang. Infected seedlings grow faster and are taller. Once established, tengkawang saplings persist for a number of years in the understorey under heavy shade, but they can respond to moderate to high light intensities with rapid growth. Nursery-grown seedlings of *S. stenoptera* grow considerably better after inoculation with the mycorrhiza *Scleroderma* sp.; seedlings of *S. pinanga* respond

best to inoculation with *Russula* sp.
As with most *Shorea*, there is little reliable information about rates of growth and development in natural stands. In planting trials in Sarawak, the annual average diameter growth of major tengkawang species ranged from 1.0–1.9 cm DBH (average of the best 10% of samples between 30–132 trees). The most important species *S. macrophylla* and *S. stenoptera* reached increments of 1.9 cm and 1.1 cm, respectively. In a plantation in Semengoh Forest Reserve (Malaysia) the mean annual growth rates varied from 1.2 cm for *S. macrophylla* to 0.8 cm for *S. pinanga*. In trial plantations in Java *S. stenoptera* had an average annual growth of 26.7 m^3/ha over a period of 30 years. These exceptional values show the potential of this species under optimal conditions. In 40 years, red meranti trees may sometimes reach a diameter of up to 80 cm (*S. scaberrima*). Good seed production tends to reduce the growth of the tree and consequently also timber production.
For commercial nut production, age at first flowering is very important. Flowering generally starts when the tree crown reaches the canopy storey, which may be 10–15 years after germination for solitary specimens of fast-growing species. In the forest, most tengkawang species flower for the first time at the age of 20–30 years. Early flowering in plantations is reported for *S. macrophylla*, *S. pinanga* and *S. sumatrana* with special shade or fertilizer treatments. Trees of *S. pinanga* planted in Malaysia flowered and fruited after only 6 years because growth was enhanced by fertilizers. As in all dipterocarps flowering and fruiting of tengkawang occurs periodically with an average of 1 year of abundant fruit production (mast year) every 3–6 years, often after a pronounced dry season or drought, e.g. those caused by the El Niño weather system. Closely related species may differ in flowering periodicity. For several tengkawang up to 50% of the trees flower during years of gregarious flowering. During these years, there is only a slight overlap in the peak blooming periods of different species, but ripening of fruits is simultaneous. In mast years fruit production in the forest may be very abundant. In Peninsular Malaysia and Borneo *S. sumatrana* flowers between March and July. In the Philippines *S. seminis* usually flowers from June to August. Most dipterocarps are predominantly outbreeders, with high within-population variability. Pollination is generally by insects including thrips, psyllid bugs and honeybees (*Apis* spp.). Tengkawang grows slowly and large specimens can be very old, several hundred years at least. Regrowth from stumps occurs after coppicing. The best coppicing ability is found in small trees (up to 20 cm in diameter) and coppice shoots grow well. Coppicing is done for firewood production.

Other botanical information Other tengkawang species with fruits that are also occasionally used for fat production, are:
- *S. lepidota* (Korth.) Blume; synonyms: *S. nitens* Miq., *S. megistocarpa* Foxw., *Vatica lepidota* Korth.; vernacular names: Malaysia: meranti langgong, meranti pala, meranti sega. Sumatra: meranti katuko, meranti sitarah, meranti sabat. *S. lepidota* is restricted to Peninsular Malaysia and Sumatra. It is a large buttressed tree; leaves subcoriaceous, stipule lanceolate, 20 mm × 4 mm, persistent, petiole 7–11 mm long, blade obovate to oblong, 6–14 cm × 3–6 cm, base cuneate, apex acuminate, veins 14–16 pairs; panicle up to 7 cm long, petals cream, stamens 15, 3 longer calyx lobes in fruit 11 cm × 2.5 cm, 2 smaller ones 7 cm × 0.7 cm; nut ovoid, up to 16 mm × 11 mm, pointed. *S. lepidota* is common in lowland dipterocarp forest on undulating land and low hills below 350 m altitude. Its wood is traded as red meranti.
- *S. pinanga* R. Scheffler; synonym: *S. compressa* Burck; vernacular names: Brunei: kawang, meranti langgai bukit. Indonesia: awang boi (southeastern Kalimantan), tengkawang biasa, tengkawang rambai (West Kalimantan). Malaysia: kawang pinang (Sabah), meranti langgai bukit (Sarawak). *S. pinanga* is an endemic species of Borneo. It is a large tree, up to 50 m tall, with bole up to 125 cm in diameter, buttresses small, up to 1.5 m tall; leaves thinly leathery, stipules up to 6 cm long, petiole 1–2 cm long, blade elliptical to narrowly ovate, 11–24 cm × 4–9 cm, with 10–20 pairs of secondary veins; panicle up to 24 cm long, petals deep pink, stamens 15, filaments adnate forming a ring around the ovary, anthers subglobose with long, slender appendages, stylopodium long and slender, larger calyx lobes 3, in fruit up to 28 cm × 3.5 cm, 2 smaller ones 17 cm × 1.2 cm; nut broadly ovoid, 2.3 cm × 2.3 cm, yellow-brown pubescent. *S. pinanga* grows on clay-rich soils, especially on ridges below 700 m altitude. Variability in tomentum density and leaf shape is great. Where habitats overlap, *S. pinanga* can have characters in common with *S. macrophylla*, suggesting hybridization. Its wood is traded as red meranti.
- *S. scaberrima* Burck; vernacular names: Brunei: meranti paya bersisek. Indonesia: kontoi en-

timus, tengkawang kijang (West Kalimantan), meranti sandakan (northern Kalimantan). Malaysia: engkabang pinang, kawang bukit (Sabah), meranti paya bersisek (Sarawak). *S. scaberrima* is an endemic species of Borneo. It is a tree up to 40 m tall, bole up to 110 cm in diameter, buttresses up to 1.5 m tall, bark appearing smooth; leaves thinly leathery, stipules hastate, 18 mm × 8 mm, caducous, petiole 2–2.5 cm long, blade oblong-ovate, 7–20 cm × 4–9 cm, with 14–17 pairs of secondary veins, lower surface tawny tomentose; panicle up to 8 cm long, petals pink, stamens 15, anthers oblong with long appendages, stylopodium narrow, 3 larger calyx lobes in fruit up to 4.5 cm × 1 cm, 2 smaller ones 3 cm × 0.3 cm; nut obovoid, 5 cm × 2.5 cm, fulvous pubescent. *S. scaberrima* occurs on sandy clay soils on low hills, on alluvium, on ridges and volcanic plateaux up to 850 m altitude. Its wood is traded as red meranti.

- *S. seminis* (de Vriese) v. Slooten; synonyms: *S. schefferiana* Hance, *Isoptera borneensis* Scheffer ex Burck, *I. seminis* (de Vriese) Burkill; vernacular names: Brunei: engkabang terendak, kawang tikus. Indonesia: tengkawang ayer, tengkawang pelepak, tengkawang terindak (Kalimantan). Malaysia: engkabang chengai, engkabang terindak (Sarawak), selangan batu terendak (Sabah). Philippines: gisok-tapang (Sulu), malayakal (Tagalog), yakal (Chabacano). *S. seminis* is found in Borneo and in the Philippines. It is a tree up to 60 m tall with bole branchless for 25–30 m and up to 130 cm in diameter but usually much less, with prominent buttresses up to 2.5 m tall; leaves thinly leathery, stipules oblong, 7 mm × 3.5 mm, caducous, petiole 1–1.5 cm long, blade oblong-ovate to lanceolate, 9–18 cm × 2.5–8 cm, secondary veins 9–15 pairs; panicle up to 10 cm long, petals narrow, cream, stamens 30–40, the appendages with a few bristles, calyx lobes subequal, in fruit up to 2 cm × 1.8 cm; nut ovoid to globose, 1 cm in diameter, style remnant up to 1 cm long. *S. seminis* often grows gregariously on alluvium banks of sluggish rivers. The fat from *S. seminis* is said to have the best taste among all the tengkawang fats, but the nuts are too small to be valued for export. Its wood is traded as balau.
- *S. singkawang* (Miq.) Miq.; synonyms: *Hopea singkawang* Miq., *Pachychlamys thiseltonii* (King) Ridley, *Shorea thiseltonii* King; vernacular names: Indonesia: sengkawang pinang, singkawang daun halus (Sumatra). Malaysia: meranti bahru, meranti sengkawang merah, siput melantai (Peninsular). Thailand: maak on (peninsular). *S. singkawang* is found in Sumatra, Peninsular Malaysia and south- eastern peninsular Thailand. It is a tree up to 30 m tall, bole branchless for 12–21 m and up to 95 cm in diameter, buttresses up to 3.5 m tall; leaves coriaceous, stipules lanceolate-falcate, up to 12 mm × 6 mm, fugaceous, petiole 6–17 mm long, blade oblong-lanceolate, 8–24 cm × 2–9 cm, secondary veins in 7–17 pairs; panicle up to 8 cm long, petals red to purple-red, stamens 15, anthers subglobose with short appendages, stylopodium indistinct, the 3 larger calyx lobes in fruit up to 8 cm × 0.8 cm, only slightly longer than the nut, the 2 smaller ones 3 cm × 0.8 cm; nut ellipsoid to ovoid or obovoid, 6 cm × 2.5 cm, apex pointed. *S. singkawang* is frequent in lowland mixed dipterocarp forest on well drained undulating land, below 400 m altitude. Its wood is traded as red meranti.
- *S. sumatrana* (v. Slooten ex Thorenaar) Sym. ex Desch; synonyms: *Isoptera sumatrana* v. Slooten ex Thorenaar; vernacular names: Indonesia: kedawang, sengkawang (Sumatra). Malaysia: balau sengkawan air, sengkawang, tengkawang batu (Peninsular). Thailand: palosale, teng-dong (Pattani). *S. sumatrana* occurs in Sumatra, Peninsular Malaysia and south-eastern peninsular Thailand. It is exactly the same as *S. seminis*, only the number of stamens is 25, and perhaps it is not a different species. *S. sumatrana* grows semi-gregariously on alluvium banks of sluggish but not brackish rivers. Its wood is traded as balau.

Ecology *Shorea* is confined to tropical climates with a mean annual rainfall exceeding 1600 mm and a dry season of less than 6 months. Most species occur below 1000 m altitude. Species and individual trees are most numerous on deep, well-drained yellow or red soils in the lowland. Most species are restricted to a single vegetation type or substratum. Some are common to gregarious in a certain habitat. *S. macrophylla* and *S. splendida* occur on periodically flooded, clayey alluvial soils, *S. stenoptera* on poorly-drained sandy alluvia. *S. pinanga* and *S. scaberrima* are found on ridges, while *S. seminis* and *S. sumatrana* often grow on the banks of sluggish flowing rivers.

Propagation and planting There is much traditional knowledge about the enhanced natural regeneration, planting and seeding of the more important tengkawang species because of their potential as multipurpose trees. This is particularly true for *S. macrophylla*, *S. seminis* (in East

Kalimantan) and *S. stenoptera* (in Western Borneo). The best time to collect fruits of *S. pinanga* and *S. stenoptera* is when part of the wing colour changes to brown. Fresh seed of *S. pinanga* has a germination rate of 93% while that of *S. stenoptera* seed is 96%. All seeds are recalcitrant; they should be planted within 4 weeks after harvest. After this period, germination rates drop drastically. Eight-week old seedlings can be transplanted into the field. Vegetative propagation is also possible. Single-node leafy cuttings from 8- and 15-month old seedlings of *S. macrophylla* root easily under continuous mist with or without auxin treatment.

Husbandry The best known tengkawang plantation is probably the collection in the Hourbentes Forest Station near Bogor in West Java. It is an excellent example of the early ex-situ conservation and proof that regeneration of dipterocarps, often regarded as difficult and sensitive, is abundant under favourable conditions. Other trial plantations of tengkawang are in Sarawak and Peninsular Malaysia. Intensive cultivation with application of fertilizer induced and enhanced early flowering in *S. pinanga*. Providing some shade during the early stages of the plantation can give the same effect. Trees of *S. macrophylla* started fruiting after 6 years when their seeds were planted in the open. A stand of *S. pinanga* with fertilizer treatment yielded at the same age.

Tengkawang cultivation has been a traditional smallholder activity for more than 100 years but a few larger plantations also exist. Smallholders in Kalimantan cultivate *S. macrophylla*, *S. pinanga*, *S. seminis*, *S. splendida* and *S. stenoptera* in traditional plantations along rivers and streams. Planting trees is one way to claim land and to prove ownership or usufruct rights, acknowledged by traditional law. New gardens are usually established in shifting cultivation schemes.

Diseases and pests *Fusarium* fungi may kill tengkawang seedlings. Seeds and seedlings of *S. pinanga* are also occasionally attacked by the fungus *Cylindrocarpon destructans*. Weevils such as *Alcidodes dipterocarpi* and *Nanophyes shoreae* are major pests of seeds, occasionally damaging up to 85% of the seeds. Other seed-attacking insects include *Microlepidoptera* moths of the families *Pyralidae* and *Totricidae*, and beetles of the family *Scolytidae*. Terrestrial vertebrates, particularly pigs and squirrels feed on fallen seeds and are the major cause of seed mortality. Ants and termites also feed on fallen seeds. Some caterpillars eat seedlings, although seedling predation is generally low.

Harvesting Nuts of tengkawang are usually collected from the ground or scooped out of streams when a tree grows on a stream bank. This should be done soon after nut fall to avoid predation and seed germination (seed germinates rapidly). The periodic character of flowering is a deterrent to the establishment of a regular and profitable chain of harvesting, processing and commercialization for nuts and fat. Hence, investment in post-harvest processing and storage is almost absent.

Yield There is no information on the yield of natural tengkawang stands. A trial plantation of 20-year old *S. macrophylla* in Peninsular Malaysia produced 1140 kg/ha of nuts. Another trial plantation of 32-year old *S. macrophylla* in Sarawak yielded 1120 kg/ha of nut and one of *S. pinanga* gave 2280 kg/ha of nuts. These figures refer to yields in mast years and indicate the potential rather than actual yields in natural stands.

Handling after harvest After collecting the fruits of tengkawang, the wings are broken off the nut. Then nuts are soaked in water for 30–40 days (in bamboo baskets in a river); this treatment loosens the nutshell for its easy removal. Afterwards, the kernel (which usually splits into 4 parts) is dried. The dried parts ('padi tengkawang') are marketed; the blacker they are the better because it means that they have been dried without decay. They are suitable for oil extraction, or can be safely stored for up to a year. As an alternative to this long soaking period, the unwinged nuts are also roasted over a fire (and marketed as such), or boiled or soaked in boiling water to remove the shell more easily. Formerly the fruits were piled in a humid place to induce germination. The fruit wall splits open as soon as the seedling reached 10–20 cm in length, the kernel could then be freed and dried, while the shell and sprout were removed. This method resulted in a lower fat content. Drying the cotyledons in the sun is better than drying them over a fire. The long soaking method is advantageous because the padi tengkawang is less severe attacked by insects. To obtain the fat, the dried cotyledons are crushed, heated in boiling water and the fat skimmed off. This fat is suitable for burning, soap or candle production; the fat solidifies into greenish or yellow-white clumps. For home use, the oil is filtered first. It can be stored for a long time without deterioration.

Genetic resources Large live germplasm collections of tengkawang trees are present in several botanic gardens like in Bogor (Indonesia) and

Kepong (Malaysia). They are important sources of seeds, although there is growing evidence that such seeds may be inferior because of inbreeding.

Breeding Proposals have been made to select trees for intensive cultivation among those that flower early, but no selection programmes are known to exist. Some natural hybridization occurs between species where habitats overlap. *S. splendida* probably occasionally hybridizes with *S. pinanga* and *S. stenoptera*.

Prospects Although restrictions on the use of cocoa butter substitutes in manufacturing chocolate in the European Union have been eased, the potential of tengkawang for the international market remains limited. It not only has to compete with cocoa and shea butter, but the fluctuations in its production also make it difficult to develop reliable markets. The long juvenile period of tengkawang trees does not make it an attractive crop for plantations. However, tengkawang fat will continue to contribute to the productivity of managed forests and shifting cultivation systems.

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Simmondsia chinensis (Link) C.K. Schneider

Ill. Handb. der Laubholzk. 2: 141 (1907).

SIMMONDSIACEAE

$2n = 52$

Synonyms *Buxus chinensis* Link (1822), *Simmondsia californica* Nuttall. (1844).

Vernacular names Jojoba, goat nut (En). Jojoba (Fr). Indonesia: jojoba. Philippines: jojoba. Thailand: jojoba.

Origin and geographic distribution Jojoba is native to the Sonora semi-desert in north-western Mexico and the south-western United States, but is thought to have originated near the Pacific coast in the Baja California peninsula, where the climate is milder and more even. The similarity of its oil to sperm whale oil was first discovered in 1933, and the later ban on the import of sperm whale oil into the United States in 1969 gave a big impetus to its development as an oil crop and its distribution outside its native habitat. Since the 1980s, its commercial production has spread to South and Central America, southern Africa, Australia and the Middle East. Experimental plantations have been made throughout the drier parts of the subtropics and tropics, including Indonesia and Malaysia.

Uses For centuries, the seed of jojoba has been eaten raw or parched and was made into a well-flavoured drink similar to coffee. However, its main product now is a liquid wax obtained from the seed. The wax, usually referred to as jojoba oil, and many of its derivatives are widely used in making cosmetics such as hair and skin care products, bath oils, soaps and ointments. In medicine, it is applied to alleviate the effects of psoriasis and other skin afflictions. Jojoba wax and especially its sulphur-containing derivatives are stable at high temperatures which make them very suitable components of industrial oils and excellent substitutes for sperm whale oil as additives in high-pressure and high-temperature lubricants for transformers and gear systems and in metal working as cutting and drawing oils. The liquid wax can easily be converted to a hard wax used e.g. in manufacturing candles. Like sperm whale oil, jojoba oil has anti-foaming properties that can be used in the production of penicillin. Other applications have been found in the manufacture of linoleum and printing inks. New derivatives and uses of jojoba wax are still being developed.

Jojoba oil is not digested by humans and has been tested as a substitute for oils and fats in low-energy foods. Clinical trials, however, found increased levels of several enzymes and of white blood cells, indicating cell damage. It is therefore no longer under consideration as a low-calorie dietary oil.

Jojoba plants are very palatable to livestock, but their growth rate is too low to make jojoba an important fodder crop. Also, jojoba should only form a small part of the diet as all of its parts contain the appetite-depressing toxin simmondsin. The presscake from the seeds contains about 30% protein and is a valuable livestock feed. However, it also contains simmondsin and even after detoxification it is suitable only in limited rations for ruminants. On the other hand, simmondsin may find application in the feed and pet-food industry as an additive to regulate intake of various feed components. It is already marketed as a sports food supplement.

In Mexico, the oil has been used traditionally as a medicine for cancer and kidney disorders and to treat baldness. Some selections are grown in gardens and parks.

Production and international trade Annual world production of jojoba oil was 1000–1500 t in the middle and late 1990s. The main producers and exporters are Mexico and the United States; smaller amounts are produced in Argentina, Australia and Israel. Production is expected to increase significantly when new plantations come into full production.

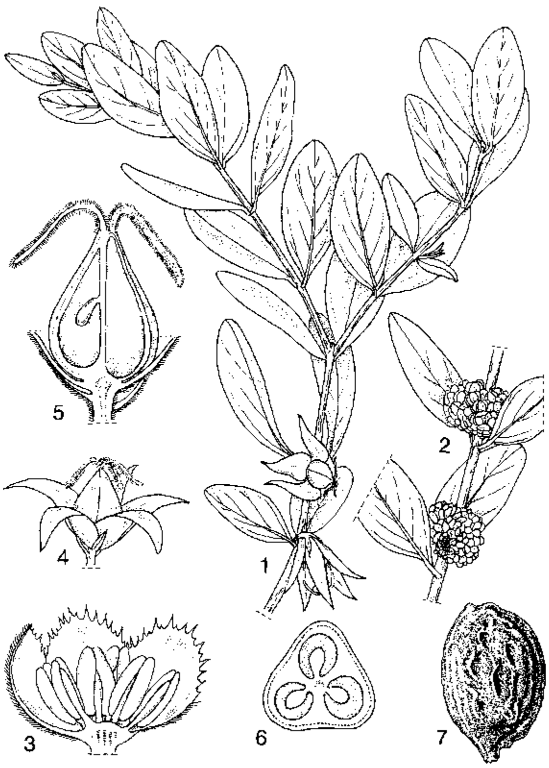
The prices of jojoba seed and jojoba oil fluctuated wildly during the 1980s and 1990s from US$ 25 to less than US$ 2 per kg of seeds. During the late 1990s, the price of seed seemed to stabilize at about US$ 2.5 per kg.

Properties Per 100 g, jojoba seed contains approximately: water 4–5 g, protein 15 g, wax 50–54 g, total carbohydrates 25–30 g, fibre 3–4 g and ash 1–2 g. The wax is clear golden-yellow and consists mainly of esters of long-chain, monounsaturated fatty acids and monounsaturated fatty alcohols (both mainly C_{20} and C_{22}). The unsaturated bonds are susceptible to chemical reactions such as sulphurization, saturation and isomerization. The wax is comparable in properties to the oil of the sperm whale (*Physeter macrocephalus* and its relatives) and oil from the deep-sea fish 'orange roughy' (*Hoplostethus atlanticus*), but is longer in chain length. The jojoba wax is a natural equivalent of the oil secreted by human skin and can be used to lubricate skin and hair for protection against e.g. ultraviolet radiation.

Jojoba seed meal contains 25–30% crude protein and is rich in dietary fibre. The protein shows an imbalance in the thioamino acids: its cystine content is high while its methionine content is low. All parts of the plant including the seed cake contain the appetite-depressing toxins simmondsin and related cyanomethylene-cyclohexyl glucosides. Simmondsin is especially toxic to non-ruminants and chicken. Rats offered a diet containing 30% jojoba seed meal died of starvation after 2 weeks. A diet containing 10% jojoba seed meal caused a reduction in weight and growth rate, but the rats did not die. When added to the feed of chicken, it causes forced moulting and also interferes with reproduction. In the United States, the Food and Drugs Administration (FDA) allows the addition of 5% detoxified seed cake to cattle feed.

In jojoba, long-chain, monounsaturated fatty alcohols act as substitutes of glycerol in the storage of fatty acids. The alcohols are formed by reduction of the homologue fatty acids. The enzyme and the gene coding for it have been identified and have been successfully transferred to *Brassica* plants.

Description Evergreen, dioecious, multi-stemmed and profusely branching shrub, in moist sites erect, 2–2.5(–6) m tall, in desert sites rounded semi-prostrate, 20–50 cm tall, young parts usually with soft hairs. Leaves thick and leathery, decussate, subsessile; blade ovate to elliptical, 1.5–4 cm × 0.5–2 cm, margin entire, dull dark-green to grey-green, sometimes larger in female plants than in male ones. Inflorescence an axillary, dense, rounded cluster of yellowish male flowers or an axil-



Simmondsia chinensis (Link) C.K. Schneider – 1, female flowering branch; 2, male flowering branch; 3, male flower cut lengthwise; 4, female flower; 5, pistil cut lengthwise; 6, ovary cut transversally; 7, seed.

lary, pendulous raceme of 2–20 greenish female flowers or, most often, female flowers solitary; male flowers about 6 mm long, female ones about 13 mm; calyx (4–)5(–6)-lobed, in male flowers with irregular denticulate margin, in female flowers margin entire, accrescent, imbricate, persistent; corolla absent; stamens (8–)10(–12), free, filaments short, stout, anthers basifixed or sometimes ventrifixed, conspicuously extrorse, 4-sporangiate, dehiscing via longitudinal slits, pistil with 3-loculed, superior ovary and 3, free styles. Fruit an ovoid capsule, 1(–3)-seeded. Seed (the 'nut' in literature) ovoid, 1–1.5(–3) cm long, light brown to black; cotyledons thickened; embryo well-differentiated, straight.

Growth and development After germination, jojoba forms a deeply penetrating taproot (10 m or deeper), which may reach 60 cm before the emergence of the shoot. After the taproot, several deeply penetrating lateral and secondary roots are formed, but lateral spread of the root system is limited. A system of finer feeder roots develops closer to the soil surface. Wild plants may develop into small trees, especially in more humid areas; however, they mostly grow into multi-stemmed shrubs. Jojoba leaves may be shed during severe drought but generally live for 2–3 seasons.

In cultivation, male plants start flowering two years after planting and female ones up to one year later. The difference in time to flowering allows a first roguing of male plants from plantations, thus reducing competition for the female plants. Flowering occurs on new growth only. It is initiated by low temperatures, but flower buds may remain dormant until sufficient moisture is available. Prolonged drought leads to abortion of flower buds and young fruits. Female flowers are mostly produced at alternate nodes, but there are selections that flower at every node.

Jojoba is pollinated by wind. Pollen is produced profusely and flowering male plants are often visited by bees. Pollen grains can travel a distance of over 30 m even with only a light breeze, thereby making pollen distribution very effective. Fruit development takes 3–6 months. In its natural area, flowering occurs between December and April, fruiting between July and October.

The life span of jojoba may exceed 200 years.

Other botanical information Formerly, *Simmondsia* Nutall has been classified in *Buxaceae* or *Euphorbiaceae*; it is now generally considered as a monotypic genus in a distinct family, *Simmondsiaceae*. Pollen morphology, dichotomic branching and stem anatomy support this classification. The anatomy of the stem is characterized by the absence of annual growth rings. Secondary growth occurs in a series of concentric rings. During thickening of a branch, a series of cambia is formed in the secondary perivascular parenchyma. These cambia form vessel elements and fibre tracheids centripetally and conjunctive parenchyma and phloem centrifugally. As one extrafascicular cambium ceases activity, a new cambium is formed through dedifferentiation and division of the outer conjunctive parenchyma cells. Formation of cork tissue is also distinctive in *Simmondsia*. It starts with the deposition of tannins in the epidermis and cortex; later the adjacent perivascular fibres and parenchyma cells also become filled with tannins. After loss of the epidermis, cortex and outer perivascular fibres, cell division and tannin deposition continue in the transitional zone between the peripheral parenchyma and the cork; a true permanent phelloderm, however, is not formed.

Ecology The milder, open parts of the Sonora semi-desert form the natural habitat of jojoba. Its spread is restricted to the east by cool highlands, to the north-west by dense shrub vegetation and to the south by thorn forest. Its expansion into areas with a climate more favourable to plant growth seems limited by its susceptibility to grazing. In its natural habitat, it occurs from sea level up to 1500 m altitude, with annual rainfall of about 250 mm in coastal populations and 400 mm for inland populations and with average annual temperatures of 16–26°C. In inland sites with less than 300 mm rainfall, jojoba is only found along temporary watercourses or where run-off water collects. It is tolerant of extreme temperatures; mature plants may tolerate a minimum of −1°C and a maximum of 55°C. Frost damage is common in natural stands and is a major risk in cultivated plants. Seedlings are very susceptible to frost. The higher extreme temperatures have caused scorching of young twigs, leaves and fruits, but not death of plants. Jojoba grows on well-drained sandy, gravelly and neutral to slightly alkaline soils that are often rich in phosphorus. Some selections are tolerant of salinity; they grow and yield well in soils with electric conductivity of 38 dS/m or when irrigated with saline water of conductivity 7.3 dS/m.
Cultivated jojoba is grown in areas with 300–750 mm rainfall. Rainfall higher than 750 mm is likely to increase the incidence of diseases.

Propagation and planting Early jojoba plantations were established from seed collected from wild stands, but they were not productive enough economically to justify planting. Many new plantations used cuttings from selected plants. When seed is used, germination is good even when seed has been stored for several years. Jojoba seed can be stored in sealed containers at 1.5°C for more than 10 years without loss of viability. Seed is sown in a nursery preferably in slightly alkaline sand at temperatures of 27–38°C. Seedlings need irrigation and should be protected from browsing animals. Transplanting should be done very carefully to avoid damage to the root system and the use of biodegradable containers is advantageous. Methods of rapid in vitro propagation have been developed, but subsequent hardening of seedlings is still a problem. Conventional mutiplication via cuttings does not require special techniques and has given good results.
After land preparation, seedlings are planted at a spacing of about 4.5 m between rows and 2 m within the row, depending on available moisture and mechanization requirements. Where mechanization is not planned, spacing between rows can be less. Hedgerow systems with a reduced spacing within the row have also been proposed.
To ensure adequate pollination, male plants should constitute about 10% of a plantation, but recommendations vary from 5–20%.

Husbandry Weeds are the biggest problem in jojoba cultivation and young plantations have to be weeded regularly during the first 3 years after establishment. Where there are grazing or browsing animals, fencing is necessary. Pruning is required to keep the lower branches free from the ground. It is generally started when plants are 1–1.5 years old. Later, pruning of female plants is done in intensive cultivation to obtain an upright shape. For male plants, a broader shape is more desirable. Systems of pruning of young plantations grown from cuttings are still being developed.

Diseases and pests In the nursery, the main diseases affecting jojoba seedlings are *Fusarium oxysporum* and *F. solani*, but other common nursery diseases have also been recorded. In the field, diseases do not cause economic damage. Grazing animals and rodents are the main pests and in many areas, plantations have to be fenced. A number of insects feed on jojoba and affect growth or production, but none of them has so far developed into a real pest.

Harvesting Irrigated jojoba plants may start producing fruits in 3 years. Fruits are harvested when mature or nearly so, i.e. about 5 months after flowering. As they do not mature simultaneously, several picking rounds are needed. In many countries, harvesting is done manually, but in the United States, Australia and Israel, harvesting is mechanized. Fallen fruits are picked up from the ground either by equipment using a vacuum system or by a sweeper. When a sweeper is used, fruit is first moved into a central windrow using blowers. The use of tree shakers can increase harvesting efficiency, but may cause damage to the plants.

Yield In early plantations, jojoba grown from seed yielded only a few hundred kg of seed/ha and could not compete with collections from wild stands. In more recent plantations that used selected clonal planting material, yield may be about 1000 kg/ha under average rainfed conditions and 2000 kg/ha under irrigation.

Handling after harvest For storage, jojoba seed requires cleaning and drying to 9–10% moisture content. Extraction of oil from the seed is performed by screw pressing. For many industrial uses, no further refining is needed.

Genetic resources The largest germplasm collection of jojoba with over 150 accessions is maintained at the USDA-ARS National Arid Land Germplasm Resources Unit, Parlier, California, United States. Other collections are maintained in Israel and Australia.

Breeding Genetic variability in jojoba is vast and selection for desirable characters can be carried out in heterogeneous plantations grown from seed of wild plants. Breeding has not yet resulted in the development of true-breeding cultivars, but high-yielding clones have been selected for various growing conditions. Breeding work focuses on yield, oil content and simmondsin content. Additional breeding objectives are frost tolerance and low chilling requirements. Superior clones have been released in Australia, Israel and the United States. High-yielding clones with a low chilling requirement include: Q-106, MS 58-13 and Gvati from Israel.

Prospects The initial enthusiasm for jojoba as a high-return crop for dry and semi-arid areas has largely faded after many failed attempts to grow it. Jojoba is still a promising crop but the demand for it is much less than anticipated and income from it will be modest. New plantations coming into production will further increase supply and keep prices down. Competition from genetically modified *Brassica* may also negatively influence the market. Success is still possible, but can only be achieved with proper management and high-yielding plant material adapted to local conditions. As the utilization of jojoba oil in South-East Asia is likely to expand in the future, the feasibility of production for the local market may be even better.

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L.P.A. Oyen

Triadica sebiferum (L.) Small

Man. of the Southeast. Fl. : 789 (1933).
EUPHORBIACEAE
$2n = 36$

Synonyms *Croton sebiferum* L.(1753), *Stillingia sebifera* (L.) Michx. (1803), *Sapium sebiferum* (L.) Roxb. (1832).

Vernacular names Chinese tallow tree, candleberry tree (En). Popcorn tree (Am). Boiré, arbre à suif (Fr). Indonesia: kasumbi, kirendang (Java). Vietnam: c[aa]y s[of]i.

Origin and geographic distribution *T. sebiferum* is native to China and probably also to Taiwan, where it is cultivated. In former times, it was grown more widely in South-East Asia. It used to be cultivated and was found naturalized in Indonesia (near Jakarta, Timor), Singapore, Indo-China and Japan. It has also been acclimatized in northern India and in north-western Pakistan where it was originally brought in as an ornamental tree. It was introduced into the United States in the late 18th Century as a wayside tree, was planted along the coast of the Gulf of Mexico in the early 20th Century and can now be found in the south-eastern states. *T. sebiferum* was also introduced into the former Soviet Union and is grown e.g. in the coastal areas along the Black Sea in Georgia.

Uses The fruit of *T. sebiferum* contains two types of fat: the white, fleshy outer seedcoat (sarcotesta) produces a fat known as Chinese vegetable tallow or 'pi-yu' in trade, while the cotyledons of the seed (kernel) yield a drying oil called stillingia oil or 'ting-yu' in trade. Chinese vegetable tallow is widely used in China for edible purposes, as a substitute for animal tallow and tung oil, and for lighting. Candles made by mixing 10 parts vegetable tallow with 3 parts white insect wax are reputed to remain pure white for any length of time, to burn with a clear bright flame without smell or smoke and are used especially in Buddhist ceremonies. Elsewhere the vegetable tallow is used to make soap, as a substitute for cocoa butter and to increase the consistence of soft edible fats. Stillingia oil is used in paints and varnishes, for illumination and to waterproof umbrellas. Both the tallow and stillingia oil are used as fuel extenders on a small scale. The presscake remaining after tallow and oil extraction is unsuitable as feed for livestock because it contains saponins, but can be used as fuel or as manure. However, the presscake can be processed to make a valuable animal feed and human food, rich in protein. The leaves contain a dye, used in Indo-China and China to dye silk black. *T. sebiferum* is also an agroforestry species and an ornamental. It is a good soil binder and contributes to nutrient recycling. In tea plantations, it is planted as a shade tree against heat and desiccation. It is a minor timber tree: its wood has been used to make various implements, toys, furniture and Chinese printing blocks. Because *T. sebiferum* has a high woody-biomass production, it is potentially an important source of energy. In traditional medicine in China, the root bark is utilized for its diuretic properties and is said to be effective in the treatment of schistosomiasis. The leaves are applied to cure shingles.

Production and international trade After the 2nd World War, when there was a shortage of linseed oil (which is the major drying oil for paints), interest in stillingia oil from *T. sebiferum* increased and the oil reached prices of UK£ 200 per t in the world market. Experimental plantations were established in several South-East Asian countries, but outside China the trials did not meet expectations. A serious obstacle in exploiting the tree commercially has been the large amount of labour involved in collecting the ripe fruits by hand, which often competes with more urgent activities on a farm. Hence, oil supply was irregular and limited; only China exported annually about 4000–5000 t. At present, almost all stillingia oil and vegetable tallow oil are produced and used locally in China. The annual tallow production has been estimated to be about 50 000 t; annual exports have been as high as 15 000 t but export is almost zero at present. Because *T. sebiferum* tolerates many unfavourable soil conditions and some frost, interest in it has grown again since the 1980s as a potential fuel and biomass producer in marginal soils particularly in the south-eastern United States. As an oil crop, it has always been considered unprofitable in the United States because of the difficulty of harvesting the seeds economically. Annual return per ha of tallow, oil and presscake together was estimated at US$ 750 in the 1980s.

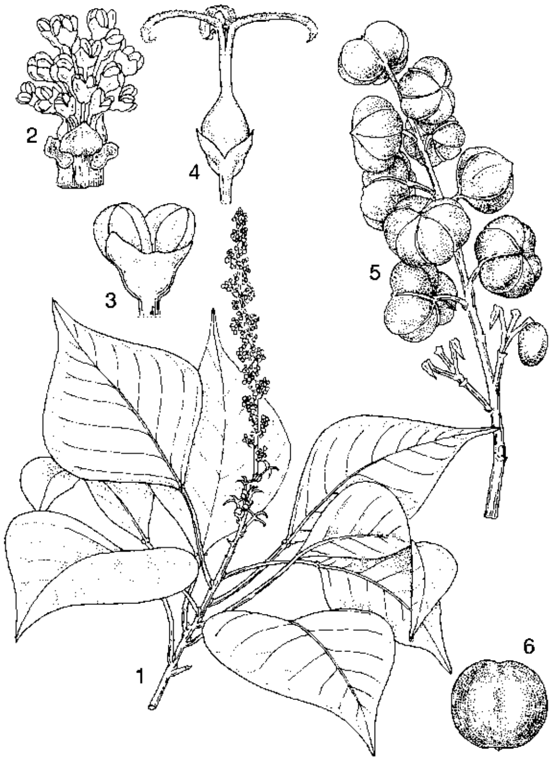
Properties The proportions of the different parts of air-dried seed (moisture content about 5%) of *T. sebiferum* are approximately: sarcotesta 30%, shell 40% and kernel 30%. The sarcotesta yields 50–80% vegetable tallow (whitish, hard, edible but tasteless) while the kernel yields 50–60% stillingia oil (strong smelling, not edible, emetic). The major fatty acid constituents of Chinese vegetable tallow are palmitic acid (60%) and oleic acid (30%). The principal glycerides are oleodipalmitin (60%), stearodipalmitin (10%), tripalmitin (10%) and oleopalmitostearin (10%). Its melting point is about 50°C.

The fatty acid constituents of stillingia oil are mainly unsaturated ones: oleic acid (20%), linoleic acid (25%) and linolenic acid (40%). The presence of unstable and easily oxidized estolides may explain why stillingia oil is a better drying oil than tung oil. Stillingia oil is poisonous and makes the vegetable tallow inedible if accidentally mixed with it. This oil also has inflammation and tumour-promoting properties.

The leaves of *T. sebiferum* are not browsed by cattle; they contain constituents such as gallic acid, astragalin (active against lymphatic leukemia cells), (–)-laliolide, kaempferol, quercetin, β-sitosterol glycoside, and a phenolic glycoside with antihypertensive activity.

T. sebiferum contains hydrolyzable tannins, including geraniin (the main type, even present in callus cultures) and ellagic acid. The stem bark contains various triterpenoids and 3,4-di-O-methyl ellagic acid. The bark contains a sticky milky-white sap which may act as a skin irritant and purgative. The bark of the roots contains xyloglucosides of xanthoxylin, moretenone, moretenol, xanthoxylin, and sitosterol-β-D-glucoside. As a fuel extender, the properties of vegetable tallow and stillingia oil were comparable to those of diesel fuel. Diesel fuel extended with 50% vegetable tallow and stillingia oil was used successfully in diesel engines in short-term tests. The power output, fuel consumption rates and thermal efficiencies of the engine were within 7% of the values obtained using pure diesel fuel. The wood of *T. sebiferum* is hard, close grained and nearly white with a density of about 500 kg/m^3 at 15% moisture content. The weight of 1000 seeds is about 150 g.

Description Monoecious, deciduous shrub or tree, up to 8(–15) m tall. Stem often gnarled (in its natural state), bark whitish-grey with vertical cracks, when wounded exuding a white juice. Leaves alternate; stipules ovate to triangular, up to 2 mm long; petiole 2.5–4 cm long, at apex (or base of blade) ending in a pair of conspicuous glands; blade broadly ovate to orbicular, 3.5–8.5 cm × 2.5–9 cm, less than twice as long as wide, base rounded, margin entire, apex acuminate, secondary veins 8–10 pairs arching and joined towards the margin, smaller veins closely and distinctly reticulate, turning orange to scarlet in autumn, falling early in the cold season. Inflorescence a terminal or upper axillary thyrse, 7–14 cm long, yellowish, basal part with female, upper part with male cymules; bracts and bracteoles present, often with a pair of glands at base, petals absent; female cymules 1-flowered, only 2–6 per thyrse; female flower with pedicel up to 1 cm long, calyx 3-lobed, ovary 3-locular, style ending in 3 stigmas; male cymules 3–8-flowered; male flower with pedicel longer than 2 mm, calyx lobes 3–6, stamens 2–3 with filaments longer than anthers. Fruit a dry, 3-seeded (3-lobed or grooved), subglobose schizocarp, 1–1.5 cm in diameter, opening regularly and nearly simultaneously septicidally and loculicidally; stalk up to 1.5 cm long; mericarps with persistent columella. Seeds 3, attached to the central columella for a considerable time after ripening, subglobose to flattened ovoid, 6–10 mm × 4–6 mm × 5–8 mm, covered with a white, waxy, persistent sarcotesta; seedcoat (shell) hard, brittle, brown.



Triadica sebiferum (L.) Small – 1, flowering branch; 2, bracteole with male-flowered cymule; 3, male flower; 4, female flower; 5, infructescence; 6, seed.

Growth and development Under favourable conditions *T. sebiferum* is a fast grower: in its early years (until 8–10 years) it grows about 1 m per year; after 20 years, it is 8–13 m tall with a stem diameter of 30–40 cm. Flowering starts 3–4 years after planting and the flowers are very fragrant and freely visited by bees and other insects. The fruits take 3–4 months to ripen. In seasonal climates, the tree is very ornamental with reddish inflorescences with green-yellow flowers in spring, conspicuous white seeds that remain long on the tree a few months later, and with leaves turning a brilliant red in autumn. In China, trees are long-lived and said to become several hundred years old. To run wild in areas where it has been introduced, it needs a fair amount of annual rainfall or a permanently moist soil. In Florida and Louisiana (United States), where such conditions occur, it has been declared a noxious weed.

Other botanical information In the taxonomic literature, Chinese tallow tree has long been named *Sapium sebiferum*, and was classified in section *Triadica* of the genus *Sapium* Jacq. in the tribe *Hippomaneae* of the family *Euphorbiaceae*. The *Hippomaneae* comprises about 30 genera now, with about 300 species. The genus delimitation in *Hippomaneae* is still in debate and the genus *Triadica* Lour. is not well known. *Triadica* comprises only 2 species at present, but the number might increase, probably to 4.

T. sebiferum has often been confused with species of *Homalanthus* A. Juss., particularly *H. populneus* (Geiseler) Pax. *Homalanthus* can be distinguished from *Triadica* by its 3-flowered staminate cymules (3–8 in *Triadica*), its small 2-carpelled fruits with thin fleshy pericarp (3-carpelled and dry in *Triadica*) and seeds with a reddish sarcotesta (white in *Triadica*).

The second *Triadica* species is *T. cochinchinensis* Lour., occurring all over South-East Asia, northern India and eastern China, used primarily as a medicinal plant, but also as timber and as forage. Its sarcotesta contains little palmitic acid and is not used. It can be distinguished from *T. sebiferum* by its leaves that are elliptical and more than twice as long as wide.

Although *T. sebiferum* has naturalized in the vicinity of Jakarta, several attempts to establish the tree in Singapore failed.

The seeds (kernels) of the related *Shirakiopsis indica* (Willd.) Esser (synonyms: *Excoecaria indica* (Willd.) Muell. Arg., *Sapium indicum* Willd.) also produce an edible oil and the tree is sometimes called 'Borneo tallow tree'.

Ecology *T. sebiferum* occurs in subtropical to warm temperate climates. It can withstand a few degrees of frost and tolerates a wide range of soils within pH range of 5–8. It thrives in waterlogged and moist locations and survives salt-water flooding. Optimum conditions are an annual rainfall of 1500–3000 mm, temperatures of 15–30°C, elevations from sea level up to 800 m on well-drained clayey-peat soils. In the United States, it survives in unburned grassland, in disturbed and undisturbed upland and wetland sites. It is shade tolerant and grows under closed canopies. In India, it can be found on gravelly soils in ravines.

Propagation and planting *T. sebiferum* can be easily propagated by seed (most common), cuttings, layering, top-grafting and root suckers (which are formed abundantly). Seeds are sown directly in the field, 3–4 per hole and 5 m distance between holes, giving 400 trees/ha. Seeds are usually planted in early spring or late autumn. Large seeds have the best germination rate (90%). In India, soaking seed in concentrated sulphuric acid for 10 minutes promoted germination effectively, while plants grown from suckers showed better growth than seedlings. An in vitro technique based on axillary bud proliferation has been developed.

Husbandry In plantations of *T. sebiferum*, trees should be trimmed and kept to a convenient size for hand harvesting.

Diseases and pests *T. sebiferum* has no serious diseases or pests. However, fungi such as *Cercospora stillingiae* and *Clitocybe tabescens*, and the plant parasite *Dendrophthoe falcata* L.f. (*Loranthaceae*) are known to attack it. In India, the tree is sometimes defoliated by larvae of the moth *Achaea janata* (synonym *Ophiusa melicerta*). The rootknot nematode *Meloidogyne javanica* has also been recorded as causing damage. Birds can inflict damage because they like the seeds.

Harvesting *T. sebiferum* starts bearing fruit 3–8 years after planting, although in Hawaii trees fruited already 18 months after sowing. In China, harvesting is done during September–November when fruit bunches have turned brownish. Where *T. sebiferum* is not cultivated, large-scale harvesting is only carried out in areas where the trees are abundant. Fruits are harvested with a sharp, crescent knife attached to a long pole or by hand by lopping off the ends of the branches, which has the effect of a severe pruning. Because *T. sebiferum* coppices very well, it is a suitable tree for biomass production.

Yield Annual seed yields per tree are estimated at 8–12 kg when 7–8 years old and 30–35 kg when fully grown. With 400 trees/ha, annual seed yields may reach 12 –14 t, giving 2–2.5 t vegetable tallow, 2–2.5 t stillingia oil, 4.5 t husk, 1 t seedcoat, 1.5 t protein-rich presscake. In the United States, *T. sebiferum* showed itself to be an interesting woody biomass supplier on poorly drained and saline soils in the hot southern coast region, yielding 6–10 t/ha dry biomass annually.

Handling after harvest Harvested fruits of *T. sebiferum* are dried on mats in the sun, they turn black and split open so that seeds can easily be removed by hand, by threshing or by treading under foot. Another way of loosening seeds is by gently pounding the capsules. The dried husks of the fruits are commonly used in China as fuel for the fires needed to extract the tallow. By heating the seed with boiling water or steam, the fat from the sarcotesta melts and forms the Chinese tallow; after that the seeds are crushed and pressed to collect the drying oil from the cotyledons. Sometimes seeds with sarcotesta are crushed and pressed and a mixture of vegetable tallow and stillingia oil is produced which has a much reduced commercial value. The sarcotesta can also be removed by passing the seed between fluted rollers that break it off without crushing the seed. In India, solvent extraction of the seeds for tallow and stillingia oil gave 50% more produce.

Genetic resources *T. sebiferum* is widespread and easily runs wild so there is no danger as yet of genetic erosion or extinction. Germplasm collections, however, are small or non-existent.

Breeding In Taiwan, there are more than 100 cultivars of *T. sebiferum*; two important cultivars are 'Eagle-claw' and 'Grape', which differ in fruit form and maturation period. In India, *T. sebiferum* easily hybridizes with the indigenous species *Sapium eugeniaefolium* Ham. The hybrid is more vigorous, possibly endangering the future of *S. eugeniaefolium* in some areas.

Prospects *T. sebiferum* is a useful tree since it produces fat, oil and biomass and is able to grow in a wide range of environments unsuited for many other plant resources. In cooler areas of South-East Asia with marginal, poorly drained soils, it is worthwhile investigating the possibilities for its cultivation. It does not require much care or input. However, to be economically profitable, the production of its various products, especially the oil, must be optimized. Research is needed to develop an efficient, low-cost extraction method to enhance the oil yield which is the crop's most important product.

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B.E. Umali & P.C.M. Jansen

Vernicia Lour.

Fl. cochinch.: 586 (1790).
EUPHORBIACEAE
$x = 11$; *V. fordii*, *V. montana*: $2n = 22$

Major species and synonyms
- *Vernicia fordii* (Hemsl.) Airy Shaw, Kew Bull. 20: 394 (1967), synonym: *Aleurites fordii* Hemsl. (1906).
- *Vernicia montana* Lour., Fl. cochinch.: 587 (1790), synonyms: *Dryandra vernicia* Corr. Méllo (1806), *Aleurites montana* (Lour.) E.H. Wilson (1913).

Vernacular names General: tung (En), aleurite (Fr).
- *V. fordii*: tung-oil tree (En). Arbre à l'huile de tung (Fr). Malaysia: tung-yu. Thailand: ma-yao. Vietnam: c[aa]y tung.
- *V. montana*: wood-oil tree, mu-tree, abrasin-oil tree (En). Arbre à l'huile de bois, abrasin (Fr). Indonesia: kemiri cina, muncang cina (Sundanese). Malaysia: mu-yu. Thailand: ma yao. Vietnam: c[aa]y tr[aar]u.

Origin and geographic distribution *Vernicia* occurs naturally in Japan, China and in continental South-East Asia from Burma (Myanmar) to Vietnam. *V. fordii* is native to Burma (Myanmar), northern Vietnam and China. It is now grown in China, the southern United States and South America and is naturalized in Queensland. *V. montana* is native to Burma (Myanmar), Thailand, Indo-China and southern China. It has been introduced into most tropical areas and cultivated in Indo-china, Indonesia, Madagascar and Malawi.

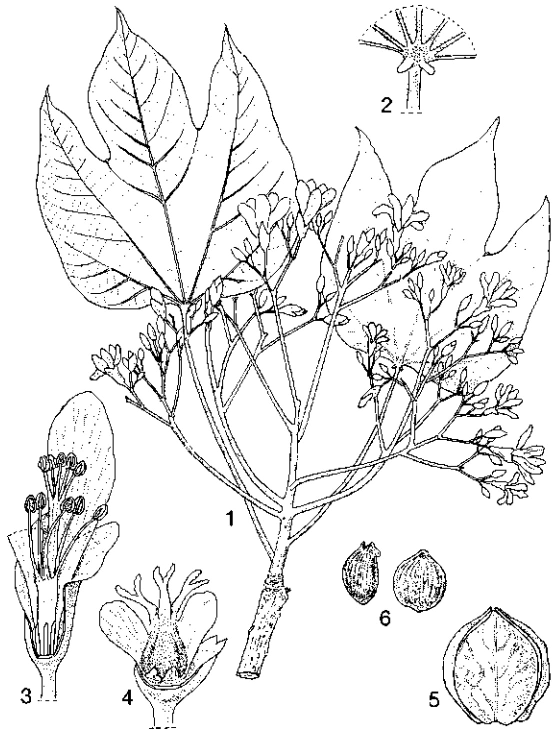
Uses Tung oil, extracted from the seed of *V. fordii* and the very similar wood oil from the seed of *V. montana* are quick-drying oils with excellent properties. Because of their similarity, they are often treated together as tung oil. In China, the oil is used traditionally in the manufacture of paints and Chinese black ink, for waterproofing cloth and paper, caulking and painting ships and as a lamp oil. It was also formerly used for insulating electric wires. Currently, its main use is in the production of paints and inks, while low-quality oil is applied in the manufacture of soap and linoleum. Teak oil which is sold for maintaining fine furniture is usually refined tung oil. Developments in environmental and health regulations have led to an increasing use of tung oil to line containers for food, beverages and medicines with an insulating coating. The press cake, after extraction of the oil, is a good fertilizer, but it is poi-

sonous and cannot be used as animal feed.
In medicine, tung oil is used to treat parasitic and other skin diseases and is a strong purgative. It is a component of nearly all Chinese plasters.
The timber is only suitable for simple construction and firewood, where better wood is not available. The timber is white, soft and perishable. Both *V. fordii* and *V. montana* are sometimes planted as shade trees.

Production and international trade The oils from *V. fordii* and *V. montana* are rarely distinguished in trade and are both referred to as tung oil, although a distinction between them has been proposed in the United States. Annual world production of tung fruits in the late 1990s was about 500 000 t from 170 000 ha, yielding 90 000 t oil. China produced 85% of the world production: 450 000 t fruit yielding 80 000 t oil. It exported 25% of its production. China was followed by Paraguay with 43 000 t seed and Argentina with 30 000 t seed, while Madagascar, Malawi and Brazil produced small quantities. No production data are available for tung oil or mu oil from South-East Asia. Production, exports and oil quality from China fluctuate yearly resulting also in price fluctuations. Prices fluctuated from over US$ 3000 per t at the end of 1993 to US$ 1200 two years later, while in 1996 prices ranged from US$ 1250 to US$ 2000. Exports from South America are declining. Tung oil was once an important crop in the United States, where the belt from Florida to eastern Texas produced about 50 000 t oil in the 1950s. Subsequent crop losses caused by frost, hurricanes and commercial difficulties led to a complete abandonment of nearly all plantations. However, following the introduction of laws to reduce the use of solvents in paints, plans are being made to establish 2000 ha of *V. fordii* plantations in Mississippi. Efforts were made in the 1930s to establish a tung oil industry in Indonesia, but little progress was made after World War II.

Properties The fruit of *V. fordii* or *V. montana* contains per 100 g 14–20 g drying oil. The oil is mainly contained in the seed which makes up about 33% of the fruit. The main fatty acid of the oil is α-eleostearic acid or cis-trans-trans 9,11,13-octadecenoic acid. It is a trienoic fatty acid, isomeric with linolenic acid. In eleostearic acid, the 3 double bonds are conjugated making them highly reactive. Under the influence of light or catalysts such as sulphur and iodine, α-eleostearic acid converts to β-eleostearic acid, which is even more reactive and spontaneously polymerizes into a solid mass. The eleostearic acid makes tung oil a virulent purgative when taken internally. The α-eleostearic acid content is 75–80%; other fatty acids include: palmitic acid 4%, stearic acid about 1% and oleic acid 15%. In the triglycerides, most eleostearic acid is bound in the 1 and 3 positions.
Other components of the fruits of both species include tannins, phytosterols and a poisonous saponin. Animals, including cattle, horses and chicken that have eaten the leaves or seed cake show haemorrhagic diarrhoea accompanied by anorexia. In severe cases, they become emaciated and may die in 1–3 weeks. The fruits of *Vernicia* are attractive in appearance and taste, but ingestion by humans of even a single seed causes severe abdominal cramps, vomiting, diarrhoea and general exhaustion after 3–5 hours.

Description Shrubs or trees, monoecious or sometimes dioecious, deciduous or evergreen. Indumentum of simple or bifurcate hairs, at least present on young shoots, leaves and petioles. Leaves alternate; stipules triangular-lanceolate, early caducous, leaving fairly prominent scars;



Vernicia montana Lour. – 1, branch with male inflorescence; 2, glands at apex of petiole; 3, male flower with calyx and petals partly removed; 4, female flower with calyx and petals partly removed; 5, fruit; 6, seed in side and dorsal view.

petiole terete, striate, with two glands at junction with blade; blade simple, ovate to broadly ovate or 3–5-palmately lobed. Inflorescence a terminal, solitary, corymbiform thyrse, branching from the base, unisexual or bisexual and protogynous with a solitary terminal pistillate flower and several staminate flowers per cymule; flowers unisexual, showy, slightly zygomorphic; calyx closed in bud, later valvately rupturing into 2(–3), often unequal lobes; petals 5(–6), free, imbricate, contorted, obovate, clawed; disk of 5–6(–7) erect glands; male flowers with pedicel usually longer than in the female flowers; stamens (7–)8–12(–14), in 2 whorls, united into a column, pistillode absent; female flowers with ovary superior, 3(–5)-locular, with 1 ovule per locule, pubescent or densely sericeous; styles nearly free to united at the base, bifid. Fruit large, capsular, ovoid to subglobose, tardily dehiscent, glabrous to pubescent. Seed without caruncle, obovoid to subglobose, dorsiventrally compressed, pointed, brown with longitudinally oriented beige variegations, smooth or warty and ridged; hilum large; embryo straight, embedded in copious endosperm; cotyledons broad, flat.

- *V. fordii*. Monoecious, flat-topped, much branched, deciduous, shrub or tree, up to 20 m tall. Indumentum fulvous to mostly ferruginous. Leaves crowded at the apex of the shoots; stipules 4–12 mm long; petiole up to 26 cm long, glands sessile, about 0.5 mm long; blade 5–25 cm × 4–22 cm, ratio length/width 1:1.2(–1.4), sometimes 3-lobed, 5-veined from the base. Inflorescence usually bisexual, appearing before the leaves, 3–16 cm long, few-flowered, with one central female flower and 4–7 lateral male cymules, 3–7-flowered; bracts linear-lanceolate, 2–10 mm long, densely hairy; flowers reddish-white to purple, suffused and veined with pink, yellow in the centre, diameter 25–35 mm; calyx lobes 8–10 mm × 5–8 mm, pubescent at the apex; petals orbicular-ovate to broadly obovate-spatulate, 20–35 mm × 8–20 mm; claw 3–6 mm long; male flower with pedicel 8–18 mm long, stamens (7–)8(–14), the (4–)5(–8) outer filaments 7–10 mm long, the 3(–6) inner ones up to 15 mm; female flower with pedicel slender, 5–14 mm long, ovary ovoid to subglobose, 4–5-locular, gradually narrowing into the styles, styles united at the base, 4–5 mm long, shortly bifid. Fruit spherical to subglobose or slightly compressed, 4–6 cm in diameter, apically sharply pointed, basally stiped, smooth, dull brown, sparingly sericeous. Seed sub-obovoid, 2–3 cm long, conspicuously warty and ridged dorsally and ventrally.
- *V. montana*. In general similar to *V. fordii* but with following major differences: evergreen shrub or tree, 10–15 m tall; stipules 3–5 mm long; glands at the apex of petiole stalked; inflorescence usually unisexual and male ones much larger than the female ones; ovary 3(–5)-locular, gradually narrowing into the styles; fruit surface wrinkled with 3(–5) distinct longitudinal grooves and ridges and few transverse ribs.

Growth and development Two branching and flowering patterns in *V. montana* are recognized in Indonesia: the Indo-China type and the China type. Similar types are also recognized in Malawi.

- Indo-China type. This is a fast-growing tree with a tall, straight trunk forming tiers of 5 spreading branches at regular wide intervals. At their distal end, these branches form 5 secondary branches. While the lower 1–2 buds of the secondary branches grow out into new branches repeating the branching structure, the upper buds and the terminal bud of the primary branch develop into short flowering branches. Trees of the Indo-China type are never completely leafless in equatorial areas. They flower throughout the year with peaks around May and October in Indonesia. The distinction between male and female trees is less sharp and even in very productive trees with the highest ratio of female inflorescences, the number of male inflorescences is higher than that of female and mixed inflorescences together. It takes 3–5 years for trees to come into bearing. At higher latitudes where trees lose their leaves during winter, flowering is concentrated in a short period of only 2 weeks in spring. Here, trees are either male or female with only occasional bisexual trees.
- China type. The tree is a more slow-growing, compact and small tree or shrub which starts bearing in the third year after planting and gives high yields in the first 6 years. In Indonesia, the growth rate of its main stem is less than that of the branches. The China type of *V. montana* behaves similarly in equatorial areas. In Indonesia, trees are leafless during a short rest period in the dry season, and they are either male or female. The flowering period is extended and may vary per tree, but there is a flowering peak around October and sometimes a minor peak of mainly male flowering in May.

Flowers open in the morning. In female flowers, the stigma is already receptive 1 day earlier, while in male flowers, pollen is released at anthesis. Pollen is sticky and pollination is performed by insects such as butterflies and bees. Some honey-bee species, however, are common visitors of male flowers, but are rarely seen on female flowers and contribute little to pollination. In clonal plantations of selected female trees in Indonesia, the number of male flowers may not be sufficient for good pollination. Planting about 5% male trees is enough to correct the problem. The number of fruits set is high and about 80% of the fruit set may abort during development. In the United States, fruit development in *V. fordii* takes about 18 weeks and mature fruits drop after 20 weeks. Fruit development in *V. montana* follows a similar pattern.

Bud-grafted tung-oil trees come into production 2–4 years after planting; trees grown from seed a few years later. Maximum production is reached when trees are 10–12 years old. Plantations remain productive for a long time. Although plantations older than 100 years exist in China, production starts to decline when trees are 20 years old and becomes uneconomical when they reach 30 years. A slight biennial or triennial bearing pattern is a common feature in *Vernicia* plantations.

Other botanical information The genera *Aleurites* J.R. Forst. & G. Forst., *Reutealis* Airy Shaw and *Vernicia* are closely related and have long been combined in *Aleurites*. *Vernicia* comprises only the two closely related species treated here and a third species *V. cordata* (Thunb.) Airy Shaw which occurs in Japan. Where *V. fordii* and *V. montana* grow together and flower simultaneously, hybridization is common, but the hybrids have no agronomic advantages. In China, many *V. fordii* cultivars exist, including 'Luxi Pupu Tong' and 'Zhetung 7'. In the United States also, some cultivars of *V. fordii* have been released, e.g. 'Folsom', a low-growing, high-yielding, late-maturing cultivar with large, purplish fruits that contain 21% oil. 'Lampton' is a very low-growing, early maturing and probably the most productive cultivar with a high tolerance to low temperatures during the cool season. Its fruits are small and contain about 22% oil.

Ecology *V. fordii* is mainly grown in the subtropics and temperate regions of Asia and North America. It needs (650–)1000–1700 mm annual rainfall and an average annual temperature of 19–26°C. During winter, it requires a period of 300–400 hours below 7.5°C for flower initiation. During active growth, however, frost may cause serious damage and is one of the reasons why tung cultivation was abandoned in the United States. Planting on hilltops or slopes helps reduce the risk. Yields are best where the difference between day and night temperatures is small. Many tung stands in China are on poor soils, but well-drained, slightly acid soils (pH 6–6.5) with a good moisture-holding capacity are required for high production. In the United States, dolomite has been used to correct soil acidity. Fertilizer requirements vary with soil type. Application of micronutrients is recommended unless soil content is adequate.

V. montana is most widely distributed in the tropics and subtropics of Asia, America and Africa. It is planted in areas with annual rainfall of 850–2000 mm and average annual temperatures ranging from 15–27°C in tropical areas at altitudes of 800–2000 m. It does not require low temperatures for flower initiation and is sensitive to frost. *V. montana* is often grown on slopes but grows well on flat land provided the area is well-drained. It prefers slightly acid soils and is very susceptible to accumulation of ash and occurs on soils of pH 5.5–8.0. Adequate soil fertility is needed for good production.

Propagation and planting Commercial plantings of *Vernicia* consist mostly of selected clones budded on to seedling rootstocks. In Malawi, budding is done in the nursery, but in Indonesia it is done in the field after transplanting. The simple shield method at a height of 5–7.5 cm above the ground is commonly applied. Propagation by seed results in variable stands with 50% male trees. Fresh seed germinates quickly, but germination of older seed may take 2–3 months unless seed is scarified. Seedlings are transplanted into the field when they are 1 year old. In China, planting density is about 600 trees/ha, whereas in Paraguay, the most common density is 330–700 trees/ha. In Florida (United States), tung trees are planted either at a wide spacing with 185 trees/ha or at a narrow spacing with over 250 trees/ha. Plantations with a close planting system reach maximum production at an earlier age but the maximum yields are the same as those from trees that are more widely spaced. Hedgerow systems have also been developed. In this case, pruning and training are recommended to obtain a frame of a few main branches and open crown. Fertilizer should be applied to seedlings in the nursery. In the United States, an application of 600 kg/ha of a NPK 5–10–5 compound fertilizer at planting is recommended.

Husbandry Young trees of *Vernicia* are often intercropped with food crops such as maize, groundnut or soya bean in China. In Malawi and Indonesia, intercropping with annuals or planting of cover crops is common. Prolonged intercropping with annual crops may cause damage to the root system, but in China even mature trees are sometimes intercropped with winter crops. Regular weeding around the plants is needed also for ease of harvesting.

Diseases and pests In China, anthracnose caused by *Colletotrichum gloeosporioides* (syn. *Glomerella cingulata*) sometimes causes severe losses. Other important diseases include: root rot caused by *Fusarium solani* and brown leaf spot caused by *Cercospora aleuritides* (syn. *Mycosphaerella aleuritides*). In Malawi, the main diseases of *V. montana* are die-back caused by *Botryosphaeria ribis* and the Armillaria root rot. In Indonesia, *Rhizoctonia solani* causes damage in the nursery but can be controlled by fungicidal treatment. Root rot caused by *Botryodiplodia theobromae*, *Phytophthora palmivora*, *Pythium* sp. and *Sphaerostilbe repens* has been recorded. Selection of adapted plant material is the best way to avoid these diseases.

Insect pests are rarely a problem as the leaves and seeds are toxic to most animal life. The thrips *Selenothrips rubrocinctus* causes damage in *V. fordii* in China, but *V. montana* is highly resistant.

Harvesting Harvesting by manual picking of fallen fruits is most common, but in China, green fruits are also picked from the trees. In subtropical areas where harvesting is done during winter months, fruits can be left on the ground for a few weeks to dry. In Java, fruits mature year-round in seedling plantations, but clonal material ripens in a short period. Careful selection of clones can extend the harvesting season. During the rainy season, fruits should be collected every 10 days, and during the dry season about once a month.

Yield In Florida (United States), fruit yields of 5 t/ha can be obtained from well-managed mature plantations, but worldwide yields are lower. Average yields are 3.5 t/ha in China and 1.8 t/ha in Malawi.

Handling after harvest In China, the fruit is traditionally collected when still green, placed in heaps and covered with straw or grass. Fermentation takes place in the heaps and the fleshy parts of the fruits rot until the seeds can be easily removed. These seeds are then crushed in a mill consisting of a circular stone trough and a heavy stone roller. After being roasted for a short time in shallow iron pans, the crushed mass is placed in wooden vats with open-worked bottoms over cauldrons of boiling water and thoroughly steamed. Subsequently, fluid is pressed out of the cake yielding commercial tung oil or wood oil. In modern processing, hulling of fruits is done by hand or mechanically. The seeds are then dried and shelled mechanically, after which the kernels are ground with some shell added to facilitate oil extraction. Cold-expression is done in screw presses yielding a clear, light-coloured oil. The cake may subsequently be warm-pressed or solvent-extracted to increase the yield, but the product is of lower quality.

Genetic resources and breeding Both *V. fordii* and *V. montana* are very variable and there are only few true breeding lines. No germplasm collections are known to exist. In the United States, the National Plant Germplasm System no longer maintains its former collection of *Vernicia*. However, important breeding and selection programmes have been implemented in China and Taiwan.

Prospects The excellent quality of tung oil may make it worthwhile to consider the possibilities of commercially producing *Vernicia* in South-East Asia. Extensive testing of new clones and production techniques should precede the establishment of new plantations in this region.

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N.O. Aguilar & H.C. Ong

3 Minor vegetable oils and fats

Astrocaryum G. Mey.

PALMAE

Major species and synonyms
- *Astrocaryum aculeatum* G. Mey., synonyms: *A. aureum* Griseb. & H. Wendl., A. *chambira* Burret, *A. tucuma* Mart.
- *Astrocaryum vulgare* Mart., synonyms: *A. awarra* de Vriese, *A. segregatum* Drude, *A. tucumoides* Drude.

Vernacular names General: tucuma, tucum, tucuma palm (En).
- *A. aculeatum*. Tucum, tucuma, tucuma palm (En).
- *A. vulgare*. Awarra, tucum, tucuma palm (En). Aoura (Fr).

Distribution All 50 known species of *Astrocaryum* originate from tropical Central and South-America, from Mexico southwards to Brazil and Bolivia; they are absent from the West Indies but present in Trinidad. Some species are occasionally cultivated pantropically. *A. aculeatum* and *A. vulgare* originate from tropical South America. *A. vulgare* has been successfully cultivated in Malaysia and Singapore.

Uses The fruits of most *Astrocaryum* species yield a pulp oil and a kernel oil. The pulp is used locally to extract an edible oil or as cattle feed; the kernel oils have gained some importance in international trade, being fine oils suitable for human consumption and for making margarine and soap. The refined oil is clear, highly edible and competes in food quality with coconut and palm-kernel oil. Most species have edible 'cabbages' ('palm hearts') and are planted as ornamentals. A fibre can be isolated from the leaves by maceration. It is used to make, for example, hammocks, hats, mats, fishing lines, fishing nets and paper.

Observations Moderate to robust, solitary or clustered, spiny, pleonanthic, monoecious palms. Leaves at first erect, finally often arching, regularly or irregularly pinnate with acute-tipped leaflets. Inflorescence at flowering erect between the leaves, at fruiting deflexed or pendulous, rachis thick and branched to one order, branches with female flowers at base and male flowers densely clustered at the ends and somewhat immersed. Fruit a usually 1-seeded drupe, mesocarp dry farinose-fibrous or carnose pulpy-fibrous; endocarp bony with 3 pores near apex.
- *A. aculeatum*. Solitary palm, trunk up to 25 m tall and 20–30 cm in diameter; petiole up to 2 m, blade 7 m long, leaflets linear, 1 m × 4–5 mm; inflorescence 2 m long, branches 40 cm long, spines 8 cm long; drupe ovoid to subglobose, about 6 cm in diameter, yellow-orange, mesocarp fleshy, edible, kernel subglobose, 5.5 cm in diameter, endocarp 3 mm thick. Very often found near actual or former human settlements.
- *A. vulgare*. Trunks few to several, up to 9 m tall and 18 cm in diameter, densely armed with black flattened spines up to 12 cm long; leaves 3 m long, leaflets 70–80 cm; inflorescence 2 m or longer, armed with prickles 1–3 cm long; drupe subglobose, 4 cm in diameter, orange, apex shortly pointed, mesocarp fibrous-fleshy, yellowish, edible; endocarp 3 mm thick, kernel narrowed towards the base, 1-seeded. Usually found on dry sandy soils.

Most species are confined to tropical lowland, some as undergrowth of primary forest, others light demanding in secondary forest, forest margins or river banks. The oil content of the kernel is 25–50%. Below the melting point of 30–33°C the oil is a somewhat brittle, firm, solid. Other species particularly mentioned for their oil-yielding fruits and seeds are *A. gynacanthum* Mart. and *A. mexicanum* Liebm. ex Mart. Several *Astrocaryum* species have been grown successfully in Indonesia, Malaysia and Singapore and they may have some potential as oil crops for South-East Asia, e.g. *A. vulgare* on poor sandy soils.

Selected sources 19, 34, 126.

Attalea cohune Mart.

PALMAE

Synonyms *Orbignya cohune* (Mart.) Dahlgren ex Standl.

Vernacular names Cohune palm, manaca, corozo (En, Sp).

Distribution *A. cohune* is a native of the Caribbean littoral from Mexico to Panama, extending to northern South America. In Central America it is also often cultivated; in other tropical regions only occasionally.

Uses The main product from the cohune palm is the kernel oil which is similar to or even finer than coconut oil and is used in baking, cooking, illumination and in making margarine and soap. Unripe kernels are sometimes used in cooking as a substitute for milk. Ripe ones are a snack food. The epicarp and endocarp are used as fuel, damaged kernels and the residue after oil extraction as animal feed. Leaves are used for thatching, building houses and temporary shelters and for making hats, umbrellas, ties and fans. The 'cabbage' can be eaten raw, cooked or pickled and palm tops are tapped for palm wine. *O. cohune* serves as a source of germplasm for improving other oil-yielding palms. Its ornamental value is important: it is by far the largest and most majestic of all the palms of Central America.

Observations Unarmed, unbranched, monoecious palm, 9–20 m tall, trunk thick, bearing persistent leaf bases above. Leaves numerous, plume-like and graceful in spite of their great size, up to 10(–18) m × 2(–2.5) m, recurving, with numerous, elongate, very narrow segments. Staminate inflorescences 1–1.5 m long, bearing numerous flowers; fruiting panicles very large and heavy, pendent, containing often 800–1000 fruits. Fruit a drupe, resembling a small coconut, about 6 cm long. Seed enclosed in a very hard endocarp. *A. cohune* is an upper canopy palm thriving in various habitats which range from swampy, wet lowlands to upland areas up to 600 m altitude. It grows abundantly in well-drained, moist, dark, organic surface soils over a deep friable subsoil, but occurs on all soil types. Cohune palm is propagated by seed that normally remains viable for 6 months after harvest; seed is planted 5 cm deep, preferably in a 3:1:1 mixture of loam, manure, and sand; seedlings are transplanted, preferably at a wide spacing of about 100 plants/ha. Annual production of a mature palm reaches 1000–2000 fruits, in total weighing about 100 kg, resulting in 10 t/ha for 100 palms. Yields vary from year to year and in Central America it is often difficult to maintain a regular fruit supply to oil mills. Cohune oil is a yellowish, non-drying oil similar to coconut oil but with a lower melting point and a smokier taste. Cohune seed contains approximately 7% protein and 52% fat, the other parts of the fruit approximately 1% protein and 0.5% fat. The fatty acid composition of cohune oil is approximately caprylic acid 7%, capric acid 7%, lauric acid 46%, myristic acid 16%, palmitic acid 10%, stearic acid 3%, oleic acid 10% and linoleic acid 1%. In order for this palm to be fully and profitably exploited there must be a ready market for its products as well as a large production area. It is questionable whether cohune palm is also promising for South-East Asia: it will grow well, but many alternatives are available for the oil and other products.

The related babassu palm *Attalea speciosa* Mart. ex Spreng. (synonyms: *Orbignya oleifera* Burret, *O. phalerata* Mart.; its nomenclature is confusing in the literature) is another source of edible oil in Latin America. Initially, fruits were collected only from the wild. Palms retained in clearings for shifting cultivation developed gradually into babassu forests. At present in Brazil the babassu area occupies some 200 000 ha. The oil extracted from the kernel is rich in lauric acid. The potential of babassu palm for South-East Asia is being investigated in Malaysia.

Selected sources 5, 6, 33, 36, 45, 46, 78, 119, 126.

Camellia sasanqua Thunb. ex Murray

THEACEAE

Synonyms *Sasanqua vulgaris* Nees, *Thea sasanqua* (Thunb. ex Murray) Cels.

Vernacular names Teaseed, sazanka camellia (En).

Distribution Native to south-western Japan (Ryukyu Islands), introduced and often cultivated elsewhere, particularly in northern India (Assam), China (most important), northern Vietnam and (formerly Soviet) Georgia.

Uses The oil extracted from the seed is used as an edible oil similar to olive oil and as a substitute for cocoa butter. The cake remaining after oil extraction is poisonous (containing saponins) and is used in China as an insecticide. In Georgia, *C. sasanqua* leaves are an industrial source of eugenol. Flowers are used to scent tea. *C. sasanqua* and its hybrids are grown as ornamentals (in pots and as cut flowers, e.g. in Australia). Due to its vigour and resistance to some pathogens, *C. sasanqua* is also used as rootstock for other *Camellia* species.

Observations Evergreen dense shrub or small tree, up to 5 m tall with slender branches. Leaves alternate, thinly coriaceous; petiole 3–5 mm long; blade elliptical-ovate, 3–5 cm × 1–2 cm, base acute, margin obtusely serrulate, apex obtuse, sometimes emarginate, veins only slightly raised. Flowers subterminal, sessile, solitary or in fascicles of 2–3, bisexual, white (also pink to rose in cultivars), 4–5 cm across; petals 6–8, free to base, spreading, obovate to oblong, up to 3.5 cm long; stamens numerous, at base attached to inner petals; pistil 11–14 mm long, ovary usually 3-carpelled, densely white-pilose, style with 3 arms. Fruit a capsule, obovoid-globose, 1.5–2 cm across, pubescent, pericarp rather thick, usually 1–2 seeds per locule. Seed 12–15 mm long, red-brown, the kernel about 70% of the seed weight. *C. sasanqua* prefers humid warm temperate and subtropical climates, in forests and forest borders. It is very sensitive to low temperatures. In Georgia, *C. sasanqua* can be grown up to 400 m altitude and coppices vigorously after fire. In Japan, flowering and fruiting is in October–December. China is the largest producer of teaseed oil in the world, with annual production of over 25 000 t, followed by Vietnam and India. Japanese cultivars derived from *C. sasanqua* have been classified into 4 cultivar groups: Hiemalis, Oleifera, Sasanqua and Vernalis, and based on e.g. flower colour, hundreds of cultivars have been distinguished. *C. sasanqua* is propagated by seed or by cuttings; propagation through immature embryo culture is also possible. *C. sasanqua* starts flowering at the age of 5–7 years, sometimes even at 2–3 years in Georgia. Pruning as applied to tea plants discourages seed formation. Harvesting is done by gathering mature fruits with seeds that have fallen to the ground. The seeds are then dried in the sun and the outer husks are removed by hand. After grinding the kernels, the meal is steam-pressed to produce the oil, or the oil is extracted with a solvent (e.g. petroleum ether). Seed of *C. sasanqua* contains up to 70% oil, the same as that of *C. japonica* L., while seed of *C. sinensis* (L.) Kuntze contains up to 30% oil. The oil is made up of 6–12% saturated acids, 72–78% oleic acid and 2–15% linoleic acid. When refined and deodorized it is chemically and physically similar to olive oil. Medicinally sasanqua oil is still under investigation; possibly it has anti-inflammatory and anti-tumor activity. Air-dried leaves of *C. sasanqua* contain about 2% eugenol and in Georgia a promising industry based on it is developing. For South-East Asia, *C. sasanqua* is only of interest in the northern areas and at higher altitudes (cultivation trials failed in Singapore; in Java plants grew well but produced only small seed). Based on experiences in Vietnam and China, it is worthwhile investigating cultivation possibilities in other suitable locations in South-East Asia.

Selected sources 1, 3, 4, 13, 14, 15, 19, 25, 38, 40, 41, 48, 50, 51, 72, 76, 88, 125, 134, 137.

Chisocheton cumingianus (C. DC.) Harms

MELIACEAE

Synonyms *Chisocheton morobeanus* Harms, *C. paniculatus* Hiern, *C. thorelii* Pierre.

Vernacular names Philippines: balukanag (Pilipino), balokanag (Bikolano), makalakad (Bisaya). Burma (Myanmar): tagat-pyu. Thailand: yom makok (northern). Vietnam: g[ooj]i ch[uf]y.

Distribution From northern India (Assam) and southern China throughout continental South-East Asia (except Peninsular Malaysia) and eastern Malesia (not in Sumatra and Java).

Uses The seed contains a non-drying oil ('balukanag' oil), used particularly in the Philippines for soap making and illumination. In the Philippines the oil is also used medicinally, externally it is applied for rheumatism and inflammation due to oedema, internally it is taken to treat cholera and gastralgia. The wood is utilized as a medium-weight hardwood timber, e.g. for light constructions. In New Guinea, *C. cumingianus* is used as a fish poison.

Observations Tree up to 40 m tall, bole up to 1.5 m in diameter with buttresses up to 3 m × 2 m or fluted up to 10 m. Leaves crowded in terminal spirals, up to 1.2 m long, pinnate with up to 15 pairs of leaflets, pseudogemmulate; petiole 5–10 cm, petiolules 4–12 mm long; leaflets ovate to elliptical, 6–42 cm × 2–14 cm, papery to coriaceous, tertiary venation conspicuous. Inflorescence a thyrse, up to 50 cm long with 2–3 branches up to 10 cm long, axillary, supra-axillary or borne on short shoots (3–8 thyrses per shoot) on defoliated twigs, branches or on bole; pedicel up to 4 mm long; flowers unisexual or bisexual, tubular, nearly 2 cm long; calyx campanulate, 1–3 mm long; petals (3–)4(–5), spatulate, 1–2.5 cm × 2.5 mm, pale yellow to white; staminal tube about 1 mm in diameter, bearing 6–9 anthers about 2 mm long;

ovary in female flowers 3–4-locular, each locule with 1 ovule, style at apex disciform to capitate. Infructescence pendulous, up to 30 cm long; fruit a globose to pyriform capsule, up to 7 cm in diameter, orange-red, glabrous to velutinous on stipe up to 1.5 cm long; pericarp usually with white latex. Seed 3–4 per fruit, subglobose to obovate, 3 cm × 2.5 cm, testa black-brown, with orange-red aril around the hilum with crenate margin and sometimes with extension to micropyle; cotyledons superposed. *C. cumingianus* is common in primary rainforest from sea-level up to 1300 m altitude. Based on differences in inflorescences (axillary, ramiflorous or cauliflorous) 3 subspecies have been distinguished. High altitude trees are usually cauliflorous. The kernel constitutes about 60% of the total weight of the seed and contains about 30% oil. The oil has about 4% free fatty acids (oleic acid), an iodine value of 78–80 and saponification value of 192. The oil has mild purgative properties, the effect of 5 parts of the oil is approximately equivalent to one part of castor oil; it has a rancid smell and a slightly bitter taste.

Selected sources 18, 42, 59, 97, 101.

Chisocheton macrophyllus King

MELIACEAE

Vernacular names Indonesia: gendis, gula (Javanese). Malaysia: bekak, pasak lingga (Peninsular). Thailand: ma aa, ta suea (peninsular).

Distribution The Nicobar Islands, peninsular Thailand, Peninsular Malaysia, Singapore, Sumatra, Anambas Islands, Java, Borneo.

Uses The seed contains an oil that has been used for illumination. Because the leaves contain triterpenoids which show antiviral activity, they might have some medicinal importance. The wood is of little use as timber because it is not durable and it splits easily.

Observations Tree up to 35 m tall, trunk up to 2 m in diameter with buttresses up to 3 m × 2 m, crown irregular, sparsely-branched, bark exuding white latex when wounded. Leaves in dense terminal spirals, up to 3 m long, pseudogemmulate with up to 28 pairs of leaflets; petiole 10–15 cm, petiolules about 1 cm long; leaflets oblong, up to 39 cm × 11 cm, with 18–25 spreading veins on each side of midrib. Inflorescence a panicle-like thyrse, up to 80 cm long, branches rather distant and up to 12 cm long, ultimate branchlets cymulose and many-flowered; calyx cupular, 3–4 mm long; petals 4 or 5, linear-spatulate, up to 15 mm long, pale yellow; staminal tube swollen at mouth, bearing 5–9 anthers each 2.5 mm long; pistil sericeous with 4-locular ovary, style head cylindrical with apical lobes. Fruit a capsule, pear-shaped, up to 15 cm in diameter, 4-valved, orange-brown, with tough latex-producing pericarp, 2–4-seeded. Seed like a segment of an orange, 4.5 cm long, covered with mealy sarcotesta. *C. macrophyllus* occurs in light, lowland rain forest, up to 1100 m altitude. In Java it flowers between June and September. The oil is obtained from the seed by expression. Seed and other plant parts taste bitter. Seeds with sarcotesta showed only 30% germination 2–6 months after sowing.

Selected sources 8, 19, 42, 56, 58, 59, 135.

Chisocheton pentandrus (Blanco) Merr.

MELIACEAE

Synonyms *Chisocheton beccarianus* (Baill.) Harms, *C. microcarpus* Koord. & Valeton, *C. spicatus* Hiern.

Vernacular names Indonesia: kasai (Bengkulu). Malaysia: jerai, sentol kera (Peninsular). Philippines: ibo (Bisaya), bagolayak, kurabdab (Bikolano) widawid (Ilokano).

Distribution Thailand (peninsular), Malesia except New Guinea.

Uses In the Philippines, oil from the kernel of the seed is applied as a hair cosmetic. The tree is planted for landscaping and the wood is locally utilized as timber for light constructions. In traditional medicine in Indonesia, the bark is used to treat jaundice.

Observations A small to medium-sized tree, up to 18(–40) m tall and 40 cm in diameter; bole branchless for up to 10 m, sometimes buttressed in the lowest 60 cm. Leaves alternate, up to 45 cm long, pinnate with up to 9 pairs of leaflets, pseudogemmulate; petiole 2–10 cm, petiolules 5–8 mm long; leaflets elliptical to ovate-oblong, up to 16(–26) cm × 6(–9) cm, veins 8–16 on each side of midrib. Inflorescence spiciform to thyrsoid, axillary or supra-axillary, up to about 60 cm long with fragrant, pedicellate flowers 8–18 mm long; calyx cupular, about 4 mm long; petals usually 5, valvate, 8–16 mm × 2 mm, cream, densely pubescent outside; staminal tube white, bearing 5 anthers; ovary 2 -locular, shortly stipitate. Fruit a 2-seeded capsule, globose or beaked, up to 2 cm in diameter, dull red, minutely tomentose, pericarp containing white latex. Seed flattened globose, up to

15 mm in diameter, covered with a sarcotesta. *C. pentandrus* occurs in wet to drier lowland forest, up to about 500 m altitude. Based on differences in size, number and form of veins, inflorescences, flowers and fruits, 3 subspecies have been distinguished, which are without practical value because numerous intermediates exist. In drier circumstances the number of veins tends to be larger, the inflorescences more branched but the flowers smaller.

Selected sources 18, 42, 59, 101, 127, 135.

Cinnamomum japonicum Sieb. ex Nees

LAURACEAE

Synonyms *Cinnamomum pedunculatum* Nees (excluding *Laurus pedunculata* Thunb.).

Vernacular names Japanese cinnamon, bush cassia-bark (En).

Distribution Japan, Korea, China, Ryukyu Islands.

Uses The fruits yield a solid fat, resembling and used like cocoa butter.

Observations Evergreen tree, sometimes shrubby, with stout, stiff branches. Leaves alternate or subopposite, petiole 1–3 cm long, blade elliptical-ovate, 5–13 cm × 2–5 cm, coriaceous, 3-veined from the base, glossy-green above. Inflorescence an axillary corymb or umbel, peduncle up to 4 cm long or simply or twice umbellate with up to 12 umbels, pedicel 5–12 mm long; flowers bisexual, tepals 6, all broadly ovate and about 3 mm long. Infructescence about 7 cm long, fruit ellipsoid, about 12 mm long, black, seated on a shallow cupule. *C. japonicum* occurs in scrub formations, secondary woods and in forest understorey. The fruits contain about 70% fat (seed kernel about 40%). The fat has a melting range of 32–33°C; the saponification value is about 274, the iodine value about 6. The fatty acids have a high proportion of lauric acid. Its possibilities for South-East Asia deserve investigation.

Selected sources 9, 19, 34, 134.

Diploknema butyracea (Roxb.) H.J. Lam

SAPOTACEAE

Synonyms *Aisandra butyracea* (Roxb.) Baehni, *Bassia butyracea* Roxb., *Madhuca butyracea* (Roxb.) J.F. Macbride.

Vernacular names Indian butter tree, phulwara, buttery bassia (En).

Distribution *D. butyracea* is distributed from northern India (including Assam), Tibet, Nepal and Bhutan to the Andaman Islands. It is occasionally cultivated, also elsewhere.

Uses The seed yields a white fat resembling lard, used in cooking as a substitute for or adulterant of ghee, for burning and to make soap and candles. The fat remains solid and does not deteriorate during hot weather. Medicinally it is used to make an ointment, often perfumed with cloves or rose oil, to relieve rheumatic pains. The fruit pulp and the oil-cake are edible but saponins sometimes make the cake poisonous. It is used as vermifuge and it kills earthworms when applied as manure on golf courses. *D. butyracea* is used in soil conservation, for fodder and bee forage, and as mulch, fish poison, an insecticide and detergent. The flowers are rich in sugar and are processed into coarse sugar and alcoholic liquor. The wood is utilized as timber, traded with wood of other *Diploknema* species under the name 'nyatoh'.

Observations Tree up to 25 m tall. Leaves alternate, usually clustered at apex of branchlets, sometimes scattered, simple; stipules lanceolate, about 5 mm long, caducous; petiole 2–4 cm long; blade elliptical-obovate-oblong, (6–)17–35 cm × (3–)8–17 cm, base cuneate, margin crenulate, apex with acumen 2–9 mm long; secondary veins 14–21, ascending, straight or curved, tertiary veins transverse, distinct below. Flowers solitary or in up to 6-flowered axillary clusters; pedicel 2–4.5 cm, in fruit up to 5 cm long; sepals (4–)5(–6), ovate, 9–15 mm × 6–10 mm, yellowish woolly outside, glabrous inside, but with scattered brownish woolly hairs in the apical part, or entirely ferruginously sericeous; corolla 1.5–2 cm long, lobes 8–10, oblong to spatulate, 7–10 mm × 4–8 mm, often irregularly crenulate; stamens 18–40, inserted at base of lobes, 9–12 mm long; ovary conoidal, about 2 mm × 5 mm, ferruginously sericeous, tapering into the style, 7–12-celled, each cell continuing into the style as a hollow vessel, base surrounded by an adnate, ferruginously tomentose disk; style terete or subangular, 1.5–5 cm long, glabrous, with 7–12 hollow vessels. Fruit an ovoid or cylindrical berry, 2–2.5 cm × 1–1.5 cm, generally pointed by a remaining portion of the style, smooth, pericarp fleshy, 1–3(–5)-seeded. Seed cylindrical to obovoid, differing in shape according to the number in each fruit, up to 1.3 cm × 1 cm × 0.6 cm, glossy, light brown, hilum lanceolate, 2–3 mm wide, pale yellow, testa crustaceous. *D. butyracea* occurs naturally in hill forest of the outer Himalayan ranges, at 500–1000 m altitude, where it flowers from November–January and fruits in August. A form from the Andaman Islands with a brown hairy calyx, ovate corolla lobes and only 18 stamens has been classified as var. *andamanensis* van Royen. *D. butyracea* is propagated by seed, cuttings or air layering. Seeds from fully ripe fruits have a high germination percentage, especially when washed and soaked in water for 24 hours before sowing. The seed is recalcitrant and loses viability when the moisture content drops below 25%. Seed with pulp stored at 3°C also loses viability within 3 weeks. *D. butyracea* seed kernels contain: fat 50–60%, protein 5–8%, carbohydrates 4%, butyraceol and a triterpenoidal sapogenin. The fat is rich in palmitic acid (55%) and oleic acid (35%), poor in stearic acid and linoleic acid (about 3–4% each); its iodine value is 40–50 and its melting range 39–47°C. Of the total protein contained in the seed about 76% is 2S protein. Defatted seed flour of *D. butyracea* is toxic and contains carbohydrates (46%), proteins (27%) and saponins (10%). The saponins are a mixture of saponin A and saponin B, which are responsible for the toxicity for e.g. fungi, insects and fish. The flowers contain the flavonoids quercetin-3-O-rhamnoside and myricetin-3-O-rhamnosides, β-amyrin acetate, friedelin, erythrodiol monopalmitate, β-sitosterol and α-spinasterol. In its area of distribution, many studies have been conducted to gain more knowledge of this potentially important but still under-exploited species. Its possible production in the mountainous regions of South-East Asia needs further study.

Selected sources 19, 31, 34, 59, 63, 64, 69, 70, 79, 86, 108, 109, 123, 124, 130.

Diploknema sebifera Pierre

SAPOTACEAE

Vernacular names Indonesia: merading, nyatoh kalan, putat (Kalimantan). Malaysia: nyatoh kekabu (Peninsula), nyatoh puteh (Sabah).

Distribution Peninsular Malaysia (very rare) and Borneo.

Uses Oil pressed from the seeds is used for making soap and candles. The oil is often referred to as 'tengkawang' oil, although genuine tengkawang oil is obtained from *Dipterocarpaceae* such as *Shorea* species. The wood is utilized and traded as 'nyatoh' timber but is not very important as the species is rare.

Observations A tree up to 45 m tall and 4 m in diameter. Leaves alternate, coriaceous, glabrous, usually crowded at apex of branchlets; stipules 2.5 mm long, caducous, petiole 1–4 cm long; blade obovate or spatulate, 7–24 cm × 3–7 cm, secondary veins 8–14 pairs, ascending, prominent below, tertiary veins few, transverse, prominent below. Inflorescence fasciculate on distinctly prominent warts, 3–7-flowered; bracts lanceolate, up to 2 mm long, ferruginously puberulous outside, glabrous inside; flowers unisexual, male ones not yet known, female ones about 0.5 cm in diameter; pedicel 5–8 mm long, ferruginously tomentose; sepals 5, ovate or elliptical, 2–4 mm × 1–3 mm; corolla 10–12-lobed, 2–4 mm long, tube 1 mm long, lobes spatulate, 2–3 mm long, margin denticulate; sterile stamens (staminodes) 16–20, in 2 rows, petal-like, lanceolate, 2–4 mm long; ovary 6–8-celled, 1 mm long, ferruginously sericeous, ovules apically and centrally attached, campylotropous; style angular, 1–4 mm long; disk cup-shaped, 1.5 mm in diameter, irregularly 16–20-toothed, glabrous. Fruit an obliquely fusiform or subobovoid berry, 3–6 cm × 1–2 cm, apex obtusely acuminate, brownish floccose but glabrescent, pericarp subligneous, 1–3-seeded. Seed obovoid, 2–3 cm × 1 cm × 7 mm, hilum covering almost half of the seed. *D. sebifera* occurs in primary forest up to 300 m altitude, on loamy soils, loamy soils with limestone, coral limestone rocks, sandstone, or sandy soils. In Borneo, it fruits in May–June. Seed germinates for about 75% in 3–5 weeks.

Selected sources 19, 56, 59, 96, 130, 135.

Horsfieldia iryaghedhi (Gaertn.) Warb.

MYRISTICACEAE

Synonyms *Horsfieldia odorata* Willd., *Myristica horsfieldii* Blume, *M. iryaghedhi* Gaertn.

Vernacular names Ceylon champaca (En). Indonesia: campaka selong (Sundanese). Malaysia: chempaca selong, pendarahan, penarah.

Distribution Originating from Sri Lanka, introduced and cultivated elsewhere, including South-East Asia (for example in Malaysia, Singapore and Java).

Uses The seed yields a red-brown fat which is used to make candles. The wood is a source of timber (trade name 'penarahan' for most timbers of *Myristicaceae*) and firewood. The tree is occasionally cultivated as an ornamental for its fragrant flowers which have an odour resembling that of *Michelia champaca* L.

Observations A tree, 5–25 m tall, up to 50 cm in diameter, in humid soils sometimes with stilt roots. Leaves alternate in two vertical rows, chartaceous; petiole 1–3 cm long; blade ovate-elliptical to oblong-lanceolate, 10–28 cm × 4–12 cm, base rounded to attenuate, apex acute-acuminate, veins 9–16 pairs, underside papillose. Inflorescence axillary, paniculate, unisexual; male ones 6–15 cm long, usually twice branched, the branches few, peduncle up to 2 cm long supporting subglobose dense clusters 5–10 mm in diameter spaced along the branches, each cluster with 80–100 subsessile very fragrant flowers; female ones smaller, little branched, up to 4 cm long, the flowers solitary or few together; male flowers with pedicel 0.3 mm long, perianth 3–4-lobed, 3 mm long, androecium elongate, narrowly obconical or ellipsoid-oblong, 1 mm long, thecae 6–10, largely sessile, erect, free apices 0.2 mm long, column narrow, hollow to halfway; female flowers on short pedicel, perianth 2–3-lobed, 3 mm long, ovary broadly ellipsoid, 2 mm long, stigma minutely 2–4-lobed. Infructescence a cluster of 3–8 fruits; fruit a 1-seeded follicle, ellipsoid, 2–4 cm × 2 cm, yellow-brown, with dense, brown-yellow, stellate hairs, pericarp 1.5–3 mm thick, not tuberculate. *H. iryaghedhi* occurs in lowland rain forest, wet evergreen forest and in disturbed forest, from sea-level up to 500 m altitude. It flowers and fruits throughout the year. The fat from the seed has a melting point of 41.5°C.

Selected sources 8, 19, 30, 42, 49, 52, 56, 59.

Horsfieldia macrothyrsa (Miq.) Warb.

MYRISTICACEAE

Synonyms *Myristica macrothyrsa* Miq.

Vernacular names Indonesia: pala rimbo (Malay).

Distribution Indonesia (Sumatra), occasionally also cultivated elsewhere.

Uses The seed has a high fat content but no use is known. The wood is a source of timber (trade name 'penarahan' as for most timbers of *Myristicaceae*) and firewood.

Observations A tree, 4–15 m tall with finely striate, non-flaking bark and wood white-yellow with red veins. Leaves alternate but arranged in two vertical rows, membranous; petiole 1–2 cm long; blade oblong to elliptical, 12–28 cm × 4–12 cm, base attenuate, apex acuminate; veins 9–17 pairs. Inflorescence paniculate, unisexual; male ones about 3 times branched, 7–20 cm long on peduncle up to 5 cm long, flowers in loose clusters of 2–4; female ones about twice branched, 3–6 cm long, flowers 1–3 together; bracts elliptical-oblong, 2–4 mm long, caducous; perianth 3–4-lobed, 3–4 mm long; male flowers on slender pedicel 1–2 mm long, greenish to yellow, aromatic, androecium subglobose or depressed obovoid, 2 mm long, thecae 30–44, completely sessile, free apices up to 0.1 mm long; female flowers never described. Infructescence a cluster of 2–6 fruits; fruit a 1-seeded follicle, ellipsoid, 2–4 cm × 1.5–2 cm, glabrous, greenish-yellow, pericarp 1.5–3 mm thick, light yellow inside. Seed pale yellow with green aril. *H. macrothyrsa* can be found in lower and mid-montane forests, also riverine forest, mixed forest and swamp forest, at 400–1600 m altitude. *H. macrothyrsa* is closely related to *H. glabra* (Blume) Warb. but the former has bigger male flowers and about twice as many anthers. Moreover *H. glabra* does not occur in Sumatra. *H. macrothyrsa* flowers and fruits throughout the year. Seed obtained from a cultivated plant in Bogor contained 45% fat which melted at 49°C.

Selected sources 42, 56, 136.

Hyptis spicigera Lamk

LABIATAE

Synonyms *Mesosphaerum spicigerum* (Lamk) O. Kunth, *Pycnanthemum elongatum* Blanco.

Vernacular names Black sesame, beni (En). Indonesia: babalu bugis (Sulawesi), mossolan (Alor). Philippines: katong matsin (Pilipino, Tagalog), kilongkogong, loko-loko (Bisaya), amotan (Bikolano), bangbangsit (Ilokano), kabling kabayo (Tagalog).

Distribution Native to tropical America but its native range is obscure because it has been introduced and naturalized pantropically, including in South-East Asia. In South-East Asia it has been observed in Indonesia (Kalimantan, Lesser Sunda Islands, the Moluccas, Sulawesi) and in the Philippines (Luzon, Mindanao, Mindoro, Palawan).

Uses The seed contains a fixed oil which is comparable to linseed oil and, in common with all aerial parts, an essential oil. The fixed oil is used in cooking and the essential oil as spice, medicine and insect repellent. In Senegal, the drying fixed oil has been used as a substitute for linseed oil in railway workshops. In large parts of Africa (Guinea, central and eastern Africa) *H. spicigera* is cultivated for the seed which is eaten roasted like sesame. In Sudan and Central Africa it is also an ingredient in stews and sauces. The aerial parts are used in Africa as food flavouring and for medicinal purposes. In northern Nigeria, it is used for making soaps, lotions, perfumes, and is included in medicinal baths to treat skin diseases. In Senegal, the plant is utilized for embalming corpses, added to skin formulations, taken as tea to relieve cough and as an expectorant to treat bronchitis. In Mexico, Burkina Faso and Sierra Leone, plant parts are put in grain containers to control insect infestation, e.g. larvae of *Callosobruchus* sp. As the plant is strongly scented; the whole plant is burned to repel mosquitoes.

Observations An erect, aromatic, annual herb, 1–1.5 m tall with scabrous and subglabrous branches. Leaves opposite, herbaceous; petiole up to 2.5 cm long; blade lanceolate to elliptical-lanceolate, 2.5–6 cm × 1–3 cm, base acuminate, decurrent, margin serrulate, apex acute or acuminate, glabrous or glabrescent on both surfaces. Inflorescence a terminal or axillary, many-flowered verticillaster, looking like a dense spike or head, 1–1.5 cm long, enlarging in fruit up to 4.5 cm; bracts subulate, 3–4 mm long, setaceous; flowers purplish, pale blue or violet; calyx tubular, 4–5 mm long, in fruit 6–7 mm, ribbed, reticulate, teeth subulate, 2 mm long, setaceous. Fruit consisting of 4 ellipsoid, compressed nutlets, about 1 mm long, finely granulate. *H. spicigera* grows in waste places, wet rice fields, on coastal coral limestone and in open dry grasslands, from sea-level up to 900 m altitude. It flowers and fruits year-round and in very dry seasons (e.g. in Sulawesi) the leaves are shed. The seed of *H. spicigera* yields about 20–40% of a yellow, drying, fixed oil which is characterized by a high content of linolenic acid. The oil is of equal or superior drying quality to that of linseed (*Linum usitatissimum* L.). The seed also contains protein but no starch, tannins or alkaloids. The aerial parts contain essential oil mainly composed of sesquiterpene hydrocarbons (75%) with a high percentage of β-caryophyllene (60%), and α-pinene (4%), sabinene (4%), α-humulene (3%). Fatty acid derivatives including fatty acid esters may contribute to the fragrance of the oil. Ethanol extracts of the plant showed positive effects in reducing the oviposition and hatching of bean weevils. Aerial parts of *H. spicigera* from Mexico contained several labdane diterpenes with insecticidal properties, including 15,19-diacetoxy-2α,7α-dihydroxy,λ-8(17),(13)-diene, which significantly inhibits larval growth of the European corn borer *Ostrinia nubilalis*. From inflorescences in Burkina Faso δ-lactone was isolated showing insecticidal properties. Because *H. spicigera* seed yields a fixed oil of equal or superior quality to commercial linseed oil and the aerial parts contain essential oil, the plant deserves further evaluation as a possible commercial source of industrial oil, perfume, herbal medicine and insecticide also in South-East Asia.

Selected sources 7, 42, 44, 66, 93.

Jessenia bataua (Mart.) Burret

PALMAE

Synonyms *Jessenia polycarpa* Karsten, *J. repanda* Engel, *Oenocarpus bataua* Mart.

Vernacular names Pataua palm, seje palm, mille pesos palm (En).

Distribution The northern half of South America. Cultivated on a small scale also elsewhere in the tropics.

Uses The ripe mesocarp of the fruit yields a nutritious, oily beverage, from which an oil similar to olive oil is obtained and which also has medicinal value. The drink is milk-like and an important source of protein and energy. The oil can be used for food, soap and cosmetics. The milky residue from oil extraction (called 'yacuta') is consumed as a beverage. The seed is edible and the 'cabbage' of the palm is an excellent vegetable. The leaves are used for thatching and for weaving e.g. baskets.

Observations Large, usually massive, solitary, pleonanthic, monoecious palm, with columnar trunk 14–30 m tall, 15–30 cm in diameter, clothed with remains of leaf sheaths, sheath fibres and spines, but becoming bare and obscurely ringed with leaf scars. Leaves 8–16 per crown, spirally arranged, suberect when young, horizontally spreading when mature, pinnately compound; sheath up to 1.5 m long, thick, inner surface with stout needle-like fibres up to 1 m long; petiole up to 1 m long, 8–12 cm wide at base; rachis 3–8 m or longer, with 65–108 pairs of pinnae; pinnae rather variable, central ones 1–2 m × 5–10 cm. Inflorescence shaped like a horsetail (hippuriform), solitary but usually 1–3 apparent at any one time, between the leaves in bud but ending below the leaves, branched to 1 order, protandrous; peduncle stout but short, rachis variable in length, bearing 100–300 hanging rachillae 0.5–1.5 m long, bearing triads of flowers (2 male ones situated above 1 female) in basal half; flowers sessile, with 3 sepals and petals, unisexual, creamy-white; male flowers asymmetrical, petals 4–8 mm × 2–4 mm, stamens 9–20, about 5 mm long; female flowers symmetrical, larger than male flowers, style with 3 large, fleshy stigmas. Fruit drupe-like, globose to ellipsoid, 2–4 cm in diameter, dark purple-black, exocarp smooth, thin, mesocarp fleshy, rich in oil, with inner bands of large flat fibres, inner layer adnate to the seed, usually bearing one seed. Seed ellipsoid, with ruminate, horny endosperm and large embryo. *J. bataua* naturally grows in rain forest in large stands in periodically flooded areas, but also as scattered individuals in upland primary forest up to about 1000 m altitude. The pulp constitutes about 40% of the fruit and contains about 50% oil. An adult palm produces on average 2 fruit clusters per year, each with 1000 or more fruits weighing 30 kg. The oil is yellow and its fatty acid composition is like that of olive oil (palmitic acid 11–15%, oleic acid 75–80%), while the linoleic acid is only 2–3%. The biological value of the protein from *J. bataua* is similar to that of casein. *J. bataua* is a very useful multipurpose palm and it would be worthwhile to study possibilities for its cultivation in suitable areas in South-East Asia.

Selected sources 10, 11, 85, 126.

Knema glauca (Blume) Petermann

MYRISTICACEAE

Synonyms *Knema cinerea* (Poir.) Warb. var. *glaucescens* auct., non (Blume) J. Sinclair, *K. palembanica* (Miq.) Warb., *Myristica glauca* Blume.

Vernacular names Indonesia: kayu bedarah (Sumatra), ki mokla (Sundanese), theureu pote (Madurese).

Distribution Thailand, Malaysia, Indonesia (Bali, Java, Kalimantan, Sumatra).

Uses Oil pressed from the seed has been used for illumination. The wood is utilized like that of other members of *Myristicaceae* as 'penarahan' timber, suitable particularly for indoor construction, and for firewood.

Observations A dioecious tree, up to 30 m tall, with coarsely striate bark, not tending to crack or flake, sometimes with 1 m tall stilt roots. Leaves alternate, simple, membranous or chartaceous; petiole 7–20 mm long; blade elliptical to lanceolate, 6–25 cm × 2–11 cm, base rounded to attenuate, apex obtuse to acuminate, veins 12–25 pairs, venation distinct above. Inflorescence looking like a compound umbel, knob-like (brachyblast), sessile or peduncle up to 3 mm long; brachyblast simple or 2–3-fid, up to 15 mm long; male ones 2–20-flowered, female ones 1–8-flowered; flowers with 3–4-lobed perianth, reddish or yellowish inside; male flowers with pedicel 4–10 mm long, buds subglobose, 2.5–3.5 mm in diameter, androphore 0.5–1 mm long, staminal disk flat to faintly convex, circular, 1.5–2.5 mm in diameter, sometimes finely papillate, anthers 8–15, subsessile to stiped, spaced, 0.3–0.5 mm long, more or less horizontal, the connective broad or narrow above, the thecae opening nearly laterally; female flowers with pedicel 1–6 mm long, buds ovoid-ellipsoid or obovoid-cylindrical, 4–6 mm long, cleft to about halfway, ovary ovoid, 1.5–2.5 mm long, stigma subsessile on ovary, flat to erect, 2-lobed and each lobe again 2–4-lobed. Infructescence with 1–4 yellowish fruits; fruit a unicarpellate capsule on stalk 3–12 mm long, subglobose to ovoid or ellipsoid, 2–4 cm × 1.5–2.5 cm, pericarp finely granulate, 1.5–2.5 mm thick when dry. Seed subglobose to ellipsoid, up to 3.5 cm × 2 cm, white, surrounded by a bright red aril. *K. glauca* occurs in primary and secondary evergreen forests, including mixed dipterocarp forest, forest edges, riverine forest, periodically inundated forest and thickets, from sea-level up to 1500 m altitude, on various soils (sandstone, clay, lateritic, granitic, black, limestone, alluvial sand). It flowers and fruits year-round. The seeds contain about 40% fat which has a melting point of 40°C. Trees in Borneo, not growing taller than 12 m, with narrow, membranous leaves and bright brown fruits on a 1 cm long stalk have been classified as var. *riparia* W.J. de Wilde.

Selected sources 8, 42, 56, 59.

Knema mandaharan (Miq.) Warb.

MYRISTICACEAE

Synonyms *Myristica mandaharan* Miq.

Vernacular names Indonesia: mandaharan (Sumatra).

Distribution Peninsular Malaysia and Sumatra.

Uses The seeds have been used as a source of oil. The oil often has a high content of resin, making commercialization difficult. The wood is utilized like that of other members of *Myristicaceae*, as 'penarahan' timber (particularly for indoor construction) and for firewood.

Observations A dioecious tree, 10–25 m tall, bark sometimes striate, occasionally tending to crack or flake, inner bark pinkish-brown, wood white. Leaves alternate, simple, coriaceous; petiole up to 2 cm long; blade oblong to lanceolate, 15–55 cm × 2.5–14 cm, base rounded to cordate, sometimes attenuate, apex acute, glossy or bright brown above, lower surface grey-brown or glaucous, venation fine, faint or distinct. Inflorescence looking like a compound umbel without peduncle, flowers on a knob-like, warted brachyblast 5–15 mm in diameter; male ones 2–10-flowered, female ones 1–8-flowered; flowers with rusty persistent hairs up to 1 mm long and 3–5-lobed perianth; male flowers with pedicel 3–6 mm long, buds obovoid, 3.5–6 mm × 3.5–5.5 mm, cleft 2/3(–3/4), androphore tapering, 1–1.5 mm long, staminal disk circular, flat or slightly convex or concave, 1.5–2.5 mm in diameter, anthers 10–17, subsessile, less than 1 mm long, oblique to nearly horizontal, not or but little touching; female flowers with pedicel 4–7 mm long, buds ellipsoid-obovoid, 8–10 mm × 5–6.5 mm, cleft about fi, ovary ovoid, 4 mm long, style up to 1 mm long; stigma more or less flat, 2-lobed and each lobe again with 8–10 linear lobes. Infructescence with 1–4 fruits; fruit a unicarpellate capsule on stalk 4–8 mm long, ovoid to ellipsoid, 3–6 cm × 2.5–4 cm, dry pericarp 2–8 mm thick with dark brown hairs 1–2 mm long. *K. mandaharan* occurs in primary or swamp forest at 100–1800 m altitude and flowers and fruits year-round. The distinctness of the venation of the upper leaf surface, the fruit size and the thickness of the pericarp are quite variable.

Selected sources 42, 59.

Lecythis Loefl.

LECYTHIDACEAE

Major species and synonyms
- *Lecythis minor* Jacq., synonyms: *Chytroma bipartita* (Pittier) R. Knuth, *Eschweilera valida* (Miers) Nied., *L. elliptica* Kunth.
- *Lecythis ollaria* Loefl., synonyms: *Eschweilera cordata* (O. Berg) Miers, *L. cordata* O. Berg.
- *Lecythis pisonis* Cambess., synonyms: *L. densa* Miers, *L. usitata* Miers, *L. velloziana* Miers.
- *Lecythis zabucajo* Aubl. (sometimes spelled *zabucaja*), synonyms: *L. crassinoda* Miers, *L. davisii* Sandwith, *L. hians* A.C. Smith.

Vernacular names Sabucaia nut, paradise nut, monkey pot (En). Marmite de singe (Fr).

Distribution *Lecythis* encompasses 26 species distributed throughout the moist forests of Latin America from south-eastern Brazil to Costa Rica. Occasionally several of them are cultivated also elsewhere, including in botanical gardens and experimental plantings in South-East Asia.

Uses Many *Lecythis* species are popular for their oil-rich seeds which are consumed raw, boiled or roasted and sometimes in cakes and candies. The oil extracted from the seeds is used locally in making soap and for lighting purposes. *Lecythis* trees are also sources of timber for heavy constructions requiring durability and high impact resistance. The woody fruits, once empty, are made into plates, pots and other small utensils. Medicinally, *Lecythis* oil is thought to be cardiotonic and haemostatic. Several *Lecythis* species are grown as ornamentals.

Observations Trees with simple, alternate, often deciduous leaves, racemose or spicate inflorescences, bisexual, zygomorphic, 6-merous flowers with peculiar androecium forming a basal ring of 70–1000 stamens inserted on the summit of the ovary, expanded on one side to form a strap-like structure arching over the summit of the ovary, the strap without appendages proximally (ligule) and with echinate appendages distally (hood), pistil with usually 4-locular ovary and well-differentiated style; fruit a woody, circumscissile capsule (pyxis or 'monkey pot'), base remaining on the tree on dehiscence, calyx lobes persisting as a woody rim; seed often with basal, fleshy aril.
- *L. minor*. Tree up to 25 m tall; leaves ovate-elliptical to oblong, 8–25 cm × 4–10 cm; inflorescence racemose, terminal or in axils of uppermost leaves, up to 35 cm long, 10–75-flowered, flowers white; fruit cup-like, globose or conical, diameter up to 9 cm; seeds fusiform, 2–3 cm × 1–2 cm, reddish-brown, aril white.
- *L. ollaria*. Tree up to 20 m tall; leaves ovate, 6–15 cm × 4–8 cm; inflorescence terminal or in axils of uppermost leaves, racemose, up to 20 cm long, 15–25-flowered, flowers yellow-white; fruit cup-shaped, up to 8 cm in diameter; seed brown, with about 4 longitudinal, lighter coloured, impressed veins, and an aril.
- *L. pisonis*. Tree up to 50 m tall; leaves elliptical, 6–18 cm × 3–8 cm; inflorescence ramiflorous, racemose, up to 15 cm long, 16–20-flowered, flowers purple or white; fruit globose or conical, up to 30 cm long; seeds 10–30 per fruit, fusiform, 4–6 cm × 2–3 cm, aril large, white.
- *L. zabucajo*. Tree up to 55 m tall; leaves elliptical, 6–12 cm × 2–6 cm; inflorescence ramiflorous, racemose, up to 10 cm long, 5–30-flowered, flowers yellow or white, tinged with purple at margins; fruit globose to conical, diameter up to 18 cm; seed fusiform, 2–4 cm × 1–1.5 cm, with aril.

Lecythis grows in lowland moist forest at elevations below 800 m, with 1000–2000 mm rainfall per year, average annual temperatures of 23–27°C and soil pH 4–8. Some species tolerate a moderate dry season of up to 6 months. *Lecythis* and related *Lecythidaceae* with zygomorphic flowers have a highly intricate method of pollination. The hood of the androecium, which is covered with appendages bearing sterile 'fodder' pollen, acts as a landing platform for pollinators. The hood is appressed against the ring of fertile stamens forcing the back of visiting insects against the pollen. When the seeds are ripe bats play an important role in their distribution while eating the aril.

Lecythis is normally propagated from seed which should be sown immediately after dehiscence because it loses its viability completely when dried to 15% moisture content. The seed of *L. pisonis* contains 43–63% oil and is comparable in composition to maize oil. The major fatty acids are palmitic acid 9–12%, stearic acid 4–8%, oleic acid 27–43% and linoleic acid 38–56%. The seed also contains protein 20%, vitamin C 17 mg/100 g, P 5–6 mg/g, Na 50 mg/g and K 46 mg/g. The seeds of *L. minor* and *L. ollaria* can cause nausea, anxiety and giddiness and when eaten in larger quantities may cause temporary loss of hair and nails. This toxicity is reported especially from areas with seleniferous soils and has been traced to be due to a selenium-containing analogue of cystathionine. The heartwood of *Lecythis* is light to dark salmon, strong, resistant to white rot and brown rot and to insects, including termites, and moderately resistant to barnacles. Its technical characteristics include: air dry density 750–1150 kg/m^3, bending strength 100–200 N/mm^2, modulus of elasticity 13–25 kN/mm^2, compression parallel to grain 95 N/mm^2 and Janka side harness 14 000 N. The wood is easy to split and the bark has been recommended for tanning.

The Biological Dynamics of Forest Fragments Project (BDFFP) near Manãus, Brazil, Centro Agronómico Tropical de Investigación y Enzeñanza (CATIE) in Costa Rica and several botanical gardens in Latin America have germplasm collections of *Lecythis*. *Lecythis* seed is currently commercially collected mainly from wild stands (cultivation is practised on a small scale only). Strong demand for exotic oil products and for edible nuts justifies research into possibilities of its domestication, not only in Latin America, but also in other parts of the humid tropics including South-East Asia.

Selected sources 19, 26, 33, 37, 77, 80, 81, 82, 83, 99, 128, 129.

Pachira aquatica Aubl.

BOMBACACEAE

Synonyms *Bombax aquaticum* (Aubl.) K. Schumann, *Carolinea princeps* L.f., *Pachira macrocarpa* (Schltdl. & Cham.) Walp.

Vernacular names Guiana chestnut, saba nut, Malabar chestnut (En). Châtaigner de la Guyane, noisetier de Cayenne (Fr). Castanheiro da Guyana, zapote bobo (Port). Castaño de agua, castaño de la Guayana (Sp).

Distribution Native to tropical America, from southern Mexico through Central America to Ecuador, northern Peru and northern Brazil. It is also cultivated pantropically.

Uses The oil obtained from the seed is used to make margarine and is suitable for industrial purposes. It smells like liquorice and fenugreek. Seeds are eaten raw, roasted or cooked and taste like chestnut or groundnut. Only fresh seed should be eaten raw otherwise they have a bitter flavour. In Panama and Colombia a kind of bread is made from ground seeds. Seeds of large fruit types are a substitute for cocoa. The young leaves and flowers are eaten cooked as a vegetable. A yellow dye from the bark colours sails, fishing nets and ropes. In its native area the wood of the tree is utilized as timber. In traditional medicine the seed is used as a cure for eye diseases; the bark and immature fruits to treat liver afflictions in Guatemala; the bark against diabetes in Panama. *P. aquatica* is a popular ornamental for its showy flowers, planted in gardens, as a wayside tree and even as an indoor plant wherever it will grow.

Observations Evergreen, unarmed tree, in cultivation often a large shrub, up to 25 m tall, trunk up to 90 cm in diameter, often with narrow buttresses reaching 2 m, bark smooth, grey-brown, inner bark reddish with white spots; in swamps it may develop stilt roots. Leaves arranged spirally, palmately compound, glabrous, 5–9-foliolate; stipules ovate, about 1 cm long; petiole up to 24 cm long, often ribbed, swollen at both ends; petiolule up to 2.5 cm long, leaflet blade elliptical to oblong, 5–30 cm × 3–15 cm, base acute and decurrent to petiolule, apex caudate-acuminate to apiculate, veins prominent especially at lower surface. Flowers usually solitary, 17–35 cm long, appearing before the upper leaves, bisexual, sweetly aromatic; pedicel stout, up to 6 cm long; calyx campanulate, 1–2 cm long, truncate or with 5 obscure lobes; petals 5, valvate, linear, 17–34 cm × 1–2 cm, greenish outside, cream inside, puberulous; stamens 200–260, erect to spreading, 16–31 cm long, variously united in small clusters basally to middle, the clusters finally uniting with staminal column, white basally, reddish in apical third, anthers horse-shoe shaped, 1-celled, 3–5 mm long, reddish, dehiscing by straightening; ovary broadly ovoid, about 1 cm long, 5-celled, style club-shaped, coloured like stamens but longer, stigma with 5 small lobes. Fruit a reddish-brown, woody capsule, ellipsoid to subglobose, up to 30 cm × 12 cm, shallowly 5-sulcate, valves 5, densely red-brown hairy outside, appressed-silky pubescent inside, usually with 2–3 seeds per carpel, in total weighing up to 3 kg. Seed irregularly angulate, 3–6 cm long at maturity, brown, buoyant, embedded in solid, white, fleshy mesocarp. *P. aquatica* occurs in tropical, usually rather open freshwater swamps, sometimes in or at the edge of brackish water at sea-level, along stream banks up to 300 m altitude. It is a non-halophytic species of coastal mangrove vegetation, preferring an average annual rainfall of 2000–5000 mm, an average annual temperature of 22–28°C and a pH of 6–8.5. *P. aquatica* can start flowering and fruiting when it reaches 2 m in height. In Central America it flowers throughout the year but most abundantly in February–April, most of the fruits mature in March–August, and new leaves appear around May. *P. aquatica* can be propagated by seed and by cuttings. Seed may germinate while floating in water and establish a root system upon reaching soil. *P. aquatica* is sometimes infested by a *Cercospora*-like fungus, causing necrotic leaf spots. The seed yields about 40% oil which is semi-solid at room temperature. Palmitic acid (55–75%) is the main fatty acid of the oil which also contains α-hydroxysterculic acid (13%). The bark of *P. aquatica* contains the fungitoxin isohemigossypolone which in pure form showed a clear antifungal activity against *Pythium ultimum* at a minimum concentration of 10g per Petri dish. Because of the high oil content of the edible seed and its ornamental value, *P. aquatica* is worth considering for introduction into South-East Asia, especially for slightly brackish or freshwater swamp locations.

Selected sources 16, 17, 19, 32, 33, 39, 68, 84, 102, 103, 110, 111, 117, 118, 119, 135.

Pachira insignis (Swartz) Savigny

BOMBACACEAE

Synonyms *Bombax insigne* (Swartz) K. Schumann, *B. spectabile* Ulbr., *Carolinea insignis* Swartz.

Vernacular names Wild chestnut, wild cocoa (En). Maronnier (Fr).

Distribution Originating from the basin of the river Amazon in South America, but also cultivated pantropically and sometimes naturalized elsewhere in South America.

Uses The oil-rich seeds are eaten or roasted and used like cocoa. Most uses are similar to those of *P. aquatica* Aubl.

Observations Evergreen tree, up to 30 m tall with trunk up to 60 cm in diameter and greenish bark. Leaves arranged spirally, digitately compound with 5–9 leaflets, often clustered towards the ends of twigs; petiole 9–31 cm long, thickened at both ends; petiolule 0–1 cm long; leaflet blade obovate to elliptical-oblong, 6–34 cm × 3–14 cm, base decurrent, apex rounded to acuminate, with 10–20 prominent lateral veins at underside. Flowers solitary or 2 together, 18–35 cm long; pedicel 1–7 cm long; calyx cupuliform, 1.5–2.5 cm long, truncate or with 5 obscure lobes; petals oblong, 17–34 cm × 1–3 cm, reddish, pubescent; stamens 450–700, up to 30 cm long, variously united in clusters and those at base united in a staminal tube up to 15 cm long, purplish in basal part, white in upper part, anthers 0.5 cm long; pistil with subglobose, 5-angled ovary 1 cm in diameter, style 16–33 cm long, stigma with 5 short lobes. Fruit a subglobose to ellipsoidal capsule, 14–36 cm long, 8–13 cm in diameter, brown pubescent, opening with 5 valves. Seeds usually with 4 flat sides, about 2 cm × 3 cm × 2 cm, brownish. *P. insignis* generally grows at freshwater sites that often are inundated periodically. The seed is used like those of *P. aquatica*. In certain areas hybrids between the 2 species exist. Flowering and fruiting is year-round. The potential of *P. insignis* in South-East Asia is the same as that of *P. aquatica*.

Selected sources 19, 102.

Paranephelium Miq.

SAPINDACEAE

Major species and synonyms
- *Paranephelium joannis* M. Davids.
- *Paranephelium macrophyllum* King.
- *Paranephelium spirei* Lecomte, synonym: *P. hainanense* Lo.
- *Paranephelium xestophyllum* Miq., synonyms: *P. gibbosum* Teijsm. & Binnend., *P. longifoliolatum* Lecomte, *P. nitidum* King.

Vernacular names
- *P. joannis*. Malaysia: kiah (Iban, Sarawak).

- *P. macrophyllum*. Thailand: ka-haa (Malay-Yala), ku-ping yasi (Malay-Pattani), khan (peninsular).
- *P. spirei*. Laos: dok fan pin.
- *P. xestophyllum*. Malaysia: ambuakat, ampungot (Dusun, Sabah). Philippines: malaalua. Thailand: khoh maai, ma haang kaen (northern), lamyai paa (central).

Distribution *Paranephelium* is a genus with only 4 species, naturally occurring in continental South-East Asia and western Malesia. Some species are also occasionally cultivated in and outside their natural area of distribution.

- *P. joannis*. Borneo.
- *P. macrophyllum*. Thailand (peninsular) and Peninsular Malaysia. Formerly it was often grown in villages of northern Malaysia for the oil of the seeds. Cultivation came to an end with the advent of kerosene.
- *P. spirei*. Thailand, Indo-China, China (Hainan) and Peninsular Malaysia.
- *P. xestophyllum*. China (Yunnan) and continental South-East Asia, Sumatra, Borneo and the Philippines.

Uses The seeds of all species yield an oil which can be used for illumination and heating and sometimes also as a cooking oil. Medicinally the oil is applied to treat skin complaints. The seeds are eaten baked or cooked and taste like the Chinese water chestnut (*Eleocharis dulcis* (Burm.f.) Trin. ex Henschel). Eating too many of them may cause giddiness. The wood is not suitable as timber but it is a good-quality firewood.

Observations Small to medium-sized, monoecious trees, sometimes shrubs. Leaves spirally arranged, impari-pinnately compound with subopposite leaflets. Inflorescences ramiflorous, axillary, panicle-like or thyrsoid, erect, branches with many clusters of several flowered cymules; flowers 5-merous, sweetly fragrant, functionally unisexual, regular; calyx cup-shaped with 5 lobes or with free sepals; petals 5, longer than calyx; disk a flat ring; stamens 5–9, free, exserted in male flowers; pistil sessile, with subglobular, tuberculate ovary, a simple style and a flat or lobed stigma. Infructescences strongly lignified; fruit a subglobose, loculicidal capsule, smooth, ribbed, warty or spiny, dehiscing with 3 or 4 valves, containing 1 seed, resembling a horse-chestnut fruit (*Aesculus* spp., *Hippocastanaceae*). Seed subglobose to slightly 2–3-lobed, without arillode but with a white hilar spot covering up to 75% of the seed. *Paranephelium* species are mainly higher understorey trees of the primary rain forest, mixed deciduous forest or dry evergreen forest, particularly near streams, from sea-level up to 300(–700) m altitude. Some distinguishing characteristics of the species are:

- *P. joannis*. Tree or shrub, 6–24 m tall, sometimes with buttresses up to 1.5 m tall or with stilt roots, trunk diameter 10–60 cm; leaves 2–3-jugate, leaflets subobovate, 10–51 cm × 4–22 cm, margin entire, midrib always visible, veins straight and abruptly curving near the margin; inflorescence stout, 20–40 cm long, flowers sometimes irregular, 1–2 mm long, white; fruit 4 cm in diameter, spiny, yellow-brown, red to black. In Borneo, it flowers in March–April and August–September, fruits in July–November and January–February.
- *P. macrophyllum*. Tree or shrub, 4–12 m tall, trunk diameter 10–60 cm; leaves 3–5-jugate, bright red when young; leaflets elliptical, 6–32 cm × 3–13 cm, margin dentate, midrib invisible, lateral veins straight, abruptly curving near the margin; inflorescence stout, 25–60 cm long, flowers 2–3 mm long, pinkish to white; fruit subglobose, 3–4 cm in diameter, densely, sharply-pointed spiny, grey-brown to red. In Peninsular Malaysia it flowers in March–April and July–September, fruits in July and October–February.
- *P. spirei*. Tree up to 25 m tall, trunk diameter up to 30 cm, often shortly fluted; leaves 2–4- jugate; leaflets elliptical, 5–34 cm × 2–15 cm, margin dentate, midrib visible, veins gradually curving; inflorescence 8–28 cm long; flowers regular, 2 mm long, fragrant, white-yellow; fruit 3–4 cm in diameter, spiny (spines with swollen bases), brown-black. Flowering year-round, in Indo-China particularly in March–May, fruiting May–July.
- *P. xestophyllum*. Tree or shrub, 3–40 m tall, trunk diameter 10–75 cm, often with stilt roots or buttresses up to 70 cm tall; leaves 1–6-jugate; leaflets elliptical, 3–42 cm × 1–14 cm, margin entire, midrib visible, lateral veins curving gradually but stronger near the margin; inflorescence delicate and clustered, up to 30 cm long; flowers regular, 1–3 mm long, white to yellowish; fruit 3–4 cm in diameter, smooth, gibbose or spiny, yellow-brown. Flowering and fruiting year-round, major flowering period in Malesia is February–July, fruiting May–September. In the northern distribution area with seasonal monsoon climate, the number of leaflets, hairiness and inflorescence size tend to increase while the fruits become more spiny.

Selected sources 19, 29, 71, 104, 116, 135.

Parinari anamensis Hance

CHRYSOBALANACEAE

Synonyms *Parinarium albidum* Craib, *P. sumatranum* Kurz.

Vernacular names Cambodia: thlok. Laos: phok. Thailand: ma-khlok (northern), pradong-luat (south-western), kathon lok (south-eastern). Vietnam: c[aa]y c[as]m.

Distribution Thailand, Indo-China. It is particularly common in Cambodia and southern Vietnam, rare in northern Vietnam. In north-east Thailand it is widely cultivated for its fruits.

Uses The seed contains a drying oil which is used to coat silverware and paper umbrellas, to produce soap, as a binding material and to make paint, ink and lacquerware. The seed and the thin, sweet, outer fleshy layer of the fruit are edible and used as food in poor regions. The wood is hard and difficult to work but not resistant to insect attack. Trees with a reasonable bole length are used as timber for light and medium constructions under cover (wood is traded as 'merbatu').

Observations A tree up to 30 m tall; bole up to 10 m long and 30–70 cm in diameter, often with buttresses, bark yellow when young, turning grey-brown; crown dense and roundish, young twigs with limp leaves drooping. Leaves arranged spirally, simple, coriaceous; stipules narrow; petiole about 1 cm long, usually with 2 small glands below the middle; blade broadly elliptical to oblong, 6–15 cm × 4–9 cm, largest near inflorescence, base truncate or rounded, margin entire, apex obtuse, rounded, acute or cuspidate, lateral veins 12–18 pairs, conspicuous in lower surface which is yellow-brown hairy (whitish in flush leaves). Inflorescence a terminal, pyramidal panicle, 8–15 cm long, densely yellow-brown pilose; flowers bisexual, sessile, white, fragrant; receptacle a short tube, 2–2.5 mm long, gibbose; calyx 5-lobed, 1.5 mm long; petals 5, 1.5 mm long, white; stamens 5–12 (fertile ones 8–10), unequal; ovary adnate to one side of the throat of the calyx, 2-locular, ovules 1 per locule, densely pilose, style as long as stamens. Fruit drupe-like with thin fleshy, edible exocarp, bony mesocarp and hard endocarp, subglobose to ellipsoid, 3–4 cm in diameter, covered by grey scabs, containing 1–2 seeds. *P. anamensis* is widespread in evergreen, mixed deciduous, and dry dipterocarp forest, up to 1500 m altitude. Flowering period is March–April, fruiting May–June, fruits remain on the tree until next flowering season. It is propagated by seed. The seed oil contains eleostearic acid which quickly polymerizes when subjected to ultraviolet radiation. *P. anamensis* needs protection in its natural distribution area because it is in danger of extinction danger due to over cutting. It much resembles *P. sumatrana* (Jack) Benth. which occurs in Sumatra and western Java and could be the same species.

Selected sources 23, 42, 43, 67, 59, 74, 114, 115.

Pentadesma butyracea Sabine

GUTTIFERAE

Synonyms *Pentadesma leucantha* A. Chevalier.

Vernacular names African butter tree, tallow tree, kiasoso (trade name) (En). Arbre à beurre, beurre de lami (Fr).

Distribution Native to West Africa, occurring from Guinea to Cameroon. It is cultivated elsewhere in tropical Africa and other tropical regions. In South-East Asia it was successfully grown in Singapore already around 1900.

Uses The seeds contain a brown, edible, tasteless but pleasant-smelling fat ('butter') which is used for cooking and made into an unguent for skin and hair; it is applied to kill skin parasites such as lice and mites. It is suitable for making soap, candles and margarine and has the advantage that it does not turn rancid. The butter is also incorporated into several commercial balms used for massage. In cross-section the seeds are red and have been used to adulterate true kola (*Cola* sp., they can easily be distinguished as the cotyledons do not differentiate as in kola). The fruits are edible when immature, becoming too hard upon ripening. Seeds also are edible when immature, turning bitter when ripe. The wood is fairly hard and heavy with a coarse structure and easy to work. There are almost no commercial applications, but poles are used for example as mine-props, for rough construction work, boat masts, canoes and fuel. The bark is used as fish poison in Ghana, a decoction as a purgative and an infusion in lotions to treat parasitic skin diseases. In Liberia the roots are used as chew-sticks and a decoction as a vermifuge.

Observations Tree, up to 30 m tall and 75 cm in trunk diameter, sometimes with narrow buttresses or stilt roots; bole straight and slender, slash soft and brittle, light to bright red, the wound exuding a pale yellow latex; crown small with spreading branches which are slightly drooping at the end. Leaves opposite, simple, coriaceous; petiole up to 1 cm long; blade elliptical to obovate, 7–22 cm × 3–7 cm, base cuneate, margin entire, apex bluntly acute, shiny dark green, new flushes dark red. Inflorescence a panicle, up to 35 cm long, with few, large and showy, cream flowers; pedicel 2–3 cm long; sepals 5, unequal, 3–6 cm long, persistent; petals 5, ovate, 4–6 cm × 2–4 cm, imbricate; stamens numerous, grouped into 5 bundles; ovary sessile, style elongated, stigma with 5 linear lobes. Fruit a berry, ellipsoid to ovoid, up to 15 cm × 10 cm, pendulous, skin coriaceous, brown, containing 3–15 seeds embedded in yellow, greasy-juicy pulp. Seed angular, often pyramidal, 3–5 cm long, 2–3 cm thick, brown, red in cross-section, cotyledons not differentiated. Seedling with hypogeal germination. *P. butyracea* grows in primary and secondary forests, often in swamps. Flowering season coincides with the rainy season, main fruiting season in West Africa is October-March. *P. butyracea* flowers open and produce nectar at night; one of the pollinators is an African long-tongued bat (*Megaloglossus woermanni*). Although the fruits fall complete, the seeds are eaten by animals and natural regeneration is rather poor. Air-dried seed contains 30–40% fat which can be extracted by pounding and cooking. The major fatty acids are palmitic acid (1%), stearic acid (45%) and oleic acid (54%); the iodine value is 51. The presscake hardly contains carbohydrates and nitrogen; tannin and other substances make it unsuitable for feed or manure. Propagation is by seed and by cuttings and sapling growth is fast. Unless the butter becomes more important, *P. butyracea* will remain a curiosity in South-East Asia grown only in botanical gardens and parks.

Selected sources 2, 19, 20, 21, 132.

Persea thunbergii (Siebold & Zucc.) Kosterm.

LAURACEAE

Synonyms *Machilus arisanensis* (Hayata) Hayata, *M. thunbergii* Sieb. & Zucc., *Persea arisanensis* (Hayata) Kosterm.

Vernacular names Chinese bandoline wood, tabu (En).

Distribution Japan, Korea, Taiwan, China and northern part of Indo-China. It is occasionally cultivated, also elsewhere.

Uses The seed contains 65% oil but details about the use of the oil are not known. The wood is sometimes used as timber (collective trade name of *Lauraceae* timber is 'medang'). Shavings of the wood yield a mucilage when soaked in water, which is used by Chinese women for pomading their hair. The wood also constitutes a mosquito-repellent incense, with also termiticidal activity. The leaves yield an essential oil. In Chinese traditional medicine the bark is applied against eczema, as a remedy for diseases of the spleen and stomach, and to treat asthma. The powdered bark is used to correct bad odour and in Korea to treat headache, apoplexy and dyspepsia.

Observations Evergreen, glabrous tree or shrub, up to 15 m tall or taller; branchlets with large terminal buds. Leaves arranged spirally, simple, coriaceous; petiole 1–3 cm long; blade oblanceolate, obovate, oblong or elliptical, 6–15 cm × 3–7 cm, base cuneate, acute or obtuse, margin entire or slightly revolute, apex obtuse to abruptly cuspidate, upper surface lustrous, lateral veins 7–12 pairs, veinlets distinctly reticulate beneath. Inflorescence a terminal-axillary cymose panicle, up to 10 cm long, peduncle 3–5 cm, pedicel 6–9 mm long; flowers bisexual with 6 elliptical-oblong tepals, about 5–7 mm × 2.5 mm; fertile stamens 9, in 3 whorls, subequal, filaments 2.5 mm long, first and second whorl eglandular, anthers 4-locular, introrse, third whorl with 2 glands, anthers extrorse, fourth whorl consists of 3 staminodes 1.5 mm long; ovary globose, 1.3 mm in diameter, style slender, 2.5 mm long, stigma capitate, 3-lobed. Fruit a compressed-globose, black-purple berry, 1 cm in diameter, with persistent reflexed enlarged tepals at base and containing 1 seed. *P. thunbergii* occurs in primary and secondary forest, from sea-level up to 2100 m altitude. In Korea it is found in areas with average temperatures of about 12°C and an average annual precipitation of 1000 mm. In Japan, seedlings could establish on young lava and scoria. In Taiwan, *P. thunbergii* flowers in February–May and fruits in June–August. The tree produces a large number of seeds in alternate years. It has higher sapling densities and shows a larger height-growth rate in forest gaps than under closed canopy. *P. thunbergii* is propagated by seed, by cuttings or through in vitro bud culture. The seed is dispersed by birds, is recalcitrant and sensitive to desiccation. The composition of the seed oil is not known. The essential oil contains 6 major components that differ greatly in quality and quantity between sources: trans-β-ocimene (7–72%), cis-β-ocimene (6–24%), α-pinene (3–16%), α-zingiberene (7–9%), α-terpineol (15%) and α-phellandrene (6%). The leaves contain licarins A (2.5 ppm) and licarins B (26 ppm). Termiticidal activity occurring in the wood is not affected by tree age and may cause 50% mortality to termites

(*Coptotermes formosanus*). In Taiwan, *P. thunbergii* was severely defoliated by the casuarina moth (*Lymantria xylina*); in Japan, it is the host of the red-spotted longicorn beetle (*Eupromus ruber*) which may cause severe damage to the tree. The potential value for South-East Asia deserves investigation.

Selected sources 12, 24, 35, 54, 60, 61, 62, 65, 71, 73, 75, 90, 92, 94, 95, 97, 106, 121, 134.

Pittosporum resiniferum Hemsl.

PITTOSPORACEAE

Synonyms *Pittosporum acuminatissimum* Merr., *P. epiphyticum* Merr.

Vernacular names Petroleum nut tree (En). Philippines: hanga (Tagalog), abkel (Igorot), bualau (Bikolano).

Distribution Northern Borneo (Malaysia), the Philippines, Solomon Islands. It is occasionally grown elsewhere, e.g. as an ornamental in California (United States).

Uses The fruit contains about 20% of a light oil, smelling like petroleum. Even the unripe fruit burns brightly and readily and has been used for illumination and as fuel source. The fuel properties of steam-distilled oil from fruits after hydrogenation are quite comparable to those of gasoline. In the Philippines, the fruit has been used medicinally as a panacea, particularly to treat abdominal pain, the oleoresin for muscular pain and skin diseases and a decoction for colds. The wood is used for indoor constructions and for fuel. The tree is also planted as an ornamental.

Observations Small tree or shrub, often epiphytic, 2–5(–30) m tall. Leaves spirally arranged, coriaceous, glabrous; petiole 2–4 cm long; blade obovate to oblanceolate, 6–21 cm × 3–6 cm, base cuneate, margin entire, apex acuminate, veins 7–10 pairs, prominent beneath. Inflorescence with flowers in a fascicle or arranged umbel-like, usually on bare branches below the leaves; pedicel 2–10 mm long; flowers 5-merous, white, fragrant; sepals 2–4 mm long, at base connate into a shallow cup; petals narrowly oblong, 9–12 mm × 1–2 mm; filaments 6–7 mm long; ovary sessile, ellipsoid, 4–5 mm × 1–2 mm, densely pubescent, style 2 mm long, stigma thickened. Fruit a subglobose capsule, 2–4 cm in diameter, yellow-black, dehiscing lengthwise into 2 very hard valves 4–5 mm thick, with large resiniferous cavities and numerous seeds. Seed irregular, 4 mm long, shiny black. *P. resiniferum* grows in mountain forest (mossy forest) on exposed ridges, at 1000–3000 m altitude, as small tree or epiphyte, in lower localities (400–600 m altitude) exclusively epiphytic. Propagation is possible by seed, cuttings and air layering. Seed remains viable for about 1 month, germination rate is about 75%, rooting rate in cuttings about 60%, 100% in air layering. In the Philippines flowering is from February–April. As its name 'petroleum nut tree' indicates, the 'oil' from *P. resiniferum* is not a true oil but a petroleum-like mixture of hexane, nonane and monoterpenes (α-pinene, β-pinene, and smaller amounts of limonene and myrcene). The presence of hexane and nonane is remarkable as alkanes are rare in plants. In the Philippines *P. resiniferum* has become very rare, due to overlogging and shifting cultivation, and deserves protection and propagation. Germplasm collections are being made by the Ecosystem Research and Development Bureau (ERDB – formerly Forestry Research Institute) of the Philippines. Experimental plantings for fuel production were promising: 18 kg fruits per tree per year with an average oil yield of 20% would result in an annual yield of oil per ha of about 3000 litres. Usually, oil yield is only 5–7% and breeding for high-yielding cultivars is a first priority. Other *Pittosporum* species in South-East Asia can also have oil-rich seeds, e.g. *P. ferrugineum* Aiton and *P. pentandrum* (Blanco) Merr.

Selected sources 18, 22, 33, 42, 87, 91, 105, 131.

Scolopia chinensis (Lour.) Clos

FLACOURTIACEAE

Synonyms *Phoberos chinensis* Lour., *P. cochinchinensis* Lour., *Scolopia siamensis* Warb.

Vernacular names Vietnam: b[oo]m, ng[aa]m xanh, gai b[oo]m.

Distribution Thailand, southern China, Indo-China. Occasionally also cultivated and sometimes naturalized elsewhere in the tropics, e.g. in India, Sri Lanka and Java.

Uses The seed yields an oil, used e.g. in Indo-China, but no data on composition and characteristics are available. *S. chinensis* is planted to make hedges that are impenetrable because of its spines.

Observations Evergreen shrub or small tree, 1–5 m tall, branches with strong simple spines 1–6 cm long. Leaves alternate, coriaceous; petiole 3–8 mm long; blade oblong-elliptical, 3–10 cm × 2–5 cm, base cuneate to rounded with 2 distinct basal glands, margin entire, apex acuminate to rounded, basal veins 3–5, secondary veins in 5–7 pairs. Inflorescence a few-flowered raceme, 2–6 cm long; pedicel up to 1 cm long; flowers 6-merous, bisexual, white-yellow, sepals and petals ovate, 2–3 mm long, receptacle with 10 disk glands, stamens 40–60, 4–5 mm long, pistil with ovoid ovary having 2 or 3 placentas each with 2 ovules, style 2–3 mm long, stigma obscurely 3–4-lobed. Fruit a berry, ellipsoid to subglobular, about 1 cm in diameter, containing 4–5 seeds. Seed about 4 mm long. *S. chinensis* grows in shrubby vegetation at low altitudes on sand or clay soils, also in swampy conditions, flowering in August, fruiting in October–November.

Selected sources 8, 19, 42, 71, 43, 113.

Tetradium fraxinifolium (Hook.) T.G. Hartley

RUTACEAE

Synonyms *Evodia fraxinifolia* (Hook.) Benth., *Philagonia fraxinifolia* Hook.

Distribution Native and cultivated from Nepal east to northern Vietnam and south-western China, occasionally cultivated also elsewhere.

Uses The seed yields an oil which fuels lamps in Indo-China. The wood can be utilized for indoor construction, but it is weak and not durable. The tree is also planted as a fodder crop and an ornamental.

Observations Dioecious, usually evergreen tree, up to 12 m tall. Leaves opposite, imparipinnately compound with 2–7 pairs of subcoriaceous leaflets; petiolules 0–1 cm long, of terminal leaflet 1–3.5 cm; leaflet blade lanceolate to elliptical, 9–25 cm × 3–9 cm, base rounded to acute, margin crenulate, apex acuminate, conspicuously oil-dotted. Inflorescence subcorymbose, 7–24 cm long, pedicel 1–6 cm long, flowers 4-merous and unisexual; sepals triangular, up to 1.5 mm long, persistent in fruit, petals ovate-elliptical, 3–7 mm long, hooked adaxially at the apex, pale yellow to green; stamens 4, opposite the petals, functional ones about 1.5 times the length of the petals; pistil with 4-carpelled ovary, ovules 2 per carpel, carpels connate toward the base abaxially, free adaxially. Fruit consisting of 1–4, 2-seeded, dehiscing follicles that are compressed subglobose 0.5–1 cm in diameter, not beaked, connate toward the base abaxially. Seed subtrigonous, 4–5 mm long, shiny dark red-brown, firmly attached in the dehisced follicle to a rather thick, fleshy, funicular aril; outer testa spongy, inner testa bony, endosperm fleshy, copious. *T. fraxinifolium* grows in well-drained forests and thickets, at 750–3000 m altitudes. Little is known about the oil, only the presence of 2 triterpenes has been reported. Seed of *T. sambucinum* (Blume) T.G. Hartley, occurring in Peninsular Malaysia and Indonesia (Sumatra, Java, Sumbawa), also yields a lamp oil.

Selected sources 19, 27, 53, 59.

Vernicia cordata (Thunb.) Airy Shaw

EUPHORBIACEAE

Synonyms *Aleurites cordata* (Thunb.) R. Br. ex Steud., *Dryandra cordata* Thunb., *Elaeococca verrucosa* A. Juss.

Vernacular names Japanese wood oil, Japanese tung oil (En). Indo-China: hwa tung.

Distribution Wild and cultivated in Japan, occasionally cultivated outside Japan.

Uses The seed yields a valuable oil that is used as a drying oil but also as fuel and lubricant. Like tung oil (*V. fordii* (Hemsl.) Airy Shaw), the oil is almost destruction proof. After heating to about 300°C it changes into a jelly-like substance and is insoluble in all ordinary solvents and cannot be melted by further heating. The quality is slightly less than that of tung oil.

Observations Monoecious, evergreen tree, 7–10 m tall with white to brownish indumentum. Leaves alternate, petiole up to 28 cm long with slenderly stalked, slightly divergent glands at apex that are often inrolled, blade not or shallowly 3–5-lobed, 10–26 cm × 8–26 cm, ratio length/width 1:1.3. Inflorescence a corymbiform thyrse, unisexual, flowers white, petals obovate-spatulate, 15–20 mm × 5–10 mm with a 5 mm long claw; male inflorescence up to 23 cm long, flowers 1.5–2 cm in diameter on pedicel 4–7 mm long, stamens 8–10; female inflorescence up to 13 cm long, flowers on shorter pedicel, ovary 3–4-locular, abruptly narrowing into the styles, styles bifid up to half their length. Fruit globose, 3-angled or lobed, about 4 cm in diameter. Seed subglobose, 1–1.5 cm in diameter, smooth. Because of the good quality oil from the seeds, *V. cordata* might be interesting for South-East Asia and deserves more research attention regarding cultivation requirements and commercialization possibilities.

Selected sources 55, 57, 120.

Xanthophyllum lanceatum (Miq.) J.J. Smith

POLYGALACEAE

Synonyms *Skaphium lanceatum* Miq., *Xanthophyllum glaucum* Wallich ex Hassk., *X. microcarpum* Chodat.

Vernacular names Indonesia: siur-siur (Sumatra). Malaysia: sesiyor (Peninsular). Burma (Myanmar): kam-gaw. Laos: seng nam, som seng, soum seng. Thailand: chum saeng (central), khang khao ton kliang (northern), saeng (north-eastern).

Distribution From Bangladesh throughout continental South-East Asia, Sumatra.

Uses The seed yields an oil that has been used for cooking and for the manufacture of candles and soap. In Sabah, the wood is used for indoor construction, cabinet making, flooring, joinery and blockboard; in Sumatra it is made into kris handles. In traditional medicine the seed oil is used against thrush and the bark is administered to treat colic.

Observations A low shrub or small tree, 3–12 m tall and up to 20 cm in diameter. Leaves alternate, simple; petiole 3–5 mm long; blade narrowly elliptical to lanceolate, 4–14 cm × 1–6 cm, base cuneate to rounded, at underside with glands up to 0.3 mm in diameter, margin undulate and often a little incurved, apex acuminate, tertiary veins finely reticulate, protruding. Inflorescence axillary, raceme-like but usually sparsely branched basally, longer than the leaves, in basal part flowers grouped 3–5 together, in upper part flowers solitary; pedicel 2–4 mm long; flowers bisexual, zygomorphic, 5-merous, pinkish or white, largest (inner) sepal 2 mm × 3 mm, longest petal 6–9 mm, carina densely hairy outside; stamens 8; ovary superior with 4 ovules. Fruit a broadly ellipsoid to globular, indehiscent capsule, 1–4 cm in diameter, pericarp rather thick but soft, smooth, glabrous, grey-brown, with 1 or 2 seeds. *X. lanceatum* is restricted to stream banks and swamps. Fruits are collected from small trees or, because the fruits fall into the water often in large amounts, from places where they strand alongside streams. They are piled in heaps for 3–4 days, after which seeds are extracted, washed and dried. From the seeds, a yellowish-green oil can be obtained by pressing. Seed with a moisture content of 9% contains about 40% oil, which is solid at ambient temperatures, liquid at 48°C. The density of the wood is about 580 kg/m^3 at 15% moisture content.

Selected sources 19, 42, 56, 59, 135.

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4 Plants yielding vegetable oils and fats but with other primary use

List of species in other commodity groups (parenthesis) which are used also as sources of vegetable oils and fats. Synonyms in the indented lines.

Acrocomia aculeata (N.J. Jacquin) Loddiges (ornamental plants)
    Acrocomia sclerocarpa Martius
Adenanthera pavonina L. (timber trees)
    Adenanthera bicolor Moon
    Adenanthera intermedia Merrill
    Adenanthera microsperma Teysm. & Binnend.
    Adenanthera tamarindifolia Pierre
Aleurites moluccana (L.) Willd. (spices)
    Jatropha moluccana L.
    Aleurites triloba J.R. & G. Forst.
    Juglans camirium Lour.
Anacardium occidentale L. (edible fruits and nuts)
Aphanamixis polystachya (Wallich) R.N. Parker (timber trees)
    Amoora aphanamixis Schult. & Schult.
    Aphanamixis cumingiana (C. DC.) Harms
    Aphanamixis grandifolia Blume
    Aphanamixis rohituka (Roxb.) Pierre
Arachis hypogaea L. (pulses)
Areca catechu L. (stimulants)
Argemone mexicana L. (medicinal and poisonous plants)
Atuna racemosa Raf. ssp. *racemosa* (timber trees)
    Atuna elata (King) Kosterm.
    Atuna excelsa (Jack) Kosterm.
    Cyclandrophera excelsa (Jack) Kosterm.
    Parinari glaberrimum (Hassk.) Hassk.
Azadirachta indica A.H.L. Juss. (medicinal and poisonous plants)
    Antelaea azadirachta (L.) Adelb.
    Melia azadirachta L.
    Melia indica (A.H.L. Juss.) Brandis
Bactris gasipaes Kunth (edible fruits and nuts)
    Bactris utilis Benth. & Hook.f. ex Hemsley
    Guilielma gasipaes (Kunth) L.H. Bailey
    Guilielma speciosa Mart.
Bertholletia excelsa Humb. & Bonpl. (edible fruits and nuts)
    Bertholletia nobilis Miers
Bombax ceiba L. (timber trees)
    Bombax malabaricum DC.
    Gossampinus malabarica (DC.) Merr.
    Salmalia malabarica (DC.) Schott & Endl.
Bombax valetonii Hochr. (timber trees)

Bombax larutensis Ridley
Gossampinus valetonii (Hochr.) Bakh.
Salmalia valetonii (Hochr.) Corner
Buchanania latifolia Roxb. (edible fruits and nuts)
Buchanania lanzan Sprengel
Caesalpinia coriaria (Jacq.) Willd. (dye and tannin-producing plants)
Caesalpinia digyna Rottler (dye and tannin-producing plants)
Caesalpinia oleosperma Roxb.
Calophyllum blancoi Planchon & Triana (timber trees)
Calophyllum glabrum Merr.
Calophyllum mindanaense Elmer
Calophyllum racemosum Merr.
Calophyllum inophyllum L. (timber trees)
Camellia japonica L. (ornamental plants)
Camellia sinensis (L.) Kuntze (stimulants)
Camellia thea Link
Camellia theifera Griff.
Thea sinensis L.
Campnosperma auriculatum (Blume) Hook.f. (timber trees)
Campnosperma oxyrhachis Engl.
Canarium balsamiferum Willd. (timber trees)
Canarium englerianum Hochr.
Canarium longissimum Hochr.
Canarium rooseboomii Hochr.
Canarium hirsutum Willd. (timber trees)
Canarium hispidum Blume
Canarium multipinnatum Llanos
Canarium subcordatum Ridley
Canarium indicum L. (edible fruits and nuts, timber trees)
Canarium amboinense Hochr.
Canarium commune L.
Canarium mehenbenthene Gaertner
Canarium moluccanum Blume
Canarium zephyrinum Duchesne
Canarium zephyrinum Rumphius
Canarium littorale Blume (timber trees)
Canarium purpurascens Benn.
Canarium rufum Benn.
Canarium tomentosum Blume
Canarium luzonicum (Blume) A. Gray (plants producing exudates, timber trees)
Canarium carapifolium Perkins
Canarium oliganthum Merr.
Canarium polyanthum Perkins
Canarium oleosum (Lamk) Engl. (timber trees)
Canarium laxiflorum Decne
Canarium microcarpum Willd.
Canarium ovatum Engl. (edible fruits and nuts, plants producing exudates, timber trees)
Canarium melioides Elmer

Canarium pachyphyllum Perkins
Canarium pseudodecumanum Hochr. (timber trees)
Cannabis sativa L. (medicinal and poisonous plants)
Carapa guianensis Aubl. (timber trees)
Carapa nicaraguensis C. DC.
Carapa slateri Standley
Granatum guianense (Aubl.) O. Kuntze
Caryocar nuciferum L. (edible fruits and nuts)
Caryocar villosum (Aublet) Pers. (edible fruits and nuts)
Ceiba pentandra (L.) Gaertner (fibre crops)
Bombax pentandrum L.
Eriodendron anfractuosum DC.
Celastrus paniculatus Willd. (medicinal and poisonous plants)
Cerbera manghas L. (medicinal and poisonous plants)
Cinnamomum verum J.S. Presl (spices)
Laurus cinnamomum L.
Cinnamomum zeylanicum Blume
Citrullus lanatus (Thunberg) Matsum. & Nakai (vegetables)
Citrullus vulgaris Schrader ex Ecklon & Zeyher
Colocynthis citrullus (L.) O. Kuntze
Momordica lanata Thunberg
Cleome gynandra L. (vegetables)
Cleome pentaphylla L.
Gynandropsis gynandra (L.) Briq.
Gynandropsis pentaphylla (L.) DC.
Croton argyratus Blume (timber trees)
Croton budopensis Gagnep.
Croton maieuticus Gagnep.
Croton tawaoensis Croizat
Cucumis melo L. (vegetables)
Cucumis sativus L. (vegetables)
Cucurbita maxima Duchesne ex Lamk (vegetables)
Cucurbita moschata (Duchesne ex Lamk) Duchesne ex Poiret (vegetables)
Cucurbita pepo L. (vegetables)
Cucurbita esculenta S.F. Gray
Cucurbita fastuosa Salisb.
Cucurbita subverrucosa Willd.
Dipteryx odorata (Aublet) Willd. (spices)
Baryosma tonga Gaertner
Coumarouna odorata Aublet
Dipteryx tetraphylla Spruce ex Benth.
Entada phaseoloides (L.) Merrill (medicinal and poisonous plants)
Entada spiralis Ridley (medicinal and poisonous plants)
Glycine max (L.) Merrill (pulses)
Glycine hispida (Moench) Maxim.
Phaseolus max L.
Soja max (L.) Piper
Gossypium arboreum L. var. *obtusifolium* (Roxburgh) Roberty (fibre plants)
Gossypium nanking Meyen

Gossypium obtusifolium Roxb.
Gossypium hirsutum L. (fibre plants)
Guioa koelreuteria (Blanco) Merr. (timber trees)
Guioa mindorensis Merr.
Guioa perrottetii (Blume) Radlk.
Guioa salicifolia Radlk.
Hernandia nymphaeifolia (Presl) Kubitzki (timber trees)
Hernandia peltata Meissn.
Hernandia ovigera L. (timber trees)
Hernandia javanica Tuyama
Hernandia labyrinthica Tuyama
Hernandia papuana C.T. White
Hevea brasiliensis (Willd. ex A. Jussieu) Muell. Arg. (timber trees, plants producing exudates)
Hibiscus cannabinus L. (fibre plants)
Hibiscus sabdariffa L. (vegetables)
Hodgsonia macrocarpa (Blume) Cogn. (edible fruits and nuts)
Hodgsonia capniocarpa Ridley
Horsfieldia irya (Gaertner) Warb. (timber trees)
Horsfieldia acuminata Merrill
Horsfieldia congestiflora A.C. Smith
Horsfieldia subglobosa (Miq.) Warb.
Horsfieldia sylvestris (Houtt.) Warb. (timber trees)
Myristica pendulina Hook.f.
Myristica pinnaeformis Zipp. ex Miq.
Myristica salicifolius Willd.
Hura crepitans L. (ornamental plants)
Illicium anisatum L. (medicinal and poisonous plants)
Illicium religiosum Siebold & Zuccarini
Irvingia malayana Oliv. ex A.W. Bennett (timber trees)
I. harmandiana Pierre
I. longipedicellata Gagnep.
I.oliveri Pierre
Jatropha curcas L. (medicinal and poisonous plants)
Curcas purgens Medik.
Curcas indica A. Rich.
Jatropha afrocurcas Pax
Jatropha gossypiifolia L. (medicinal and poisonous plants)
Jatropha elegans (Pohl) Klotzsch
Jatropha multifida L. (medicinal and poisonous plants)
Adenoropium multifidum (L.) Pohl
Jatropha janipha Blanco
Lactuca sativa L. (vegetables)
Lepidium sativum L. (medicinal and poisonous plants)
Linum usitatissimum L. (fibre plants)
Litsea garciae Vidal (edible fruits and nuts)
Litsea sebifera (Blume) Blume
Litsea glutinosa (Loureiro) C.B. Robinson (timber trees)
Litsea chinensis Lamk

Litsea geminata Blume
Litsea glabraria A.L. Juss.
Litsea tetranthera (Willd.) Pers.
Litsea monopetala (Roxburgh) Pers. (timber trees)
Litsea polyantha A.L. Juss.
Tetranthera alnoides Miq.
Tetranthera monopetala Roxb.
Luffa acutangula (L.) Roxburgh (vegetables)
Cucumis acutangulus L.
Luffa aegyptiaca P. Miller (vegetables)
Momordica cylindrica L.
Momordica luffa L.
Luffa cylindrica (L.) M.J. Roemer sensu auct.
Lycopersicon esculentum Miller (vegetables)
Solanum lycopersicum L.
Lycopersicon lycopersicum (L.) Karsten
Macadamia integrifolia Maiden & Betche (edible fruits and nuts)
Macadamia ternifolia F. v. Muell. var. *integrifolia* (Maiden & Betche) Maiden & Betche
Madhuca betis (Blanco) McBride (timber trees)
Madhuca philippinensis Merr.
Madhuca cuneata (Blume) J.F. McBr. (timber trees)
Bassia cuneata Blume
Isonandra cuneata (Blume) Baehni
Madhuca longifolia (Koenig) McBride (timber trees)
Madhuca latifolia McBride
Madhuca motleyana (de Vriese) J.F. Macbr. (timber trees, plants producing exudates)
Ganua motleyana (de Vriese) Pierre ex Dubard
Ganua scortechinii (King & Gamble) H.J. Lam
Madhuca utilis (Ridley) H.J. Lam ex K. Heyne (timber trees)
Isonandra utilis (Ridley) Baehni
Madhuca stenophylla H.J. Lam
Payena utilis Ridley
Mallotus barbatus Muell. Arg. (medicinal and poisonous plants)
Mallotus philippensis (Lamk) Muell. Arg. (dye and tannin-producing plants)
Melia azedarach L. (auxiliary plants)
Melia composita Willd.
Melia dubia Cavanilles
Melia sempervirens (L.) Sw.
Mesua ferrea L. (timber trees)
Momordica charantia L. (medicinal and poisonous plants, vegetables)
Momordica chinensis Sprengel
Momordica elegans Salisb.
Momordica indica L.
Momordica cochinchinensis (Loureiro) Sprengel (medicinal and poisonous plants, vegetables)
Momordica mixta Roxburgh
Muricia cochinchinensis Loureiro

Moringa oleifera Lamk (vegetables)
    Guilandina moringa L.
    Moringa polygona DC.
    Moringa pterygosperma Gaertner
Myristica argentea Warb. (spices)
    Myristica finschii Warb.
Myristica fragrans Houtt. (spices)
    Myristica aromatica Lamk
    Myristica moschata Thunb.
    Myristica officinalis L.f.
Myristica iners Blume (timber trees)
    Myristica heritieriifolia Pierre ex Lecomte
    Myristica vordermanii Warb.
Nephelium lappaceum L. (edible fruits and nuts)
    Nephelium chryseum Blume
    Nephelium glabrum Cambess.
    Nephelium sufferrugineum Radlk.
Nephelium ramboutan-ake (Labill.) Leenh. (edible fruits and nuts)
    Nephelium mutabile Blume
    Nephelium intermedium Radlk.
    Nephelium philippense Monsalud
Nerium oleander L. (ornamental plants)
    Nerium indicum Miller
    Nerium odorum Sol.
Oryza sativa L. (cereals)
    Oryza aristata Blanco
    Oryza glutinosa Lour.
    Oryza montana Lour.
    Oryza praecox Lour.
Pachyrhizus erosus (L.) Urban (plants yielding non-seed carbohydrates)
    Dolichos erosus L.
    Pachyrhizus angulatus Rich. ex DC.
    Pachyrhizus bulbosus (L.) Kurz
Palaquium amboinense Burck (timber trees)
    Isonandra amboinensis (Burck) Baehni
    Palaquium javense Burck
Palaquium burckii H.J. Lam (timber trees)
    Croixia burckii (H.J. Lam) Baehni
Palaquium gutta (Hook.f.) Baillon (timber trees, plants producing exudates)
    Croixia gutta (Hook.f.) Baehni
    Palaquium acuminatum Burck
    Palaquium oblongifolium (Burck) Burck
    Palaquium optimum Becc.
Palaquium hexandrum (Griffith) Baillon (timber trees)
    Croixia hexandra Griffith)
Palaquium philippense (Perrottet) C. Robinson (timber trees)
    Madhuca philippensis (Perrottet) Baehni
Palaquium rostratum (Miq.) Burck (timber trees)
    Croixia rostrata Miq. Baehni

Palaquium bancanum Burck
Palaquium semaram H.J. Lam
Croixia semaram (H.J. Lam) Baehni
Palaquium stellatum King & Gamble (timber trees)
Bassia watsoni Ridley
Madhuca watsoni (Ridley) H.J. Lam
Palaquium xanthochymum (de Vriese) Pierre ex Burck (timber trees)
Croixia xanthochyma (de Vriese) Baehni
Pandanus conoideus Lamk (edible fruits and nuts)
Pandanus butyrophorus Kurz
Pangium edule Reinw. (medicinal and poisonous plants)
Papaver somniferum L. (medicinal and poisonous plants)
Payena leerii (Teysm. & Binnend.) Kurz (plants producing exudates)
Madhuca leerii (Teysm. & Binnend.) Merrill
Payena croixiana Pierre
Pentaspadon motleyi Hook.f. ex King (timber trees)
Pentaspadon minutiflora B.L. Burtt
Pentaspadon moszkowskii Kaut.
Pentaspadon officinalis Holmes ex King
Perilla frutescens (L.) Britton var. *crispa* (Thunberg) Hand.-Mazz. (spices)
Ocimum frutescens L.
Perilla ocymoides L.
Perilla nankinensis (Lour.) J. Decaisne
Persea americana Miller (edible fruits and nuts)
Persea drymifolia Schlecht. & Cham.
Persea gratissima Gaertn.f.
Persea nubigena L.O. Williams
Phoenix dactylifera L. (edible fruits and nuts)
Pongamia pinnata (L.) Pierre (auxiliary plants)
Derris indica (Lamk) J.J. Bennett
Pongamia glabra Ventenat
Millettia novo-guineensis Kanehira & Hatusima
Psophocarpus tetragonolobus (L.) DC. (vegetables)
Botor tetragonolobus (L.) O. Kuntze
Dolichos tetragonolobus L.
Raphanus sativus L. (vegetables)
Raphanus caudatus L.)
Raphia vinifera Palisot de Beauvois (fibre plants)
Ravenala madagascariensis J.F. Gmelin (ornamental plants)
Santalum album L. (essential-oil plants)
Santalum myrtifolium (L.) Roxb.
Santalum ovatum R. Br.
Sirium myrtifolium L.
Santiria tomentosa Blume (timber trees)
Canarium micrantherum Stapf ex Ridley
Santiria mollissima Ridley
Santiria multiflora Bennett
Shorea falciferoides Foxw. (timber trees)
Shorea balangeran S. Vidal, non (Korth.) Burck

Shorea gisok Foxw.
Shorea glaucescens Meijer
Shorea seminis (de Vriese) Slooten (timber trees)
Isoptera borneensis Scheffer ex Burck
Isoptera seminis (de Vriese) Burkill
Shorea schefferiana Hance
Shorea siamensis Miq. (timber trees)
Pentacme malayana King
Pentacme siamensis (Miq.) Kurz
Pentacme suavis A. DC.
Sinapis alba L. (spices)
Brassica alba (L.) Rabenhorst
Brassica hirta Moench
Sindora supa Merr. (timber trees)
Sterculia foetida L. (timber trees)
Sterculia polyphylla R. Br.
Sterculia oblongata R. Br. (edible fruits and nuts, timber trees)
Sterculia forbesii Warb.
Sterculia kunstleri King
Sterculia spectabilis Miq.
Sterculia urceolata auct. non J.E. Smith
Sterculia insularis R. Br. (timber trees)
Sterculia longituba Adelb.
Sterculia treubii Hochr.
Terminalia bellirica (Gaertner) Roxburgh (dye and tannin-producing plants)
Terminalia catappa L. (dye and tannin-producing plants)
Terminalia latifolia Blanco non Swarz
Terminalia moluccana Lamk
Terminalia procera Roxburgh
Terminalia chebula Retzius (dye and tannin-producing plants)
Tetradium sambucinum (Blume) Hartley (timber trees)
Euodia sambucina (Blume) Hook.f. ex Koord. & Valeton
Thespesia populneoides (Roxb.) Kostel. (auxiliary plants, timber trees)
Hibiscus populneus L.
Hibiscus populnoides Roxb.
Thespesia populnea (L.) Soland. ex Correa
Thespesia macrophylla Blume
Vitis vinifera L. (edible fruits and nuts)
Xanthium strumarium L. (medicinal and poisonous plants)
Xylocarpus granatum J. Koenig (timber trees)
Carapa granatum (J. Koenig) Alston
Carapa obovata Blume
Xylocarpus obovata (Blume) A. Juss.
Xylocarpus moluccensis (Lamk) M. Roem. (timber trees)
Carapa moluccensis Lamk
Xylocarpus australasicus Ridley
Xylocarpus gangeticus (Prain) C.E. Parkinson
Xylocarpus mekongensis Pierre
Zea mays L. (cereals)

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Acronyms of organizations

- APSA: Asian Pacific Seed Association (Bangkok, Thailand).
- ASEAN: Association of South-East Asian Nations (Jakarta, Indonesia).
- AVRDC: Asian Vegetable Research and Development Center (Shanhua, Tainan, Taiwan).
- BDFFP: Biological Dynamics of Forest Fragments Project (Manãus, Brazil).
- CAAS: Chinese Academy of Agricultural Sciences (Wuhan, Hubei, China).
- CATIE: Centro Agronómico Tropical de Investigación y Enzeñanza (Turrialba, Costa Rica).
- CIMMYT: Centro Internacional de Mejoramiento de Maiz y Trigo [International Maize and Wheat Improvement Center] (Mexico City, Mexico).
- CIRAD: Centre de Coopération Internationale en Recherche Agronomique pour le Développement (Montpellier, France).
- CITES: Convention on International Trade in Endangered Species of Wild Fauna and Flora (Lausanne, Switzerland).
- CNRA: Centre National de Recherche Agronomiques [National Centre for Agricultural Research] (Abidjan, Ivory Coast).
- COGENT: Coconut Genetic Resources Network (c/o IPGRI, Singapore).
- CPCRI: Central Plantation Crops Research Institute (Kasaragod, Kerala, India).
- DGIS: Directorate-General for International Cooperation of the Netherlands Ministry of Foreign Affairs (Den Haag, the Netherlands).
- FAO: Food and Agriculture Organization of the United Nations (Rome, Italy).
- FRIM: Forest Research Institute Malaysia (Kepong, Malaysia).
- IBPGR: International Board for Plant Genetic Resources (see IPGRI).
- ICGR: Institute of Crop Germplasm Resources (Beijing, China).
- ICRISAT: International Crops Research Institute for the Semi-Arid Tropics (Hyderabad, India).
- IEBR: Institute of Ecology and Biological Resources (Hanoi, Vietnam).
- IITA: International Institute of Tropical Agriculture (Ibadan, Nigeria).
- INTSOY: International Soybean Program (University of Illinois, Urbana-Champaign, Illinois, United States).
- IOCR: Insitute of Oil Crops research (Wuhan, China).
- IOOC: International Olive Oil Council (Madrid, Spain).
- IPGRI (formerly IBPGR): International Plant Genetic Resources Institute (Rome, Italy).
- IRD (formerly ORSTOM): Institut de Recherche pour le Développement.
- LIPI: Indonesian Institute of Sciences (Jakarta, Indonesia).
- MPOB (formerly PORIM): Malaysian Palm Oil Board (Kuala Lumpur, Malaysia).
- NARS: National Agricultural Research System

- NBPGR: National Bureau of Plant Genetic Resources (New Delhi, India).
- NCDP: National Coconut Development Programme (Dar-es-Salaam, Tanzania).
- NIFOR: Nigerian Institute for Oil Palm Research (Benin City, Nigeria).
- NSSL: National Seed Storage Laboratory (Fort Collins, Colorado, United States).
- OPGL (now part of MPOB): Oil Palm Genetics Laboratory (Layang Layang, Johor, Malaysia).
- OWC: Olive World Collection (Cordoba, Spain).
- PCA: Philippine Coconut Authority (Quezon City, the Philippines).
- PCARRD: Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (Los Baños, Laguna, the Philippines).
- PROSEA: Plant Resources of South-East Asia (Bogor, Indonesia).
- RDCIC: Research and Development Centre for Industrial Crops (Bogor, Indonesia).
- TISTR: Thailand Institute of Scientific and Technological Research (Bangkok, Thailand).
- UNITECH: Papua New Guinea University of Technology (Lae, Papua New Guinea).
- USDA: United States Department of Agriculture (Washington State University, Washington, United States).
- USDA-NAPIS: United States Department of Agriculture – North Central Regional Plant Introduction Station (Ames, Iowa, United States).
- VIR: N.I. Vavilov Institute of Plant Industry (St. Petersburg, Russia).
- VNIIMK: Research Institute for Oil-bearing Crops (Krasnodar, Russia).
- WHO: World Health Organization (Geneva, Switzerland).
- WU (formerly WAU): Wageningen University (Wageningen, the Netherlands).
- WUR: Wageningen University and Research Centre (Wageningen, the Netherlands).

Glossary

abortifacient: causing abortion; an agent that causes abortion
abscission: the natural detachment of leaves, branches, flowers or fruits
accession: in germplasm collections: plant material of a particular collection, usually indicated with a number
accrescent: increasing in size with age
achene: a small dry indehiscent one-seeded fruit
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
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
adaxial: on the side facing the axis (ventral)
adnate: united with another part; with unlike parts fused, e.g. ovary and calyx tube
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
aerenchyma: a spongy tissue having large thin-walled cells and large intercellular spaces, serving for aeration or floating tissue
aflatoxin: a toxic factor produced by *Aspergillus flavus* and *A. parasiticus* and implicated as a cause of human hepatic carcinoma
agglutinin: antibody which aggregates a particular antigen; any other substance that is capable of agglutinating particles
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
AIDS: acquired immune deficiency syndrome (acquired immunodeficiency syndrome), an epidemic, transmissible retroviral disease due to infection with HIV (human immuno-deficiency virus), in severe cases manifested as a profound depression of cell-mediated immunity
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
aliphatic: molecule consisting of a straight chain of carbon molecules with no branching or ring structure
alkaloid: large group of organic bases containing nitrogen and usually oxygen that occur for the most part in the form of salts; usually optically and biologically active
allelopathy: the reputedly baneful influence of one living plant upon another due to secretion of toxic substances
allergenic: acting as an allergen; inducing allergy
allogamous: from allogamy, cross-fertilization
allotetraploid: an alloploid produced when a hybrid between two species doubles its chromosome number (also mentioned: amphidiploid)
alluvium: soil material deposited by running water in recent geological time
alternate: leaves, etc., inserted at different levels along the stem, as distinct from opposite or whorled
androecium: the male element; the stamens as a unit of the flower
androgynous: having male and female flowers on the same inflorescence
androphore: a stalk supporting the androecium or stamens
annual: a plant which completes its life cycle in one year
annular: used of any organs disposed in a circle
anorexia: lack or loss of the appetite for food

anthelmintic: destructive to worms: a drug or agent that destroys intestinal worms
anther: the part of the stamen containing the pollen
anthesis: the time the flower is expanded, or, more strictly, the time when pollination may take place
anthocyanin: the blue, sometimes red, colouring of plant parts
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
anti-glycation activity: suppression of non-enzymatic reaction of protein with reducing sugar
anti-inflammatory: suppressing or counteracting inflammation; an agent that suppresses or counteracts the inflammatory process
antibiotic: any of a large class of substances produced by various micro-organisms and fungi and having the power of arresting the growth of other micro-organisms or destroying them; a chemical, produced by plants, animals or synthetically, having similar properties
apex (plural: apices): the tip or summit of an organ
apical: at the apex of any structure
apiculate: ending abruptly in a short point
apomixis: reproduction by seed formed without sexual fusion (apomictic)
apoplexy: sudden neurologic impairment due to a cerebrovascular disorder, either an arterial occlusion or an intracranial haemorrhage; copious extravasation of blood within any organ
appendage: a part added to another; attached secondary or subsidiary part, sometimes projecting or hanging
appressed (adpressed): lying flat for the whole length of the organ
aril: an expansion of the funicle enveloping the seed, arising from the placenta; sometimes occurring as a pulpy cover
arillode: a false aril, a coat of the seed not arising from the placenta
armed: bearing some form of spines
articulate: jointed, or with places where separation takes place naturally
ascendent, ascending: curving or sloping upwards
asexual: sexless; not involving union of gametes
asthma: a chronic disorder characterized by paroxysms of the bronchi, shortness of breath, wheezing, a suffocating feeling, and laboured coughing to remove tenacious mucus from the air passages
attenuate: gradually tapering
auct., 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
auxin: an organic substance characterized by its ability in low concentrations to promote growth of plant shoots and to produce other effects such as root formation and bud inhibition
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
bamboos: a taxonomic group of plants comprising the tribe Bambuseae of the Bambusoideae, a subfamily of the Gramineae; living plants, or culms (stems) severed from plants of this group
bark: the tissue external to the vascular cambium collectively, being the secondary phloem, cortex and periderm
basifixed: attached or fixed by the base
beak: a long, prominent and substantial point, applied particularly to prolongations of fruits
beaked: used of fruits which end in a long point
bending strength: = modulus of rupture
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
biennial bearing: a more or less regular alternation of heavy and light fruit crops in successive years
bifid: forked, divided in two but not to the base
bifurcate: twice forked
bisexual: having both sexes present and functional in the same flower
blade: the expanded part, e.g. of a leaf or petal
blight: a general term applied to any of a wide range of unrelated plant diseases
blockboard: a plywood in which the core layers are replaced by blocks of wood
bole: the main trunk of a tree, generally from the base up to the first main branch
bollworm: any of several genera of moths belonging to the *Noctuidae*
brachyblast: a short reproductive branch
bract: a reduced leaf subtending a flower, flower stalk or the whole or part of an inflorescence
bracteate: provided with bracts
bracteole: a secondary bract on the pedicel or close under the flower

bran: the husks or outer coats of ground corn, separated from the flour by bolting
breeding: the propagation of plants or animals to improve certain characteristics
bristle: a stiff hair or a hair-like stiff slender body
broadcast: to sow seed scattered, not in lines or pockets
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
budding: the process of inserting a scion, which consists of the bud in a leaf axil on a shield of rind, with or without a small piece of wood attached, into a plant (rootstock) with the intention that it will unite and grow there, usually in order to propagate a desired cultivar
bulb: an underground storage organ with a much-shortened stem bearing fleshy leaf bases or scale leaves enclosing the next year's bud
bunch: cluster, growing together
bush: a low thick shrub without a distinct trunk
cabbage: of palms, a terminal bud of a palm tree that resembles a head of a cabbage and is eaten as a vegetable
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
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
campylotropous: applied to an ovule or seed, one side of which has grown faster than the other so as to bring its true apex (micropyle) near the hilum
canaliculate: channelled, with a longitudinal groove
cancer: a malignant neoplasm or tumour, characterized by a morbid proliferation of epithelial cells in different parts of the body, resulting in progressive degeneration and often ending fatally
canker: a sunken, necrotic lesion of main root, stem or branch, due to disintegration of tissue outside the xylem cylinder, sometimes limited in extent because of host reactions resulting in overgrowth of surrounding tissues
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
capitulum: a dense inflorescence of an aggregation of usually sessile flowers, as in *Compositae*
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
carbohydrates: compounds formed from water and carbondioxide; they can be grouped into sugars and polysaccharides
carcinogenic: producing cancer
cardiac: pertaining to, situated near, or affecting the heart; pertaining to the opening between the oesophagus and the stomach
cardiotonic: having a tonic effect on the heart; an agent that has a tonic effect on the heart
cardiovascular: pertaining to the heart and blood vessels
carina: keel, the two inner united petals of a papilionaceous flower
carnose: fleshy, pulpy
carotenoids: a subgroup of the terpenoids, containing 8 isoprene units (C40) named after β-carotene
carpel: one of the foliar units of a compound pistil or ovary; a simple pistil has only one carpel
caruncle: an outgrowth of a seed near the hilum
caudate: with a tail-like appendage
cauliflorous: with the flowers borne on the trunk
cellulose: a carbohydrate, being the material base of the cell wall; the residue when hemicellulose is extracted from the holocellulose; often referred to as α-cellulose
chaffy: with small membranous scales, degenerate bracts in many *Compositae*
chartaceous: papery
chlorophyll: green pigment in plants which absorbs light for photosynthesis
cholera: acute, infectious inflammation of the intestine, caused by an enterotoxin elaborated by *Vibrio cholerae*, and characterized by severe, watery diarrhoea
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
circumscissile: dehiscing or falling off along a circular line
claw: the basal, narrow part of a petal or sepal
clawed: furnished with a basal, narrow part (the claw)
cleavage: a measure for the resistance of wood to splitting
cleft: cut halfway down
clone: a group of plants originating by vegetative

propagation from a single plant and therefore of the same genotype

clustered: compactly gathered together; with several stems

colic: acute, spasmodic pain in the bowels; pertaining to the bowels

collapse: in wood, a defect due to abnormal and irregular shrinkage and resulting in a wrinkled or corrugated appearance of the surface and sometimes also an internal honeycombing

columella: a persistent central axis round which the carpels of some fruits are arranged

column (botany): a cylindrical body, e.g. a tube of connate stamen filaments or the central axis of a fruit

compatibility: in floral biology: capable of cross- or self-fertilization; in plant propagation: stock-scion combinations resulting in a lasting union

composite: a variety developed by intermating (3 or 4 generations) open-pollinated parent varieties selected on the basis of their phenotypic performance or general combining ability; it is maintained by open pollination

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

compression parallel to grain: in timber, a measure for the compression strength parallel to the direction of the fibres necessary to bring about failure in a sample (maximum crushing strength)

concave: hollow

cone: in botany: 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

connivent: having a gradually inward direction, as in many petals (convergent)

conoidal: similar in shape to a geometrical cone

constipation: a condition of the bowels in which the expulsion of waste matter is infrequent and difficult

contorted: twisted or bent

contraceptive: reducing the likelihood of or preventing conception; an agent that reduces the likelihood of or prevents conception

convex: having a more or less rounded surface

coppice: a small wood which is regularly cut at stated intervals; the new growth arising from the stool

cordate: heart-shaped, as seen at the base of a leaf, etc., which is deeply notched

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

cortex: the bark or rind

cortical: relating to the cortex

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

costa: a rib, when single, the midrib or vein

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

cracking: to decompose long chain fatty acids by heat and pressure with or without catalyst to produce lighter compounds

crenate: the margin notched with blunt or rounded teeth

crenulate: slightly crenate, with small teeth

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; a short rootstock with leaves; the base of a tufted, herbaceous, perennial grass

crustaceous: of hard but brittle texture

cryopreservation: maintaining the viability of tissue or organs by storage at very low temperatures

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 by '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

cupuliform: cupule-shaped

cuspidate: abruptly tipped with a sharp rigid point

cutting: a portion of a plant, used for vegetative propagation
cymose: bearing cymes or inflorescences related to cymes
cymule: a diminutive, usually few-flowered cyme or portion of one
DBH: diameter of a tree trunk at breast height (1.3 m)
deciduous: shedding, applied to leaves, petals, etc.
decoction: a medicinal preparation or other substance made by boiling, especially in water
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
density: the ratio of mass to volume of a substance at a certain moisture content
dentate: margin prominently toothed with the pointed teeth directed outwards
denticulate: minutely toothed
depressed: sunk down, as if flattened from above
dermatitis: inflammation of the skin
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
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
diffuse: growing in open array
digestibility: the percentage of a foodstuff taken into the digestive tract that is absorbed into the body
dimeric: showing the characteristics of a dimer
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
dipterocarp forest: woodland dominated by trees belonging to the family *Dipterocarpaceae*
disc: = disk
disciform: shaped like a disk
discoid: resembling a disk or discus, being flat and circular, e.g. of a leaf with a round thickened lamina and rounded margins
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
divaricate: extremely divergent
DNA, deoxyribonucleic acid: biomolecule containing the genetic information necessary for inheritance of all living organisms; it is contained in chromosomes of the cell nucleus and also in certain cytoplasmic bodies (mitochondria and chloroplasts)
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
downy: covered with very short and weak soft hairs
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
dysentery: any of various diseases characterized by inflammation of the intestines, abdominal pain and frequent bloody, mucous faeces
dyspepsia: a condition of disturbed digestion
echinate: bearing spines or bristles
egg: the female gamete or germ cell
eglandular: without glands
ellipsoid: a solid which is elliptical in outline
ellipsoidal: of a solid which is elliptical in outline
elliptical: oval in outline but widest about the middle
emarginate: notched at the extremity
embryo: in plants, the rudimentary plant within a seed, developed from a zygote (sexual) or from other nuclei in the embryo sac or cells of the nucellus or integuments (apomictic)

emetic: tending to induce or cause vomiting; an agent that induces or causes vomiting
emollient: soothening and softening; an agent that soothes or softens the skin or soothes an irritated internal surface
endemic: exclusively native to a specified or comparatively small region; also used as a noun for a taxon thus distributed
endocarp: the innermost layer of the pericarp or fruit wall
endogenous: originating from within the organism
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)
entire (botany): with an even margin without teeth, lobes, etc.
epidermis: in plants, the true cellular skin or covering of a plant below the cuticle
epigeal: above the ground; in epigeal germination the cotyledons are raised above the ground
epipetalous: borne upon or placed before the petals
epiphyte: a plant that grows on another plant but without deriving nourishment from it
erect: directed towards summit, not decumbent
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
ester: compound formed by the linking of a carboxylic acid or an acyl derivative with an alcohol or its equivalent
esterification: process whereby an ester is formed
evergreen: bearing foliage all year long; a plant that changes its leaves gradually
ex situ: in an artificial environment or unnatural habitat
exalbuminous: lacking albumen
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
exstipulate: without stipules
extraction: a process for separating a substance e.g. oil from animal or plant matter using a volatile solvent
extrafascicular: outside of vascular bundles
extrorse: directed outward, as the dehiscence of an anther
exudate: the secreted substance
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)
farinose: mealy; producing or covered with fine powder or dust; covered with short white hairs that can be detached like dust
fascicle: a cluster of flowers, leaves, etc., arising from the same point
fasciculate: connected or drawn into a fascicle
fermentation: a chemical change accompanied by effervescence and suggestive of changes produced in organic materials by yeasts
ferruginous: rust-coloured
fertile: in plants: 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: in plants: any long, narrow cell of wood or bark other than vessel or parenchyma elements
fibrous: composed of or containing fibres
filiform: slender; threadlike
filler: a composition (as of powdered silica and oil) used to fill the pores and grain of wood
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
flaky: lamelliform, in the shape of a plate or scale
flatulence: the presence of excessive amounts of air or gases in the intestine
flavonoids: a group of natural products in which the basic structure is the 2-phenyl-chromane skeleton
fleshy: succulent
floccose: covered with dense hairs that fall away in tufts, locks or flocci
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
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)

foliolate: 2-, 3-, 4- etc., with 2-, 3-, 4- leaflets

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

foveola: a small pit

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 different 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

free fatty acid: a fatty acid in which the acid group is not chemically bound to another compound

free radical: a radical (a group of atoms which enters into and goes out of chemical combination without change and forms one of the fundamental constituents of a molecule) which is extremely reactive, has a very short half-life, and carries an unpaired electron

fruit: the ripened ovary with adnate parts

fugacious: withering or falling off rapidly or early

fulvous: yellow, tawny

fungicidal: destroying fungi

fungicide: an agent that destroys fungi or inhibits their growth

fusiform: spindle-shaped; tapering towards each end from a swollen centre

gastralgia: gastric colic

gene: the unit of inheritance located on the chromosome

genetic engineering: the manipulation of DNA (or RNA) of different species producing recombinant DNA, which includes some genes from both species

genetic erosion: the decline or loss of genetic variability

genetic linkage map: diagram representing the linear relationship of markers on chromosomes; markers can be genes or non-coding regions of DNA; linkage groups usually represent the haploid number of chromosomes of an organism

genetic transformation: the transfer of genes not by the usual sexual process but by recombinant DNA technology

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

germ: a bud or growing point; an ovary or young fruit; a reproductive cell, especially in bacteria

germplasm: the genetic material that provides the physical basis of heredity

gibbose: more convex in one place than another; a pouch-like enlargement of the base of an organ, as of a calyx

glabrescent: becoming glabrous or nearly so

glabrous: devoid of hairs

glandular: in botany: having or bearing secreting organs or glands

glaucous: pale bluish-green, or with a whitish bloom which rubs off

globose: spherical or nearly so

glucoside: compound that is an acetal derivative of sugars and that on hydrolysis yields glucose

glyceride: compound having 1 or more fatty acids attached to a glycerol

glycerol: a 3-carbon chain with each carbon containing an alcohol group

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

goitrogenic: producing goitre

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: of wood, the general direction or arrangement of the fibres; texture

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

gum: a colloidal polysaccharide substance that is gelatinous when moist but hardens on drying; gum is exuded by plants or extracted from them

gynoecium: the female part or pistil of a flower, consisting, when complete, of one or more ovaries with their styles and stigmas

habit (botany): external appearance or way of growth of a plant

habitat: the kind of locality in which a plant grows
haemostatic: arresting the flow of blood; an agent that checks the flow of blood
hardwood: the wood of an angiospermous tree as distinguished from that of a coniferous tree
hastate: with more or less triangular basal lobes diverging laterally
haustorium: a food-absorbing outgrowth of an embryo as in coconut; food-absorbing organ of a parasitic plants
head: a dense inflorescence of small crowded often stalkless flowers (a capitulum)
heartwood: wood from the inner portion of a tree in which the cells are dead and no longer engaged in sap conduction and food storage
hedgerow: a closely planted line of shrubs or small trees, often forming a boundary or fence
herb: any vascular plant which is not woody
herbaceous: with the texture, colour and properties of a herb; not woody
heritability: the proportion of variability that results from genetic causes; also that proportion of the variation of a population that is transmitted to progeny
hermaphrodite: bisexual; in flowers, with stamens and pistil in the same flower
heterogeneous: lacking in uniformity; exhibiting variability
heterosis: exceptional vigour of organisms through crossbreeding between two different types
heterozygous: the condition in which homologous chromosomes of an individual possess different alleles at corresponding loci
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
homozygous: possessing identical genes at corresponding loci on homologous chromosomes
hull: see husk
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
hydrolysis: a chemical reaction of water in which a bond in the reactant other than water is split and hydrogen and hydroxyl are added
hydrophilic: having a strong affinity for water
hypocotyl: the young stem below the cotyledons
hypogeal: below ground; in hypogeal germination the cotyledons remain below ground within the testa
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
impressed: marked with slight depressions
in situ: in the natural environment
in vitro: outside the living body and in an artificial environment
inbred line: the product of inbreeding; a line originating by self-pollination and selection
inbreeding: breeding through a succession of parents belonging to the same stock
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
inflammation: a protective response of the body in response to injury, infection, irritation, etc., characterized by redness, pain, heat, and swelling
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
infructescence: a ripened inflorescence in the fruiting stage
infusion: a liquid extract obtained by steeping or soaking something in a liquid for the purpose of extracting its medicinal principles without boiling; the therapeutic introduction of a fluid, other than blood, into a vein
inner bark: the secondary phloem; the living part of the tissue outside the cambium
inoculation: grafting, more properly budding, a single bud only being inserted; introduction of microorganisms, infective material, serum and other substances into tissues of living plants and animals, or culture media promote growth
insecticidal: destroying or controlling insects
insecticide: an agent that destroys insects

intercropping: the growing of two or more crops in different but proximate rows

internode: the portion of the stem (culm) between two nodes

introgression: incorporation of genes of one species into the gene pool of another species by hybridization and backcrossing

introrse: turned inward, towards the axis, as the dehiscence of an anther

involucral: belonging to an involucre

isomer: a compound, radical or ion containing the same numbers of atoms of the same elements in the molecule as one or more others, and hence having the same molecular formula, but differing in the structural arrangement of the atoms and consequently in one or more properties

joinery: the construction of articles by joining pieces of wood

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

keeled (carinate): having a keel or carina

kerangas: heath forest, a type of tropical forest generally consisting of comparatively small trees with thin trunks (pole forest), often overlying a podsolic soil

kernel: the nucellus of an ovule or of a seed, that is, the whole body within the coats

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

lateral: on or at the side

latex: a juice, usually white and sometimes sticky, exuding from broken surfaces of some plants

laxative: aperient, mildly purgative; an agent that promotes evacuation of the bowel

layer: a branch caused to root while still connected to the parent and used for propagation (layering)

leaching: of a soil, the removal of soluble and nutritive elements by a vertical, downward water movement

leaflet: one part of a compound leaf

lectins: protein parts of glycoproteins, which are not antibodies or enzymes, but which have the ability to attach themselves to specific sugars; the binding is not covalent, and the sugar can either be free or constituent part of a larger molecule, which may be present, e.g. in a membrane

lepidote: covered with small scales

lignans: a group of natural products (dimers) derived from condensation of 2 phenylpropane units

lignified: converted into wood or woody tissue

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

line: used in plant breeding for a group of individuals from a common ancestry

linear: long and narrow with parallel sides

liquorice: black substance extracted from the root of *Glycyrrhiza glabra* L. used in medicine especially against coughs and colds

lobe: any division of an organ or specially rounded division

lobed: divided, but not to the base

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 crops) be laid flat on the ground as by strong wind or rain

longitudinal: lengthwise

maceration: a method of extract preparation in which the matter to be extracted is mixed with the prescribed extraction solvent, and allowed to stand in a closed container for an appropriate time; the residue is separated from the extraction solvent, and if necessary, pressed out; in the latter case, the two liquids obtained are combined; see also percolation

macronutrients: chemical elements obtained from the soil of which relatively large quantities are essential for plant growth (N, P, K, Ca, Mg)

Malesia: the biogeographical region comprising 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

margin: the edge or boundary line of a body
mass selection: a system of breeding in which seed from individuals selected on the basis of phenotype is used to grow the next generation
membranous: thin and semi-transparent, like a fine membrane
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
micropyle: a minute opening in the integument of an ovule through which the pollen tube penetrates
microspore culture: culture of a spore or an immature pollen grain into a haploid callus which can be induced to form haploid plants or into embryoids in vitro without an intervening callus phase
midrib: the main vein of a leaf which is a continuation of the petiole
mildew: a superficial, usually whitish growth on living plants produced by fungi
miscella: mixture of solvent and oil that results from the solvent extraction of oil from seeds
mixed cropping: the growing of two or more crops simultaneously in the same field at the same time, but not in row arrangement
modulus of elasticity: a measure of the stiffness of beams or long columns
moisture content: the weight of water expressed as a percentage of the dry weight
molecular markers: genetic markers that characterize genotypes based on polymorphisms at protein or DNA level
monadelphous: of stamens, united into one group by their filaments
monoclonal: belonging to one clone
monoecious: with unisexual flowers, but male and female flowers borne on the same plant
monogastric: having a stomach with only one compartment (e.g. swine, chicks)
monopodial: of a primary axis which continues its original line of growth from the same apical meristem to produce successive lateral branches
monoterpenes: a subgroup of the isoprenoids, formed by coupling of 2 C5 units
monotypic: consisting of a single element, e.g. of a genus consisting of only one species
moulding: of wood or plywood, shaping by cutting and/or pressing into various contours
mucilage (mucilaginous): a gelatinous substance that is similar to gum but that swells in water without dissolving and forms a slimy mass
mucilaginous: slimy
mucous: pertaining to, resembling, producing, containing or covered with mucus
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
multiple (anatomy): a vessel arrangement where clusters of adjacent vessels are aligned parallel to the rays (radial multiple) or in a line oblique to the rays (oblique multiple)
mutagenic: capable of inducing genetic mutation
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)
naturalized: introduced into a new area and established there, giving the impression of wild growth
nausea (nauseous): an uncomfortable feeling in and about the stomach associated with aversion to food and a need to vomit
necrosis: in plants, death of a portion of tissue often characterized by a brown or black discolouration
nectar: a sweet fluid exuded from various parts of the plant (e.g. by the flower to attract pollinators)
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
node: the point on the stem or branch at which a leaf or lateral shoot is borne
nucleus (plural: nuclei): an organized proteid body of complex substance in the protoplasm of cells; the central point in a starch granule
nut: a one- to many-seeded indehiscent fruit with a hard dry pericarp or shell
oblanceolate: reverse of lanceolate
oblique: slanting; of unequal sides
oblong: longer than broad, with the sides parallel or almost so
obovate: reverse of ovate
obovoid: a solid object which is obovate in section
obtuse: blunt or rounded at the end
oedema: the presence of abnormally large amounts of fluid in the intercellular tissue spaces of the body
offset (offshoot, rhizome cutting): a lateral shoot used for propagation

oleoresin: a natural plant product consisting of a viscous mixture of mainly essential oil and non-volatile odourless solids

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

orbicular: flat with a more or less circular outline

order (and its extensions, first, etc.): a sequence, as of branching: a first order branch branches to produce a second order branch, etc.

organoleptic: of or pertaining to sensations and their evaluation

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

oxidation: the processes of combining a compound with oxygen, dehydrogenating, or increasing the proportion of the electro-negative part

p.v.: physiological variety

panacea: a universal remedy; a herb credited with remarkable healing properties

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

parasitic: deriving nourishment from some other organism

parenchyma: in plants: ground tissue composed of thin-walled, relatively undifferentiated cells, e.g. the pith and mesophyll

parietal: placentation type, when the ovules are attached to the wall of a one-celled ovary

paripinnate: a pinnate leaf with all leaflets in pairs

particle board: board made from bonded particles of wood and/or other ligno-cellulosic material

pedicel: the stalk of an individual flower

pedicellate: furnished with a pedicel

pedigree selection: a breeding system in which individual plants are selected in the segregating generations of a cross, based on individual performance and on a pedigree record, until genetic purity is reached

peduncle: the stalk of an inflorescence or partial inflorescence

peltate: of a leaf, with the stalk attached to the lower surface, not at the edge

pendent, pendulous: drooping; hanging down from its support

percolation: a method of extract preparation in which the matter to be extracted is mixed with a portion of the prescribed extraction solvent, and allowed to stand for an appropriate time; the mass is then transferred to a percolator and the remaining extraction solvent is allowed to flow through slowly, making sure that the matter to be extracted is always covered with liquid; the residue may be pressed out and the expressed fluid combined with the percolate; see also maceration

perennial: a plant living for many years and usually flowering each year

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

peristalsis: the movement by which the digestive tract and other tubular organs with both longitudinal and circular muscle fibres propel their contents

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

petiolate: having a petiole

petiole: the stalk of a leaf

petiolule: the stalk of a leaflet

phelloderm: the innermost layer of the periderm

phenolics: phenols are compounds which have an aromatic ring with an alcoholic group attached to it

phenology: the complex annual course of flushing, quiescence, flowering, fruiting and leaf fall in a given environment

pheromone: a substance which is secreted to the outside of the body by an individual and which is perceived (e.g. by smell) by another individual of the same species, leading to a specific reaction of behaviour in the percipient

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

phyllody: transformation of flower parts into leaves

phyllotaxis: the arrangement of leaves or floral parts on an axis or stem

phytosanitary: of or relating to health or health measures of plants

phytosterols: a group name for the widespread plant sterols sitosterol, campesterol and stigmasterol

pilose: hairy with rather long 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

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

pith: the soft core occurring in the structural centre of a log; the tissue, sometimes soft, in the centre of the stem of a non-woody dicotyledon

pleonanthic: of plants (e.g. some palms) flowering continuously, not dying after flowering (cf. hapaxanthic)

plumule: the primary bud of an embryo or germinating seed

plywood: a panel material consisting of wood veneers glued together with the grains of adjacent layers arranged at right angles or at a wide angle

pod: a dry fruit composed of a single carpel and dehiscing by sutures, as in legumes; a general term for a dry dehiscent fruit

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

polyclonal: belonging to more than one clone

polygamous: with unisexual and bisexual flowers in the same plant

polygenic traits: characters that are controlled by several unlinked genes known as QTL

polyploid: with more than two sets (genomes) of chromosomes in the somatic cells, e.g. triploid (3 sets), tetraploid (4), pentaploid (5), hexaploid (6), heptaploid (7), octoploid (8), etc.

polyploidy: the state of having more than two full sets of homologous chromosomes

preservative: a chemical formulation (usually in liquid form) used for the treatment of timber to increase its durability

press cake: material that remains when oil is extracted from oilseeds

primordium: a group of undifferentiated meristematic cells, usually of a growing point, capable of differentiating into various kinds of organs or tissues

progeny: offspring

prostrate: lying flat on the ground

protandrous: of flowers, shedding pollen before the stigma is receptive

proteolytic: pertaining to, characterized by, or promoting proteolysis

protogynous, proterogynous: of flowers, the stigma is receptive before the pollen is shed; of inflorescences, the female flowers mature before the male ones

protoplast fusion: fusion between irradiated donor protoplasts and untreated recipient protoplast enabling new combinations of chromosomal and cytoplasmic DNA to be achieved in so-called somatic hybrids

pruning: cutting off the superfluous branches or shoots of a plant for better shape or more fruitful growth

psoriasis: a common chronic, scaly dermatosis with polygenic inheritance and a fluctuating course

psyllid: belonging to the homopterous insect family *Psyllidae*, which includes the jumping plant lice

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

pulses: dry edible seeds of legumes

pulvinus: a minute gland or swollen petiole base

pungent: bearing a sharp point; causing a sharp or irritating sensation
purgative: causing evacuation of the bowels; an agent causing evacuation of the bowels, especially through stimulating peristaltic action; also called cathartic
pyriform: resembling a pear in shape
pyxis: a capsule with circumscissile dehiscence, the upper portion acting as lid
QTL: quantitative trait loci
quadrangular: four-cornered or four-edged
quantitative trait: traits such as yield that are determined by the action of many genes; also called polygenic traits
rabi season: dry season in India
raceme: an unbranched elongated indeterminate inflorescence with stalked flowers opening from the base upwards
racemose: raceme-like
rachis (plural: rachides): the principal axis of an inflorescence or a compound leaf beyond the peduncle or petiole
radial: lengthwise, in a plane that passes through the pith; radiating, as from a centre (cf. tangential)
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
ramiflorous: bearing flowers on the branches
rancidity: off flavour in fat or oil caused by either oxidation or by the release of flavourful fatty acids from the triglyceride
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
recalcitrant: of seeds, not tolerating desiccation or temperatures below 10°C
receptacle (botany): the flat, concave or convex part of the axis from which the parts of the flower arise
reciprocal recurrent selection: a breeding system with recurrent selection in two genetically different populations with the objective of improving the populations simultaneously for combining ability; this is mainly used to increase the performance of hybrids between plants, clones or lines developed from the two populations
recurrent selection: a breeding system designed to increase the frequency of favourable genes of a quantitatively inherited characteristic by repeated cycles of crossing and selection
reduced: subnormal in size; connotes also either a failure to fulfil a normal function, or a diminution the expected number of parts in a set (of stamens, for example)
reflexed: abruptly bent or turned downward or backward
reforestation: the planting of a formerly forested area with forest trees
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
resinous: exuding, made of, or similar to resin
reticulate: netted, as when the smallest veins of a leaf are connected together like the meshes of a net
retuse: with a shallow notch at a rounded apex
revolute: of leaves with the margins, rolled downwards towards the midrib
rheumatism: any of various disorders, characterized by inflammation, degeneration, or metabolic derangement of the connective tissue structures of the body, especially the joints and related structures, and accompanied by pain, stiffness or limited mobility of these parts
rind: the tough outer layer of the fruit
rootstock: 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
rot: disintegration of tissue due to the action of invading organisms, usually bacteria or fungi; a disease so characterized
rotundate: rotund in outline
rudimentary: of organs, imperfectly developed and non-functional
ruminant: an animal that chews again what has been swallowed (e.g. sheep, cows, camels, goats)
ruminate: of endosperm, mottled in appearance, due to the infolding of a dark inner layer of the seed-coat into the paler coloured endosperm
rust: a disease caused by, and a species in, the class *Urediniomycetes*, order *Uredinales*; so called because of the yellowish to orange brown colour of the spores
saccate: pouched
sagittate: shaped like an arrowhead; of a leaf base with two acute straight lobes directed downwards

sapling: a young tree of more than 1.5 m tall and with a bole of less than 10 cm in diameter
saponification: chemical reaction caused by the addition of alkali to a fat in which the fatty acids attached to a glycerol are cleaved off to produce soap and glycerol
saponin: a glycoside with soap properties
saponins: the term is applied to a group of glycosides which have the ability to lower the surface tension of aqueous solutions
sarcotesta: the fleshy outer seed-coat
saturated fatty acid: a fatty acid with an aliphatic chain of carbons mutually connected by single bonds
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
schistosomiasis: infection with flukes of the genus *Schistosoma*; sometimes called bilharzia
schizocarp: a dry fruit formed from a syncarpous ovary which splits into one-seeded portions, mericarps or 'split fruits'
schizocarpous: in the form of a schizocarp
scleroderma: chronic hardening and thickening of the skin, which may be a finding in several different diseases
scrub: vegetation whose growth is stunted because of lack of water coupled with strong transpiration
scurf: abnormal skin condition in which small flakes or scales become detached
section (botany): a taxonomic rank between the genus and the species accommodating a single or several related species
secund: arranged on one side
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
selfing: fertilization of female gametes with male gametes from the same individual
semi-: prefix, meaning half or incompletely, e.g. semi-inferior
senescence: advancing in age
sensu stricto (s.s.): in the strict sense
sepal: a member of the outer series of perianth segments
sepaloid: sepal-like
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 C15H24, e.g. caryophyllene and farnesene
sessile: without a stalk
shaggy: villous
shear: a measure for the resistance of wood when the forces acting on it tend to make one part slide over another in the direction parallel to the grain
sheath: a tubular structure surrounding an organ or part, as the lower part of the leaf clasping the stem in grasses
shell: the hard envelope of a nut
shingles: an acute, infectious skin disease, characterized by neuralgia and eruptions sometimes extending half round the body like a girdle; also called herpes zoster
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
silique: a dry and many-seeded dehiscent fruit splitting into 2 valves with a false partition
silviculture: the theory and practice of controlling the establishment, composition, constitution, and growth of forests; the science and art of cultivating forest crops
simple (botany): not compound, as in leaves with a single blade
slash: a cut or stroke along the stem of a tree to reveal exudates and colours of bark and sapwood
sludge: a muddy or slushy deposit or sediment
softwood: the wood of a coniferous tree
solitary: single stemmed, not clustering
solubility: the weight of a solute required to saturate 100 g of a solvent at a given temperature
solvent extraction: see extraction
somatic embryogenesis: the production of embryo-like structures (embryoids) from sporophytic or somatic cells of the plant, as opposed to gametophytic or germ cells (zygotic embryogenesis)
somatic hybrids: plants produced by fusion of isolated plant protoplasts
sooty mould: saprophytic fungus of the family *Capnodiaceae* or other families of the order *Dothideales*, which forms superficial, brown to black colonies on living plants, is often associated with insect secretion, and can be detrimental to the plant

spadix: a flower spike with a fleshy or thickened axis, as in aroids and some palms
spathe: a large bract enclosing a spadix, or two or more bracts enclosing a flower cluster
spatulate (also: spathulate): spoon-shaped
spear leaf: extended but not yet unfolded leaf of palms
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
spheroblast: woody protuberance at the base of the trunk with additional lateral roots, as in olive tree
spicate: spike-like
spiciform: with the form of a spike
spike: a simple indeterminate inflorescence with sessile flowers along a single axis
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
spore: in cryptogams a cell which becomes free and capable of direct development into a new bion; the analogue of seed in phanerogams
sprue: a chronic deficiency syndrome due to subnormal absorption of dietary constituents
staminate: a flower bearing stamens but no pistil
staminode: an abortive or rudimentary stamen without or with an imperfect anther
standard (botany): the fifth, posterior or upper petal of a papilionaceous corolla
starch: polysaccharide made up of a long chain of glucose units joined by α-1,4 linkages, either unbranched (amylose) or branched (amylopectin) at a α-1,6 linkage, and which is the storage carbohydrate in plants, occurring as starch granules in amyloplasts, and which is hydrolysed by animals during digestion by amylases, maltase and dextrinases to glucose via dextrins and maltose
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
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
stoma (plural: stomata): a breathing pore or aperture in the epidermis
stone: the hard endocarp of a drupe containing the seed or seeds
stratification: a moist, cold treatment of seed to overcome physiological dormancy
striate: marked with fine longitudinal parallel lines, as grooves or ridges
style: the part of the pistil connecting the ovary with the stigma
stylopodium: enlargement or swelling at the base of the style
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
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
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
synthetic cultivar: a cultivar produced by crossing inter se a number of inbred lines selected for their good general combining ability; it is subsequently maintained by open pollination
syphilis: a disease usually communicated by sexual contact, or via the blood or bite of an infected person, caused by a spirochete (*Treponema pallidum*) and characterized by a clinical course in 3 stages continued over many years
tannins: a large group of plant-derived phenolic compounds
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)
terete: cylindrical; circular in transverse section
terminal: placed at the end or apex; a termination, end or extremity

termite: ant-like organism of the order *Isoptera* damaging wood by characteristic irregular honeycombing or wide channels with dry bore-dust or dust cemented together

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

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

theca (plural: thecae): a spore- or pollen-case

thinning: removing trees, stems or plants from immature or mature stands in order to stimulate the growth of the remaining trees, stems or plants

thorn: a woody sharp-pointed structure formed from a modified branch

throat (botany): of a corolla, the orifice of a gamopetalous corolla

thrombosis: the formation, development or presence of an aggregation of blood factors (thrombus), often causing vascular obstruction

thrush: infection of the mucous membrane of the mouth with a fungus of the genus *Candida* and characterized by the formation of creamy, white, somewhat elevated lesions

thyrse (thyrsus): a compound inflorescence composed of a panicle (indeterminate axis) with the secondary and ultimate axes cymose (determinate)

thyrsoid: like a thyrse

timber: any wood other than fuelwood

tomentose: densely covered with short soft hairs

tomentum: pubescence

tonic: restoring or producing the normal 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

transgenic: pertaining to the experimental splicing of a segment of DNA from one genome to DNA of a different genome

transgenic crop plants: plants of cultivars containing gene(s) inserted by genetic transformation, that show significant and stable expression of the desired character(s) over several generations of propagation

transverse: straight across; of tertiary veins, connecting the secondary veins, not necessarily in a perpendicular way

trauma: a wound or injury, whether physical or psychic

tree: a perennial woody plant with a single evident trunk

tribe: a taxonomic rank between the family and the genus

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

tungsten carbide: a heavy and very hard type of metal

turning: of wood, shaping, especially in a rounded form, by applying a cutting tool while revolving in a lathe

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)

unarmed: devoid of thorns, spines or prickles

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

unisexual: of one sex, having stamens or pistils only

unsaturated fatty acid: a fatty acid with an aliphatic chain of carbons with one or more double bonds

valvate: of perianth segments, with their edges in contact, but not overlapping in the bud

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: with a coating of fine soft hairs; the same as tomentose but denser so that the surface ressembles velvet

venation (botany): the arrangement of the veins in a leaf

veneer: a thin sheet of wood

venereal: pertaining or related to or transmitted by sexual contact

ventrifixed: fixed to the anterior or inner face

vermifuge: an agent expelling worms or intestinal animal parasites; an anthelminthic

vernalization: the treatment of seeds or bulbs before planting to hasten flowering
versatile (botany): turning freely on its support, as anthers on their filaments
verticillaster: a false whorl, composed of a pair of opposed cymes, as in Labiatae
vessel: a continuous tube formed by superposition of numerous cells whose common walls are perforated or have broken down
viability: ability to live, grow and develop
villous: bearing long weak hairs
viscous: glutinous, or very sticky
warty: covered with firm roundish excrescences
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
whorl: arrangement with more than two organs of the same kind arising at the same level
wilt: loss of turgidity, usually in leaves, typically caused by pathogens which colonize the vascular system
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
xeromorphic: protected from desiccation by special structures such as hair, wax, and thick cuticle
xerophytic: relating to a plant structurally adapted for life and growth with a limited water supply
zygomorphic: irregular and divisible into equal halves in one plane only

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Triadica sebiferum: Pax, F., 1896. Euphorbiaceae. In: Engler, A. & Prantl, K. (Editors): Die natürlichen Pflanzenfamilien [The natural plant families]. Teil 3, Abteilung 5. W. Engelmann, Leipzig, Germany. Fig. 63, p. 97. Redrawn and adapted by P. Verheij-Hayes.

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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 4 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;
- Prosea beyond 2000 (phase 2001–2005): handbook finalization; emphasis on lesser-known useful plants, and making the information services demand-driven.

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 Publishers, Leiden, the Netherlands, and by Prosea South-East Asia for developed countries (becoming available two years after publication of the hardbound edition). The bibliographies are distributed by Prosea South-East Asia.

The handbook

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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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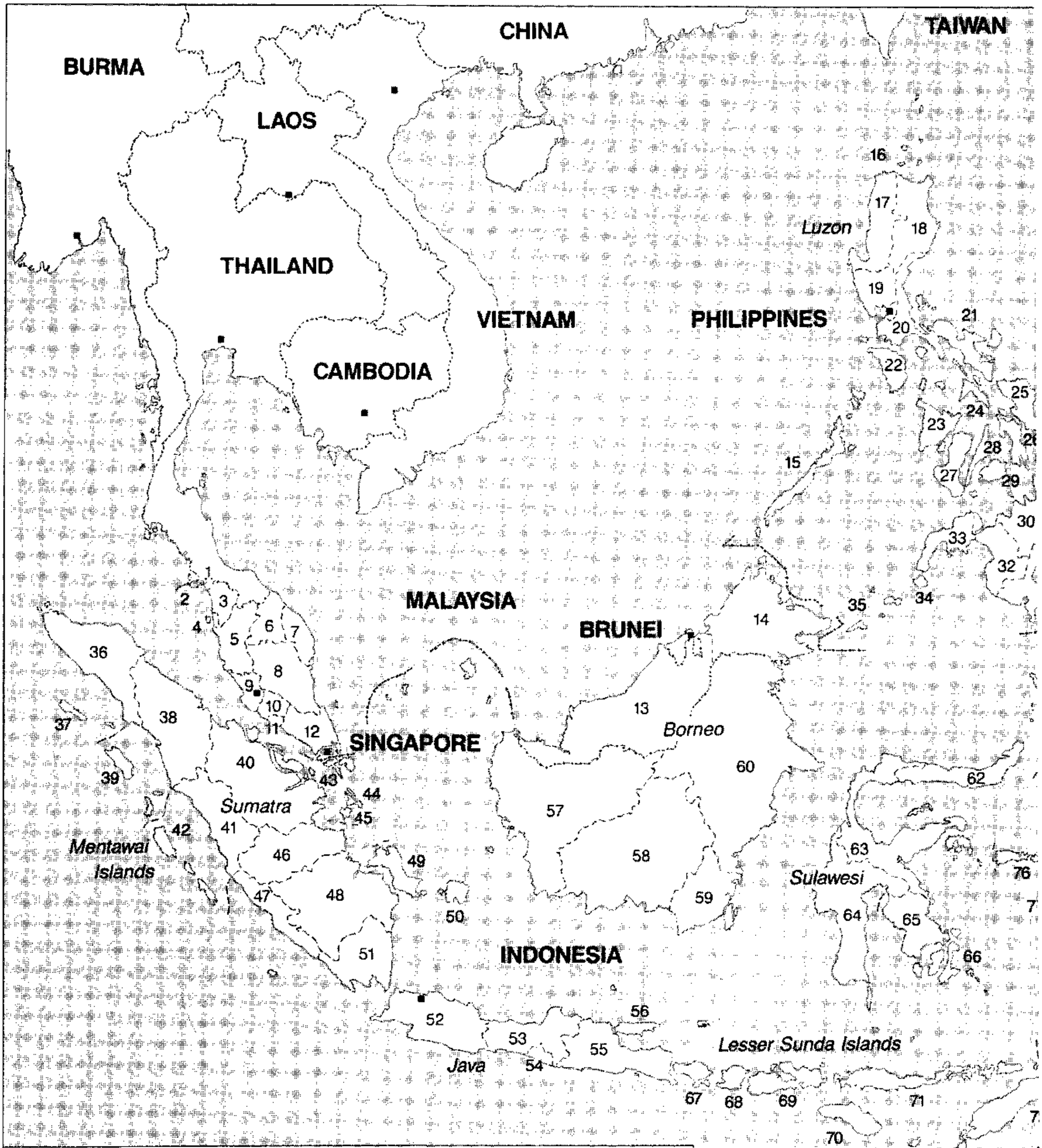

MAP OF SOUTH-EAST ASIA FOR PROSEA

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*).

MALAYSIA
East Malaysia *r* 13-14
Johor *s* 12
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
Perak *s* 5
Perlis *s* 1
Pinang *s* 4
Sabah *s* 14
Sarawak *s* 13
Selangor *s* 9
Terengganu *s* 7

PHILIPPINES
Babuyan Islands *i* 16
Basilan *i* 34
Bicol *r* 21
Bohol *i* 29
Cagayan Valley *r* 18
Cebu *i* 28
Central Mindanao *r* 32
Central Luzon *r* 19
Ilocos *r* 17
Leyte *i* 26
Masbate *i* 24
Mindoro *i* 22
Negros *i* 27
Northern Mindanao *r* 30
Palawan *i* 15
Panay *i* 23
Samar *i* 25
Southern Tagalog *r* 20
Southern Mindanao *r* 31
Sulu Archipelago *i* 35
Western Mindanao *r* 33

INDONESIA
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Ambon *i* 79
Aru Islands *i* 82
Bali *i* 67
Bangka *i* 49
Belitung *i* 50
Bengkulu *p* 47
Buru *i* 77
Butung *i* 66
Central Java *p* 53
Central Kalimantan *p* 58
Central Sulawesi *p* 63
East Java *p* 55
East Kalimantan *p* 60
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Halmahera *i* 74
Irian Jaya *p* 84
Jambi *p* 46
Kai Islands *i* 83
Lampung *p* 51
Lingga *i* 44
Lombok *i* 68
Madura *i* 56
Morotai *i* 73
Nias *i* 39
North Sulawesi *p* 62
North Sumatra *p* 38
Obi *i* 75
Riau *p* 40
Riau Archipelago *i* 43
Seram *i* 78
Siberut *i* 42
Simeuluë *i* 37
Singkep *i* 45
South-East Sulawesi *p* 65
South Kalimantan *p* 59
South Sulawesi *p* 64
South Sumatra *p* 48
Sula Islands *i* 76
Sumba *i* 70
Sumbawa *i* 69
Talaud Islands *i* 61
Tanimbar Islands *i* 81
Timor *i* 72
West Daya Islands *i* 80
West Java *p* 52
West Kalimantan *p* 57
West Sumatra *p* 41
Yogyakarta *p* 54

PAPUA NEW GUINEA
Bougainville Island *i* 87
D'Entrecasteaux Islands *i* 88
Louisiade Archipelago *i* 89
New Britain *i* 86
Papua *r* 85