PROTA

Vegetable oils

Plant Resources of Tropical Africa 14

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Plant Resources of Tropical Africa 14

Vegetable oils

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Introduction

Choice of species

PROTA 14: 'Vegetable oils' describes the cultivated and wild plant species of tropical Africa which yield oils or fats, collectively called vegetable oils in this volume. They are water-insoluble substances, consisting of mixtures of triglycerides of fatty acids and also containing small amounts of other compounds, such as sterols and tocopherols, which are antioxidants and play important roles in biological processes. Oils are liquid and fats are solid or semi-solid at temperatures of 18–24°C.
Vegetable oils are important in human nutrition, providing energy, essential fatty acids and lipophilic vitamins. Traditional non-food applications are soap, lamp oil and lubricants. About 15% of all vegetable oils are used for the manufacture of various industrial and technical products. Vegetable oils constitute about 80% of the world's natural oils and fat supply, the remainder is of animal origin.
PROTA normally assigns a single primary use and, where relevant, one or more secondary uses to all plant species used in Africa. PROTA 14: 'Vegetable oils' comprises only accounts of species of which oil is the main product. Cocos palm (*Cocos nucifera* L.) is primarily used as an oil crop, and thus it is treated in PROTA 14, but it has many secondary uses, e.g. the leaves are used for thatching and making baskets, the shell of the coconut is made into utensils or activated carbon, 'coconut water' from young fruits and the sap exuding from the cut-off stalk of the inflorescence are refreshing drinks. Cotton (*Gossypium* spp.) is the main example of a crop that is an important source of oil, but it is primarily a fibre crop and is treated in PROTA 16: 'Fibres'.
Species of which the oil is used in tropical Africa but have another primary use are listed after the primary use vegetable oil species, and are fully described in other commodity groups. Some other well-known species included in this list are: *Anacardium occidentale* L. (cashew nut), *Dacryodes edulis* (G.Don) H.J.Lam (butter fruit tree), *Persea americana* Mill. (avocado) and *Zea mays* L. (maize).
Six species are treated which have two primary uses, including use as oil plant, and consequently will be described in two commodity groups. These species are: *Arachis hypogaea* L. and *Glycine max* (L.) Merr. (also treated in PROTA 1: 'Cereals and pulses'), *Brassica carinata* A.Braun and *Brassica juncea* (L.) Czern. & Coss. (also in PROTA 2: 'Vegetables'), *Ongokea gore* (Hua) Pierre (also in PROTA 7: 'Timbers') and *Jatropha curcas* L. (also in PROTA 11: 'Medicinal plants').
In PROTA 14: 'Vegetable oils' comprehensive descriptions are given of 40 important species. These major oil plants comprise most cultivated species, but also several wild or partly domesticated ones. The accounts are presented in a detailed format and illustrated with a line drawing and a distribution map. In addition, accounts of 8 species of minor importance are given. Because information on these species is often scanty, these accounts are in a simplified format. For another 17 species the information was too scarce to justify an individual treatment and they have only been mentioned in the accounts of related species.

Plant names

Family: Apart from the classic family name, the family name in accordance with the Angiosperm Phylogeny Group (APG) classification is also given where it differs from the classic name.
Synonyms: Only the most commonly used synonyms and those that may cause confusion are mentioned.
Vernacular names: Only names in official languages of regional importance in Africa are included: English, French, Portuguese and Swahili. It is beyond the scope of PROTA to give an extensive account of the names of a species in all languages spoken in its area of distribution. Checking names would require extensive fieldwork by specialists. Although regional forms of Arabic are spoken in several countries in Africa, the number of African plant species that have a name in written, classical Arabic is limited. Arabic names are therefore omitted. Names of plant products are mentioned under the heading 'Uses'.

Origin and geographic distribution

To avoid long lists of countries in the text, a distribution map is added for major species. The map indicates in which countries a species has been recorded, either wild or planted. For many species, however, these maps are incomplete because they are prepared on the basis of published information, the quantity and quality of which varies greatly from species to species. This is especially the case for wild species which are not or incompletely covered by the regional African floras, and for cultivated species which are only planted on a small scale (e.g. in home gardens). For some countries (e.g. Central African Republic, Chad, Sudan, Angola) there is comparatively little information in the literature. Sometimes they are not covered by recent regional or national floras and although species may be present there, this cannot be demonstrated or confirmed.

Properties

The oil content of the produce is given together with the fatty acid composition of the oil. The fatty acids are grouped as saturated and unsaturated fatty acids, and are listed in accordance with the length of the carbon chain. More complex fatty acids are described in some detail. They include fatty acids with epoxy, hydroxy, phenyl or oxy-groups. These are poisonous, but are important source materials in the chemical industry. Other chemical compounds characteristic of oils, including sterols and tocopherols, are also mentioned.
The most common fatty acids are:

C6:0	caproic acid	9-C16:1	palmitoleic acid
C8:0	caprylic acid	9-C18:1	oleic acid
C10:0	capric acid	9,12-C18:2	linoleic acid
C12:0	lauric acid	9,12,15-C18:3	linolenic acid
C14:0	myristic acid	9,11,13-C18:3	bolekic acid
C16:0	palmitic acid	9,11,13-C18:3	eleostearic acid (trans bonds)
C18:0	stearic acid	C20:1	eicosenoic acid
C20:0	arachidic acid	13-C22:1	erucic acid

C22:0	behenic acid	12-OH,9-C18:1	ricinoleic acid
C24:0	lignoceric acid		

The fatty acid composition of an oil largely determines its physical characteristics. Physical characteristics are only given where relevant.
Where applicable, other aspects of the food value of plants are mentioned. The analytical method used to determine the various elements of the nutritional composition considerably influences the values found. For this reason a few standard sources were used wherever possible and the sources are mentioned in the text. These sources are: the USDA Nutrient database for standard reference; McCance & Widdowson's The composition of foods; FAO Food composition table for use in Africa.

Description

A morphological characterization of the species is given. The description is in 'telegram' style and uses botanical terms. Providing a description for the general public is difficult as more generally understood terms often lack the accuracy required in a botanical description. A line drawing is added for all major species to complement and visualize the description.

Management

Descriptions of husbandry methods including fertilizer application, irrigation, and pest and disease control measures are given under 'Management' and under 'Diseases and pests'. These reflect actual practices or generalized recommendations, opting for a broad overview but without detailed recommendations adapted to the widely varying local conditions encountered by farmers. Recommendations on chemical control of pests and diseases are merely indicative and local regulations should be given precedence. PROTA will participate in the preparation of derived materials for extension and education, for which the texts in this volume provide a basis, but to which specific local information will be added.

Genetic resources

The genetic diversity of many plant species in Africa is being eroded, sometimes at an alarming rate, as a consequence of habitat destruction and overexploitation. The replacement of landraces of cultivated species by modern cultivars is another cause of genetic erosion. Reviews are given of possible threats for plant species and of the diversity within species and reference is made to the IUCN red list of threatened species where relevant. Information on ex-situ germplasm collections is mostly extracted from publications of Bioversity International (formerly the International Plant Genetic Resources Institute - IPGRI).

References

The main objective of the list of references given is to guide readers to additional information; it is not intended to be complete or exhaustive. Authors and editors have selected two categories of references; 'major references' are limited to 10 references (5 for minor species), the number of 'other references' is limited to 20 (10 for minor species). The references listed include those used in writing the account. Where the internet was used, the website and date are cited.

Alphabetical treatment of vegetable oils

ADANSONIA GRANDIDIERI Baill.

Protologue Grandid., Hist. phys. Madagascar pl. 79Bbis 2, 79E 1 (1893).

Family Bombacaceae (APG: Malvaceae)

Chromosome number $2n$ = 60–64, 88

Vernacular names Grandidier's baobab, giant baobab (En). Baobab malgache (Fr).

Origin and geographic distribution *Adansonia grandidieri* is endemic to south-western Madagascar, from just north of Morondava to just north of Morombe.

Uses *Adansonia grandidieri* is locally called 'renala' or 'reniala', meaning 'mother of the forest' and is the most valuable and most widely exploited of all Malagasy baobabs. The fruit pulp and seeds are eaten fresh. Cooking oil is extracted from the seeds, and in some villages near Morondava the fruits are fed to goats, which digest the pulp but pass the seeds intact. The seeds are then used for oil extraction. Rope is made out of the thick (up to 15 cm) and fibrous bark, particularly for use in canoes. The undried spongy and fibrous wood is sometimes fed to cattle in times of drought; dried sheets of wood have been used as thatch. Wood of dead trees is a substrate for an edible fungus. The spectacular trees play a role in local folklore and religion.

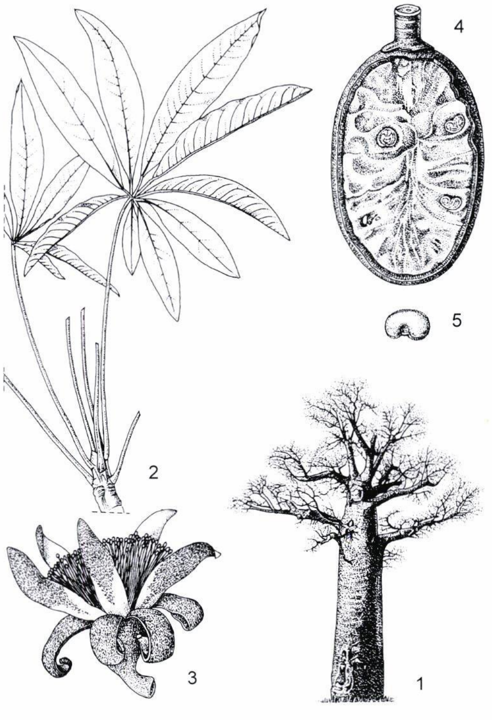
Production and international trade There is no international trade in the oil extracted from *Adansonia grandidieri*, but the oil is of good quality and export has been considered. During the late 19th century and early 20th century, seeds were exported to Marseille (France) for the extraction of cooking oil, but low and erratic supply prevented further commercialization. At that time the fruit was exported to England to make small dry tea cakes.

Adansonia grandidieri – wild

Properties Seed oil content is 36–39%. The fatty acid composition of the oil is: palmitic acid 38%, stearic acid 4%, oleic acid 23% and linoleic acid 16%. The oil also contains the rare fatty acids: malvalic acid 7%, sterculic acid 8%, and dihydrosterculic acid 2%.

Description Deciduous, medium-sized, unarmed tree up to 25 m tall; bole massive, cylindrical, up to 3 m in diameter; outer bark smooth, reddish grey, inner bark thick, with tough fibres; crown flat-topped; branches regularly distributed, mainly horizontal. Leaves arranged spirally, palmately compound, with (6–)9–11 leaflets; stipules up to 2 mm long, caducous; petiole 5–13 cm long, pubescent; petiolules 1–5 mm long; leaflets narrowly elliptical to lanceolate, medial ones 6–12 cm × 1.5–3 cm, margin entire, bluish green, densely hairy with short, clumped, yellowish hairs. Flowers solitary in leaf axils at end of branches, bisexual, regular, 5-merous, large, showy and fragrant; flower bud erect, ovoid, dark brown; pedicel up to 1.5 cm long and 1 cm in diameter, dark brown hairy, jointed; calyx with tube c. 1 cm long, lobes 7.5–8.5 cm × 1.5–2 cm, reflexed, and twisted, reddish brown hairy outside, creamy hairy inside; petals free, narrowly lanceolate to oblanceolate, 9–10 cm × 1.7–2 cm, twisted, white, yellowing with age; stamens numerous, shortly fused at the base, up to 7.5 cm long, white; ovary superior, broadly rounded-conical, c. 1 cm long, lemon-yellow hairy, style longer than central stamens, white, persistent, stigma shortly lobed, white to pinkish. Fruit a large, oblong-ovoid to almost globose berry, with fragile, 2.5–4 mm thick wall, reddish brown hairy, many-seeded. Seeds kidney-shaped, 12–14 mm × 10–12 mm × 9–10 mm. Seedling with hypogeal germination; first 4–5 leaves simple, later ones lobed and finally compound.

Other botanical information *Adansonia* comprises 8 species, of which 6 are endemic to Madagascar, 1 occurs in continental Africa and is introduced in Madagascar, and 1 is endemic to Australia. *Adansonia grandidieri* is classified in section *Brevitubae* together with its nearest relative *Adansonia suarezensis* H.Perrier, an endangered species from the extreme north of Madagascar. The seeds of the latter species are equally rich in oil and fruit and seeds are eaten, while a bark infusion is taken to treat diabetes. Unique characteristics of *Adansonia grandidieri* are bluish green and densely stellate-pubescent leaves and a dark brown floral bud.



Adansonia grandidieri – 1, tree habit; 2, part of branch with leaves; 3, flower; 4, fruit in longitudinal section; 5, seed.
Redrawn and adapted by Achmad Satiri Nurhaman

Growth and development Taking into account its dry habitat, early growth of *Adansonia grandidieri* is fast; it can reach 2 m in height in 2 years and 12–15 m, with a bole diameter of 60 cm in 12 years. It produces new leaves at the very beginning of the rainy season and uses water stored in the trunk to support new leaf growth and cuticular transpiration, but stomata remain closed until the roots can supply sufficient water. It is in leaf throughout the wet season from October to May. It flowers in May–August and fruit ripens at the end of the dry season in November–December. Flowers are produced at the tips of leafless branches. They open around dusk and anthesis takes 15 minutes. The open tube of the cuplike calyx can accumulate about 2 ml of nectar, and flowers are frequently visited by fruit bats and fork-marked lemurs, which are probably responsible for pollination.

Ecology *Adansonia grandidieri* is found largely in dry deciduous forest at low altitudes, where it commonly occurs close to waterholes and rivers. Most mature trees are now found in degraded agricultural land.

Propagation and planting Propagation by seed is straightforward. Seeds weigh approximately 1.4 g.

Harvesting Fruits are collected from the ground or picked from the tree using steps made from wooden pegs hammered into the trunk. To get bark for rope-making, the bark is cut from ground level up to about 2 m high. The scar persists but new bark regenerates over the damaged parts. In some areas, most trees show such scars.
To obtain wood for use in thatching, trees are felled and sheets of fibrous wood are peeled from the bole. After drying them in the sun, the sheets are sold in local markets.

Genetic resources *Adansonia grandidieri* occurs in reduced and scattered populations. It is threatened by the loss of a significant proportion of mature trees (20% or more), poor regeneration and continuing pressure from man. The trees are now found mainly in degraded forests and agricultural lands. In certain locations, where the larger and fitter individuals have been harvested, genetic decline or loss of fitness of the population is present. Fire, seed predation, cultivation of crops and competition from weeds all contribute to poor regeneration. Incursions of invasive species and changes in native species dynamics are further altering the population ecology. The IUCN carried out an assessment of *Adansonia grandidieri* in 1998 and classified it as Endangered in the Red List of Threatened Species, indicating that it faces a high risk of extinction in the wild in the near future. Rates of decline in distribution and occupancy over the last 10 years have been in the order of 50%.

Prospects Because of the endangered status of *Adansonia grandidieri*, possibilities of planting trees in plantations or as landmarks, as e.g. the kapok tree (*Ceiba pentandra* (L.) Gaertn.) in East Africa, should be investigated.

Major References Baum, 1995a; Baum, 1995b; Baum, 1996; Baum & Oginuma, 1994; Bianchini et al., 1982; Perrier de la Bâthie, 1952b; Perrier de la Bâthie, 1953; Ralaimanarivo, Gaydou & Bianchini, 1982.

Other references Baker & Baker, 1968; Keraudren, 1963; Mangenot & Mangenot, 1962; Miège, 1974; Rey, 1912; M.M.P.N.D., undated; World Conservation Monitoring Centre, 1998.

Sources of illustration Baillon, 1889; Hochreutiner & Perrier de la Bâthie, 1955.

Authors B. Ambrose-Oji & N. Mughogho

ADANSONIA RUBROSTIPA Jum. & H.Perrier

Protologue Matières Grasses 1308 (1909).
Family Bombacaceae (APG: Malvaceae)
Chromosome number $2n = 72, 88$
Synonyms *Adansonia fony* Baill. ex H.Perrier (1952).

Vernacular names Fony baobab (En). Baobab de Madagascar, petit baobab de Madagascar (Fr).

Origin and geographic distribution *Adansonia rubrostipa* is endemic to Madagascar, where it is found along the west coast from Itampolo in the south to Soalala in the north.

Uses The tree is used only occasionally. The fruits, oil-rich seeds and roots are edible, and fruits are sometimes sold in the local market. Sheets of wood of trees killed by fire are dried and used as thatch. A popular edible fungus grows on the trunks of dead trees.

Properties Seed oil content is 11%. The fatty acid composition of the oil is: palmitic acid 30%, stearic acid 2%, oleic acid 30% and linoleic acid 23%. In addition, the oil contains the rare fatty acids malvalic acid 5%, sterculic acid 2%, and dihydrosterculic acid 3%.

Botany Small to medium-sized tree up to 20 m tall; bole cylindrical or bottle-shaped, with distinct constrictions beneath the branches; outer bark usually reddish brown, exfoliating; crown irregular; branches horizontal, erect distally. Leaves arranged spirally, palmately compound, with 3–5 leaflets; stipules caducous; petiole thin and tapering, 3–7 cm long, glabrous; leaflets sessile, elliptical, medial one 4–6(–8) cm × 1–2 cm, margins toothed. Flowers solitary in leaf axils at end of branches, bisexual, regular, 5-merous, large, showy and fragrant; flower bud horizontal, cylindrical, 16–28 cm long; pedicel 1–2.5 cm long, green; calyx with short tube, lobes linear, 15–25 cm × 7–12 mm, reflexed and tightly twisted at base, almost glabrous, yellowish green with faint reddish stripes outside, bright red and sparsely hairy inside; petals free, linear with broadened, overlapping bases, 12–16 cm × 1.5–2.5 cm, bright yellow to orange-yellow; stamens numerous, longer than corolla, fused into a cylindrical tube 6–10 cm long; ovary superior, broadly rounded-conical, c. 7.5 mm long, golden hairy, style 20–25 cm long, pink, hairy at base, fitting tightly in staminal tube, stigma with 5–8 irregular, spreading lobes, red, blackening with age. Fruit a large, globose berry with woody, 4–5 mm thick wall, densely reddish brown hairy, many-seeded. Seeds kidney-shaped, laterally flattened, up to 16 mm × 12 mm × 8 mm. Seedling with hypogeal germination.

The tree is in leaf from November to April and flowers from February to April, rarely up to June. Fruit ripens in October–November.

Adansonia comprises 8 species, of which 6 are endemic to Madagascar, 1 occurs in continental Africa and is introduced in Madagascar, and 1 is endemic to Australia. *Adansonia rubrostipa* has been classified in the section *Longitubae*, together with *Adansonia gibbosa* (A.Cunn.) Guymer ex D.A.Baum from Australia and 2 species from Madagascar : *Adansonia madagascariensis* Baill. and *Adansonia za* Baill. Unique characters of *Adansonia rubrostipa* are leaflets with toothed margins and a central bundle of filaments fused beyond the top of the staminal tube.

Ecology *Adansonia rubrostipa* is a locally dominant tree species in the deciduous forests of western Madagascar. It occurs in spiny and dry forest and in sublittoral scrub, up to 500 m altitude. It normally grows on well-drained calcareous soils and limestone.

Management Germination can be erratic, either occurring quickly with a good germination rate, or taking longer with a poorer rate. Germination depends on the temperature and humidity of the soil, and on other parameters which are not well understood. *Adansonia rubrostipa* is fairly resistant to insect pests that attack other *Adansonia* spp. Fruits are collected by climbing the trees with the aid of wooden pegs hammered into the trunk.

Genetic resources and breeding In the IUCN Red List of Threatened Species *Adansonia rubrostipa* is classified as a 'near threatened' species that is close to being classified as 'vulnerable' in the wild. The main threats come from continuing deforestation. The populations to the north of Toliara are especially at risk.

Prospects The fruits and seeds of *Adansonia rubrostipa* are likely to remain of little importance. Felling of the trees should be discouraged to ensure the survival of the species.

Major references Baum, 1995a; Baum, 1995b; Baum, 1996; Perrier de la Bâthie, 1953; Ralaimanarivo, Gaydou & Bianchini, 1982.

Other references Bianchini et al., 1982; Baum & Oginuma, 1994; Du Puy, 1996; Mangenot & Mangenot, 1962; Miège, 1974; Salak, 2001.

Authors B. Ambrose-Oji & N. Mughogho

ADANSONIA ZA Baill.

Protologue Bull. Mens. Soc. Linn. Paris 2: 844 (1890).

Family Bombacaceae (APG: Malvaceae)

Chromosome number $2n = 48, 88$

Synonyms *Adansonia alba* Jum. & H.Perrier (1909), *Adansonia bozy* Jum. & H.Perrier (1910).

Vernacular names Za baobab, baobab (En). Baobab de Madagascar (Fr).

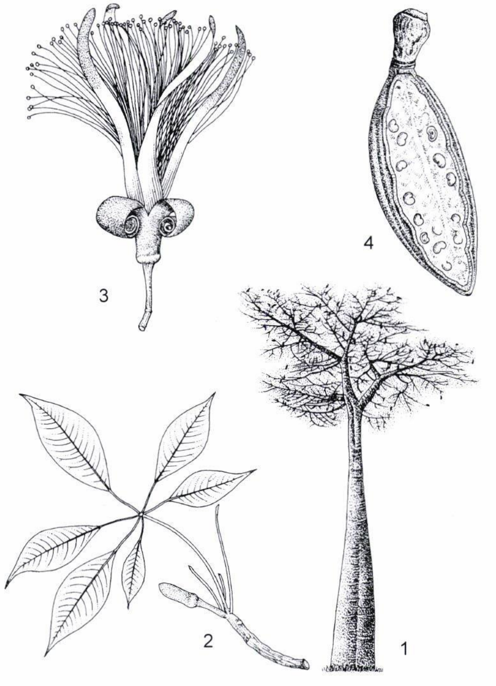
Origin and geographic distribution *Adansonia za* is endemic to Madagascar, where it occurs throughout the northern, western and southern parts.

Uses The fruit pulp and oil-rich seeds are eaten, as well as the seedling roots. The fruit pulp has a pleasant acidic taste. Moist wood from newly felled trees is fed to cattle in times of scarcity. The trunk is sometimes hollowed out to make a cistern for storing water. The bark fibre is used for making cloth and cordage. The flowers are used in medicine to treat a sore throat.

Properties Seeds contain 11% oil. The fatty acid composition of the oil is: palmitic acid 27%, stearic acid 3%, oleic acid 30%, linoleic acid 23%. The oil also contains the rare fatty acids malvalic acid 7%, sterculic acid 8% and dihydrosterculic acid 2%.

Description Deciduous, medium-sized tree up to 30 m tall; bole cylindrical or slightly tapering with irregular swellings, up to 3 m in diameter; outer bark more or less smooth, grey; crown rounded; main branches often tapering and ascending. Leaves arranged spirally, palmately compound with 5–8 leaflets; stipules caducous; petiole 5–15 cm long; petiolules 0–3

Adansonia za – wild



Adansonia za – 1, tree habit; 2, part of branch with leaf and flower bud; 3, flower; 4, fruit in longitudinal section.
Redrawn and adapted by Achmad Satiri Nurhaman

cm long; leaflets broadly elliptical to lanceolate, medial ones up to 20 cm × 8 cm, margins entire, glabrous or sometimes rough, with 10–20(–many) pairs of lateral veins. Flowers solitary in leaf axils at end of branches, bisexual, regular, 5-merous, large, showy, fragrant; flower bud erect to horizontal, elongated to cylindrical, 15–24 cm × 1.5–2.5 cm; pedicel 2–3 cm long, jointed, green; calyx tubular, tube fitting tightly around the petal bases, with a marked annular swelling at base, c. 2 mm wide, lobes linear, 15–22 cm × 10–12 mm, reflexed and twisted, green and rough outside, dark red and hairy inside; petals free, linear, 14–24 cm × 1–1.5 cm, twisted, yellow; stamens numerous, fused at base into a cylindrical or tapering tube 4–6.5 cm long; ovary superior, conical to ovoid, densely hairy, style 16–22 cm long, dark red, glabrous densely hairy at base, usually fitting loosely in staminal tube and persistent in fruit, stigma 3–5 mm in diameter, irregularly lobed, red. Fruit an oblong to ovoid or globose berry 10–30 cm × 6–15 cm, with thick, woody, fibrous wall, ridged, blackish, many-seeded. Seeds kidney-shaped, laterally flattened, up to 12 mm × 11 mm × 8 mm; seed-coat hard. Seedling with hypogeal germination; first leaf simple, later leaves gradually becoming 3-foliolate and palmately compound.

Other botanical information *Adansonia* comprises 8 species, of which 6 are endemic to Madagascar, 1 occurs in continental Africa and is introduced in Madagascar, and 1 is endemic to Australia. *Adansonia za* is very similar to *Adansonia madagascariensis* Baill. and these two species cannot always be clearly distinguished. The latter is characterized by its usually red petals, non-persisting style and broader fruit. It is restricted to northern and north-western Madagascar, where the fruits are rarely used as food. The swollen roots of seedlings are eaten more commonly. *Adansonia perrieri* Capuron is another species of northern Madagascar, where it is rare and endangered. Its fruit pulp is edible.

Within *Adansonia za* there is some variation between the south and the north of the distribution range; southern specimens have distinctly stalked leaflets and fruits with swollen peduncles, whereas towards the north the leaflets become sessile and larger, and the peduncles not swollen.

Growth and development Trees produce new leaves during the dry season and are in leaf throughout the wet season. They use water stored in the trunk to support new leaf growth and cuticular transpiration, but stomata remain closed until the rainy season. Trees flower in the early wet season from November to February, somewhat earlier in the north than in the south. Pollination is probably by *Coelonia* hawkmoths. Fruit ripens at the end of the dry season.

Ecology *Adansonia za* occurs in dry deciduous and spiny forest, savanna and scrubland up to 800 m altitude. It is a dominant species in some deciduous forests in southern Madagascar, but is less abundant in the northwest, where it is concentrated near rivers. On sandy soil or on limestone outcrops its growth becomes stunted.

Propagation and planting The germination rate of the seed is low, often not more than 10%. Mechanical scarification is needed to break seed dormancy caused by the hard seed-coat that is impermeable to water. Storage behaviour of the seed is orthodox.

Genetic resources Although the genetic health of *Adansonia za* may be secure because of its extensive geographical range, poor regeneration could threaten its longer-term survival. The species appears on the IUCN Red List of Threatened Species as a 'near threatened' species that is close to being classified as 'vulnerable' in the wild. The main threats come from forest clearance and poor natural regeneration.

Prospects *Adansonia za* is likely to remain of limited use, although the seedling roots may become popular as a food, as has been suggested for the young roots of the Australian *Adansonia gibbosa* (A.Cunn.) Guymer ex D.A.Baum.

Major references Baum, 1995a; Baum, 1995b; Baum, 1996; Baum & Oginuma, 1994; Bianchini et al., 1982; Chapotin, Razanameharizaka & Holbrook, 2006; Perrier de la Bâthie, 1953; Ralaimanarivo, Gaydou & Bianchini, 1982.

Other references Bihrmann, undated; Du Puy, 1996; Jumelle & Perrier de la Bâthie, 1909; Jumelle & Perrier de la Bâthie, 1910; Miège, 1974; Neuwinger, 2000; Perrier de la Bâthie, 1952a; Perrier de la Bâthie, 1952b; Razanameharizaka et al., 2006; Wickens, 1982.

Sources of illustration Baillon, 1889; Hochreutiner & Perrier de la Bâthie, 1955.

Authors B. Ambrose-Oji & N. Mughogho

AFROLICANIA ELAEOSPERMA Mildbr.

Protologue Notizbl. Bot. Gart. Berlin-Dahlem 7: 483 (1921).

Family Chrysobalanaceae

Chromosome number $2n = 22$

Synonyms *Licania elaeosperma* (Mildbr.) Prance & F.White (1976).

Vernacular names Po-yok, mahogany nut, nikko (En). Po-yok (Fr).

Origin and geographic distribution *Afrolicania elaeosperma* occurs from Guinea and Sierra Leone to the Central African Republic, Gabon and Congo.

Uses The seed oil is used as a hair oil and body scent. It was formerly used as a substitute for linseed oil in paints and varnishes, and as a poor substitute for tung oil.

Production and international trade There is some export of the oil, e.g. from Ghana, but amounts involved are not known.

Properties The stones from the fruits weigh about 9.5 g of which 58–67% is kernel. The kernels contain 40–58% oil. The fatty acid composition of the oil is: saturated fatty acids 13%, mono-unsaturated fatty acids 9%, licanic acid 44% and eleostearic acid 34%. Due to the high content of licanic acid (4-oxo-9,11,13-octadecatrienoic acid) and eleostearic acid, the oil is drying and solidifies rapidly into a varnish-like mass. The main commercial source of licanic acid is oiticica oil from *Licania rigida* Benth. from tropical America, which contains up to 80%. The presscake of *Afrolicania elaeosperma* remaining after oil extraction is not suitable as cattle feed.

Botany Small tree up to 15 m tall; bole irregular and with long, deep grooves, up to 50(–80) cm in diameter, with buttresses up to 2 m high; outer bark brown with greyish or greenish patches, slightly rough, inner bark dark red to pink-orange, granular; crown hemispherical, dense; branches glabrous when young. Leaves alternate, simple and entire; stipules linear, 3–6 mm long, long persistent, margins minutely toothed; petiole 0.5–1 cm long, grooved above, with 2 glands; blade elliptical, 7–16 cm × 3–8 cm, base cuneate, apex acuminate, leathery, glabrous on both surfaces when mature, pinnately veined with 7–10 pairs of lateral veins. Inflorescence a terminal or axillary panicle up to 25 cm long with flowers in groups of 2–3(–5), sparsely grey pubescent. Flowers bisexual or male, regular, c. 2 mm long; pedicel 1–2 mm long; receptacle flattened, pubescent outside; calyx lobes 5, triangular, grey pubescent; petals absent; stamens c. 20, free, short; ovary superior, c. 1 mm long, 1-celled, style c. 1 mm long. Fruit a dry, ovoid drupe c. 5 cm long, densely warty, golden brown, 1-seeded; endocarp thin, hard but brittle, hairy inside. Seed with thick, fleshy cotyledons. Seedling with hypogeal germination; first leaves alternate.

Afrolicania comprises a single species. It is closely related to *Licania* and has long been included in this genus as the sole African representative, but molecular and morphological evidence suggests that it is better separated.

Trees are slow to mature and 20–30-year old trees are known that still do not bear fruit. Fruits may be dispersed by water.

Ecology *Afrolicania elaeosperma* occurs in coastal and riverine primary and secondary forest in the Guineo-Congolian rainforest zone, sometimes on the land-side behind mangroves. In Cameroon it always occurs in seasonally flooded forest. It often grows on very poor sandy soils.

Management The fruits are collected from wild stands, often from the shore. In Sierra Leone they are collected in March–June. The stone of the fruit is brittle and the oily kernel is easily removed from it.

Genetic resources and breeding *Afrolicania elaeosperma* has a large distribution area and it is unlikely that it is threatened by genetic erosion, although it has a scattered distribution.

Prospects Although the oil has interesting chemical properties, it is unlikely that it will become more important as an industrial oil as the very long juvenile period of *Afrolicania elaeosperma* makes it uneconomical as a plantation species.

Major references Burkill, 1985; Letouzey & White, 1978; Prance & Sothers, 2003; Saville & Fox, 1967.

Other references Anonymous, 1942; Fauve, 1944; Kunkel, 1966; Lemée, 1959; Rheineck, 1937.

Authors L.P.A. Oyen

ALEURITES MOLUCCANA (L.) Willd.

Protologue Sp. pl. 4(1): 590 (1805).

Family Euphorbiaceae

Chromosome number $2n$ = 22, 24, 44

Vernacular names Candlenut tree, Indian walnut, lumbang tree, kukui nut (En). Bancoulier, noix des Indes, noix de bancoul, noix des Moluques (Fr). Noz da India, nogueira de Iguape, calumbàn (Po). Mkaa, mkaakaa (Sw).

Origin and geographic distribution Since ancient times *Aleurites moluccana* occurs from India and China, throughout South-East Asia, to Polynesia and New Zealand. It has also been introduced for cultivation in many tropical countries and has become the national tree of Hawaii. In Africa it is grown on a limited scale, e.g. in DR Congo, Tanzania, Uganda, the Comoros, Madagascar, and South Africa (KwaZulu-Natal and Mpumalanga).

Uses The fatty seed oil (kukui oil or lumbang oil) is not suitable for cooking, but is used in cosmetics, industrially (in paints, varnishes, linoleum, soap manufacture, wood preservation), for illumination (lamp oil, candles) and medicinally (mild purgative, embrocation for sciatica, against hair loss). In Indonesia the oil is used in the batik industry. For illumination, the oily kernels can be burnt as such, or pounded and made into candles. The seed of *Aleurites moluccana* is an indispensable spice in Indonesian cuisine, where it is known as 'kemiri'. It possesses little flavour of its own, but mainly acts as a flavour enhancer. It is added to numerous dishes in small quantities, raw, or briefly roasted, pounded and mixed with other ingredients. In Hawaii a spice called 'inamona' is prepared from the seeds mixed with seaweed and salt. Raw seed is slightly poisonous, acting as a laxative, but the seeds of a type in Vanuatu are eaten without any apparent toxic effect. In Indonesia the residual oil cake is sometimes processed into a snack-food called 'dage kemiri'. The presscake is an excellent organic fertilizer rich in N and P; it should be used with caution as animal feed because of its toxic effects.

Aleurites moluccana is commonly planted in villages and as roadside tree. Its silvery-green foliage makes it an attractive ornamental in landscaping. It is also used for reforestation and to suppress weeds. Where the wood is abundantly available it is used for carving and to make furniture, small utensils and matches. It is suitable for paper pulp.

In traditional medicine in Indonesia the seed is used as a laxative, pulped kernels are used in poultices to treat headache, fevers, ulcers, swollen joints and constipation, the bark is used to treat dysentery, the bark sap (mixed with coconut milk) to treat sprue, and boiled leaves are applied externally to treat headache and gonorrhoea. In Japan the bark is used to treat tumours.

The hardness of the stone of the fruit is exploited in a gambling game in which the objective is to break the opponent's stone by hitting it with one's own. In Indonesia a special cultivar is grown for this purpose. In Hawaii the shells of the stones are used in making traditional garlands ('leis'). In Polynesia dyes made from various parts of the tree were used on tapa cloth and canoes and in tattooing.

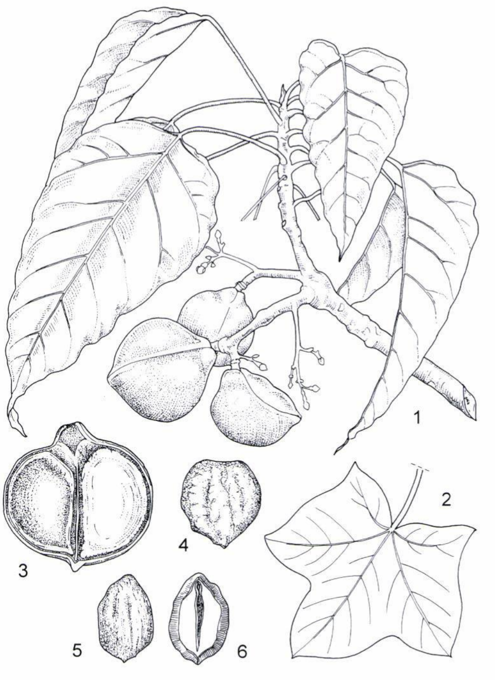
Production and international trade In Indonesia there is a considerable internal trade in candlenuts, mainly with Java as the destination. In the late 1980s, annual exports of candlenuts were in the order of 400–600 t with a total value of US$ 200,000–500,000. Candlenut is traded and transported as stones or 'nuts'. At the retail level, small quantities are marketed as seed (hard shell removed).

Properties The weight of the stone of the fruit is 10–14 g; it is made up of shell (65–70%) and seed (30–35%). Per 100 g edible portion, dry seed of *Aleurites moluccana* contains: water 5–8 g, protein 8–22 g, fat 60–62 g, carbohydrate 7–18 g, fibre 2–3 g, ash 3–4 g. The energy value is about 2675 kJ/100 g. Possessing very little flavour of its own, it seems that candlenut mainly acts as a flavour enhancer, making the taste buds temporarily more sensitive. The cold-pressed oil is pale yellow, with agreeable smell. When left to stand, it dries into a thin frosty film. The fatty acid composition of the oil is: palmitic acid 5–9%, stearic acid 2–7%, oleic acid 11–35%, linoleic acid 34–49%, linolenic acid 21–35%. The content of free fatty acids is generally very low. To improve the drying properties of the oil, it can be mixed with linseed oil and thermally polymerized (blown).

The moderate toxicity of the seed has been ascribed to a toxalbumin similar to the ones in *Abrus* and *Ricinus* spp. The wood is rather lightweight and not durable.

Adulterations and substitutes Kukui oil resembles linseed oil, but its qualities for the paint industry are poorer.

Description Large, evergreen, monoecious tree, up to 40 m tall; bole up to 1.5 m in diameter, bark grey, rather rough with lenticels; crown heavy, irregular, appearing whitish or frosted from a distance due to a cover of white stellate hairs especially on young parts. Leaves alternate, simple; stipules small, early caducous; petiole up to 30 cm long, bearing a pair of



Aleurites moluccana – 1, fruiting branch; 2, leaf of young tree; 3, fruit in longitudinal section; 4, stone in front view; 5, stone in side view; 6, stone in longitudinal section.
Source: PROSEA

small, green-brown glands at the top on the upper side; blade in young trees and suckers circular in outline, up to 30 cm in diameter, with a cordate base and 3–5 triangular lobes, blade in adult trees ovate-triangular or ovate-oblong, 12–23 cm × 6–12 cm, apex pointed, curved and drooping, margins entire or slightly sinuate, dark green with a silvery gloss, pinnately veined. Inflorescence a terminal or axillary panicle composed of cymes, 10–20 cm long. Flowers unisexual, female flowers terminating the ultimate branchlets of the cymes, male flowers much more numerous, smaller, arranged around the female flowers in bunches; calyx 2–3-lobed at anthesis, stellate hairy; petals 5, lanceolate, 6–7 mm long in male flowers, 9–10 mm in female ones, white; disk glands 5; male flowers with 10–20 stamens, arranged in 3–4 series, the outer ones free, the inner ones fused; female flowers with 2–4-celled, stellate hairy ovary and 2–4, deeply 2-lobed styles. Fruit a drupe, laterally compressed, ovoid-globose and with 2 stones or semiglobose and with 1 stone, 5–6 cm × 4–7 cm, stellate hairy, indehiscent, olive-green with whitish flesh; endocarp thick, bony, rough. Seeds compressed-globose, up to 3 cm × 3 cm; endosperm thick, rich in oil.

Other botanical information *Aleurites* is a small genus of 2 species. Formerly it was larger, but was divided into 3 genera: *Aleurites* comprising *Aleurites moluccana* and *Aleurites rockinghamensis* (Baill.) P.I. Forst., a rainforest tree from Australia and New Guinea, *Reutealis* comprising a single species, *Reutealis trisperma* (Blanco) Airy Shaw, endemic to the Philippines, and *Vernicia* comprising 3 species, all from Asia, but widely cultivated. All these species yield oil and have been confused in the past.

Growth and development *Aleurites moluccana* first flowers when it is about 4 years old. Flowering can occur year-round, and flowers and fruits of all stages of development may be present on a tree. Fruits need 3–4 months to develop and mature. Growth is moderately fast, up to 1.5 m/year in height under favourable conditions. In the Philippines trees reached a height of 12.5 m with a stem diameter of 15 cm 8 years after planting.

Ecology *Aleurites moluccana* occurs in tropical and subtropical regions with at least 700 mm rainfall and a dry season of not more than 5 months; in drier areas it depends on permanent streams or subsurface water. In more humid areas it is found on well-drained sands near the coast and on limestone, but it is also present naturalized in mixed and teak forests. It requires a mean maximum temperature of the hottest month 26–30°C, a mean minimum temperature of the coldest month 8–13°C.
It occurs on various soils that should be well drained, with pH 5–8. It tolerates strong winds and some salt spray, but is not tolerant of waterlogging, fire or frost lasting several days.

Propagation and planting Propagation of *Aleurites moluccana* is usually by seed. Fruits are left to decay for a few days before stones are extracted. The hard-shelled seeds retain their viability for over a year. The hard shell, however, is also the cause of uneven and often slow germination. Germination percentage is usually low (30–40%), but can be improved by scarification by mechanical, physical or chemical means. Repeated warming and cooling of the stones, as well as sun-warming in a moist medium, have been tried to improve germination. Acid treatment has been recommended, but other reports indicate that it does not improve germination. Cracking the stone speeds up germination but may lead to fungal infections. Direct seeding is also possible as the young trees compete well with weeds. There are 100–120 seeds/kg (with shell).
Seeds are sown in a seedbed or in polythene bags at a depth of 3–10 cm. In the field the planting distance is 7–10 m × 7–10 m when grown for seed, whereas closer spacings of 4 m × 4 m are applied if pulpwood is the main objective. In windbreaks trees can be planted 3–4 m apart.
Vegetative propagation, e.g. by cuttings or marcotting, seems possible, but may produce trees with excessive vegetative growth.

Management Established seedlings require little care. The leaves are renewed regularly, and old leaves left on the soil soon rot, enriching the soil with organic matter and nutrients. Trees coppice well, but regrowth is too slow to use them in hedgerows in agroforestry.

Diseases and pests A root-collar disease caused by *Ustulina deusta* has been observed on *Aleurites moluccana* in Indonesia. *Botryodiplodia theobromae* has been found to infest the wood, causing blue stain. No pests of economic importance occur.

Harvesting Fruits of *Aleurites moluccana* are allowed to fall and lie on the ground until the outer fruit wall has decayed, after which the stones are collected.

Yield Yield estimates of *Aleurites moluccana* vary from 2500–15,000 stones per tree per year, or 25–150 kg. This corresponds to 8–50 kg kernels per tree per year, or 5–30 kg oil per tree per year.

Handling after harvest Most commercially available oil is expeller pressed. Grinding the whole stones and pressing the oil gives a rather low oil yield and the oil cake is of less value as organic fertilizer, but extracting the seeds from the stones is difficult.
Traditionally, a combination of mechanical (hammering) and physical (successive heating and cooling) methods is applied to crack the stone of *Aleurites moluccana*. The best quality seeds for use as a spice are obtained by sun-drying the stones for 5–10 days, followed by mechanical cracking.
Stones may be stored for over a year without appreciable change in the amount and composition of the oil. Kernels cannot be stored for long, since they are attacked by beetles, and the oil acidifies.
To prepare the snack-food 'dage kemiri' the presscake is pounded, soaked for 48 hours in running water, steamed and then covered with a banana leaf with a weight on top of it to press out remaining liquid and left to ferment for 48 hours in a dark place.

Genetic resources A living collection of *Aleurites moluccana* is maintained by the Research Institute for Spice and Medicinal Crops (RISMC), Bogor, Indonesia.

Breeding No breeding programmes are known to exist for *Aleurites moluccana*.

Prospects The oil of the candlenut tree will continue to be used in cosmetics and may find wider use in applications that currently use imported linseed oil or petrochemicals. However, it is still doubtful whether this will be economically viable. In Indonesia the value of 'kemiri' as a spice is uncontested. The use of the wood in the paper industry might become feasible in the long term. In Africa *Aleurites moluccana* will probably remain of limited importance.

Major references Airy Shaw, 1966; Elevitch & Manner, 2006; Gaydou et al., 1982; Heine & Legère, 1995; Kabele Ngiefu, Paquot & Vieux, 1977; Katende, Birnie & Tengnäs, 1995; Radcliffe-Smith, 1987; Radcliffe-Smith, 1996; Siemonsma, 1999; Stuppy et al., 1999.

Other references Ako, Kong & Brown, 2005; Brown et al., 2005; Gaydou & Ramanoelina, 1983; Hadad & Mansur, 1992; Poteet, 2006; Semangun, 1988; Tapa Darma, 1993; World Agroforestry Centre, undated.

Sources of illustration Siemonsma, 1999.

Authors L.P.A. Oyen
Based on PROSEA 13: Spices.

ALLANBLACKIA FLORIBUNDA Oliv.

Protologue Fl. trop. Afr. 1: 163 (1868).
Family Clusiaceae (Guttiferae)
Vernacular names Vegetable tallow tree (En). Bouandjo, ouotéra (Fr). Kionzo (Po).

Origin and geographic distribution *Allanblackia floribunda* occurs in the rainforest zone from Nigeria east to the Central African Republic and eastern DR Congo, and south to northern Angola; there is one old herbarium specimen collected in Benin.

Uses The fat obtained from the seed, known as 'allanblackia fat' or 'beurre de bouandjo' in Congo, is used in food preparation. Recently, the international food industry has become interested in the fat as a natural solid component for margarines and similar products. The seeds are eaten in times of food scarcity and are also used as bait in traps for small game. The fruit's slimy pulp can be made into jams and jellies. The wood is locally used, but is of secondary importance. In Nigeria it is used in construction of local houses. Twigs have been used as candlesticks. In Gabon a decoction of the inner bark is taken to treat dysentery and as a mouthwash to treat toothache, in Congo to treat stomach-ache. In DR Congo a decoction of the bark or leaves is taken to treat asthma, bronchitis and cough. Sap squeezed from the bark is a component of a medicine used to treat urethral discharge. Small twigs are used as chew-sticks or toothpicks.

Production and international trade Tradi-

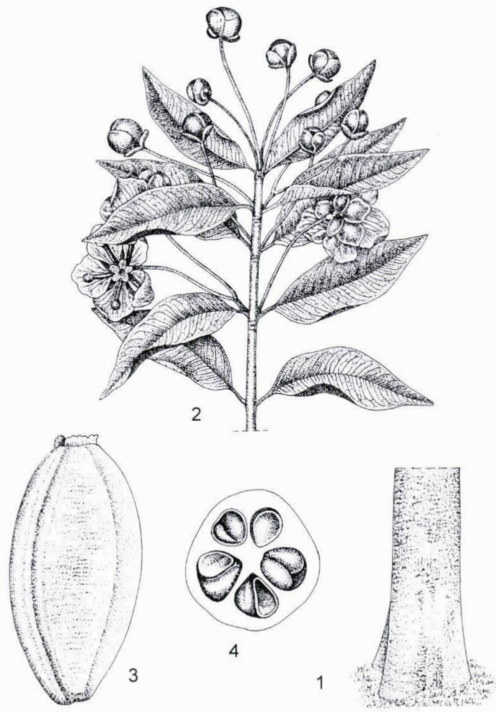
Allanblackia floribunda – wild

tionally, the seeds and fat are marketed on a small scale in local markets, e.g. in Cameroon. Currently, an international market chain for the seed and fat of *Allanblackia floribunda* is being established in Nigeria. It is estimated that Nigeria produced about 50 t of allanblackia oil in 2006.
The wood is nowhere important as timber, although the tree is locally common.

Properties The seeds contain a fat that is solid at ambient temperatures. The kernel, which makes up about 60% of the seed, contains about 72% fat. The fatty acid composition of the fat is approximately: stearic acid 45–58% and oleic acid 40–51%. Only traces of other fatty acids are present. Its composition and relatively high melting point (35°C) makes the fat a valuable raw material that can be used without transformation to improve the consistency of margarines, cocoa butter substitutes and similar products.
The fairly hard heartwood of *Allanblackia floribunda* is pale red or brown and usually fairly distinctly demarcated from the thick, pinkish beige sapwood. The grain is fairly straight, texture medium to coarse. The wood has little lustre. The density is 860 kg/m^3 at 12% moisture content. At 12% moisture content, the modulus of rupture is 107 N/mm^2, modulus of elasticity 13,700 N/mm^2, compression parallel to grain 46 N/mm^2 and Chalais-Meudon side hardness 3.3. Dry wood saws well, but green wood may spring on conversion. It is fairly easy to work with hand and machine tools. It is fairly durable, and moderately resistant to termites.
A prenylated xanthone, named allanxanthone A, has been isolated from the bark, as well as 1,5-dihydroxyxanthone and 1,5,6-trihydroxy-3,7-dimethoxyxanthone. The compounds isolated showed moderate in-vitro cytotoxicity against the KB cancer cell line.

Adulterations and substitutes The fat from the seeds of *Allanblackia floribunda* is very similar in composition to that of *Allanblackia parviflora* A.Chev. and *Allanblackia stuhlmannii* (Engl.) Engl.

Description Evergreen, dioecious, medium-sized tree up to 30 m tall; bole fairly short, straight, cylindrical, without buttresses but sometimes basally thickened; bark surface reddish brown to blackish, with small irregular scales, inner bark granular, reddish or brown, exuding a little clear sap; branches numerous, whorled, horizontal, hollow, with longitudinal grooves, brownish black, glabrous. Leaves opposite, simple and entire; stipules absent; petiole c. 1 cm long, glabrous; blade elliptical to ovate, rarely obovate, 8–25 cm × 3–8 cm, base rounded or cuneate, apex acuminate, thinly leathery, glabrous and shiny, pinnately veined with numerous lateral veins. Inflorescence a terminal raceme or panicle with strongly reduced branches or flowers single or in pairs in leaf axils. Flowers unisexual, regular, 5-merous, pinkish or reddish, rarely white; pedicel 3–8 cm long; sepals orbicular, unequal, outer ones 5–8 mm in diameter, inner ones 12–15 mm in diameter, glabrous; petals obovate to orbicular, 20–25 mm long, glabrous; male flowers with numerous stamens in 5 bundles opposite the petals, 10–15 mm long, anthers arranged on the internal face of the bundle; disk star-shaped with deeply folded glands; female flowers with superior, incompletely 5-celled ovary and sessile stigma, staminal bundles reduced to a few free, 4–5 mm long staminodes, disk glands grooved. Fruit a large ellipsoid berry 20–50 cm × 5–14 cm, with 5 longitudinal



Allanblackia floribunda – 1, base of bole; 2, flowering twig; 3, fruit; 4, fruit in cross section showing seeds.
Redrawn and adapted by Achmad Satiri Nurhaman

ridges, 40–80-seeded. Seeds ovoid, 2.5–3 cm × 1.5–2 cm, enclosed in a pinkish aril; embryo small, embedded in oily endosperm. Seedling with hypogeal germination.

Other botanical information *Allanblackia* comprises about 10 species, and is restricted to tropical Africa. *Allanblackia parviflora* A.Chev. is sometimes included in *Allanblackia floribunda*. However, their areas of distribution are disjunct, the former occurring from Guinea and Sierra Leone to Ghana. *Allanblackia gabonensis* (Pellegr.) Bamps occurs in Cameroon and Gabon. The fat from its seeds, locally also called 'beurre de bouandjo', is used in cooking.

Growth and development Under natural conditions, trees start flowering after about 12 years. Flowering occurs during a large part of the year, in particular from January to September. Fruits take nearly a year to mature and ripe fruits are also found during a large part of the year. The fruits are eaten by wild pigs and porcupines, which may distribute the seeds.

Ecology *Allanblackia floribunda* is a common understorey tree of lowland closed evergreen rainforest and riverine forest, and also in secondary and swamp forest, up to 1000 m altitude. It is common on strongly leached, acid soils with pH 3.8–4.1. Estimates in Cameroon indicate that in very wet forest, densities of trees with a stem diameter of >10 cm are about 150 stems per km^2; estimates for similar areas in Nigeria are about 250 stems per km^2.

Propagation and planting Seeds are recalcitrant. Germination takes 6–18 months and germination rates are very low. Natural regeneration is affected by seed predation and collection. The weight of 100 seeds is about 1 kg. Keeping the fruits for a few months on damp sites (covered with banana leaves and buried partially) and scarification of the seedcoat improve germination rates only slightly. Methods of propagation by cuttings and grafting are being developed. When planting vegetatively propagated material, both male and female trees should be planted.

Management Efforts to domesticate *Allanblackia floribunda* are underway, but at present seed is only collected from wild stands or from trees retained on farm land. Trees are left on the farms when clearing the land for cultivation and managed especially for shading cocoa.

Diseases and pests The fruits and seeds are eaten by many wild animals and losses are great unless mature fruits are collected frequently. There have been observations of seed borers.

Harvesting The degree of maturity of fruits on the tree can not be estimated, so mature fruits are left to drop to the ground and are then collected. The harvesting season is long (from January to April) and in some places peaks coincide with labour demands on the farm or with the harvest season of other forest products. For individual groups of trees the fruiting season is shorter and preliminary work indicates that collection of fruits from wild stands can be economical.

Handling after harvest Fruits are stored under a cover of leaves to allow the fruit pulp to disintegrate. To extract the seeds, fruits are crushed between the hands and seeds are rubbed clean. For oil extraction, the seeds are dried well before they are taken to the buying centres, where trained personnel check the moisture content and weight, after which the seeds are ready for storage in gunny bags. To extract the fat, seeds are dried and crushed; the resulting mass is mixed with water and boiled until the fat separates and floats to the surface, from where it is scooped off. More modern hydraulic and screw press equipment is now also used.

Genetic resources *Allanblackia floribunda* occurs in a vast area and although rainforest areas are decreasing, it is not considered vulnerable. Collection of the seeds and wildlings may locally influence the natural regeneration.

Breeding Selection of high-yielding trees for seed collection and vegetative multiplication has started recently. Selection criteria include seed and fruit size and abundance, and tree size and structure.

Prospects If domestication efforts are successful, *Allanblackia floribunda* or one of the related large-fruited *Allanblackia* species may become a promising crop in the rainforest zone of Africa. Collection of seed from wild stands is possible, but its economical viability is poor, except possibly in areas where *Allanblackia floribunda* is most common.

Major references Bamps, 1969; Bamps, 1970; Eyog Matig et al. (Editeurs), 2006; Takahashi, 1978; World Agroforestry Centre, undated.

Other references Bolza & Keating, 1972; Heckel, 1902; Hendrickx, 2006; Menninger, 1977; Nkengfak et al., 2002; Normand & Paquis, 1976; Van Rompaey, 2003; Vivien & Fauré, 1988a; Wilks & Issembé, 2000.

Sources of illustration Thonner, 1915; Wilks & Issembé, 2000.

Authors C. Orwa & M. Munjuga

ALLANBLACKIA PARVIFLORA A.Chev.

Protologue Veg. Ut. Afr. Trop. Franc. 5: 163 (1909).

Family Clusiaceae (Guttiferae)

Chromosome number $2n = 56$

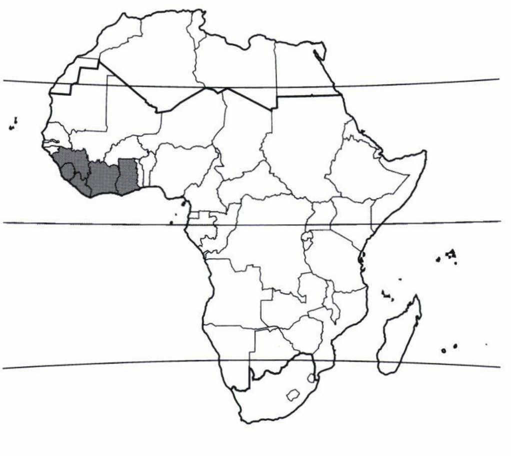
Vernacular names Vegetable tallow tree (En). Ouotéra (Fr).

Origin and geographic distribution *Allanblackia parviflora* occurs in the forest zone from Guinea and Sierra Leone to Ghana.

Uses The seeds of *Allanblackia parviflora* yield a solid fat used in cooking. Recently, the international food industry became interested in the fat as a natural solid component for margarines and similar products. The seeds are used as bait in traps for small game. In Ghana latex from the bark is used as pitch. The wood, called 'lacewood' in Liberia, is locally used, e.g. in house construction for walls, doors and window frames. In Ghana small trees are used as poles, pit props and bridge piles. The trees are often retained when land is cleared for cocoa production. Because of their relatively small crown, they are valued as shade trees. Small twigs are used as chew sticks or tooth picks. The pounded bark is rubbed on the body to relieve pain. In Côte d'Ivoire a decoction of the fruit pulp is used to relieve elephantiasis of the scrotum.

Production and international trade An international market chain for seed of *Allanblackia* spp., including that of *Allanblackia parviflora* is being established. It is estimated that Ghana produced about 50 t of allanblackia oil in 2006.

Properties The dry seeds contain per 100 g about: water 6 g, energy 2700 kJ (648 kcal), protein 4 g, fat 64 g, carbohydrate 24 g, fibre 3 g, Ca 122 mg, P 169 mg. The fatty acid composition of the fat is approximately: stearic acid 45–58% and oleic acid 40–51%. Only traces of other fatty acids are present. Its composition and relatively high melting point (35°C) makes the fat a valuable raw material that can be used without transformation to improve the consistency of margarines, cocoa butter substitutes and similar products.



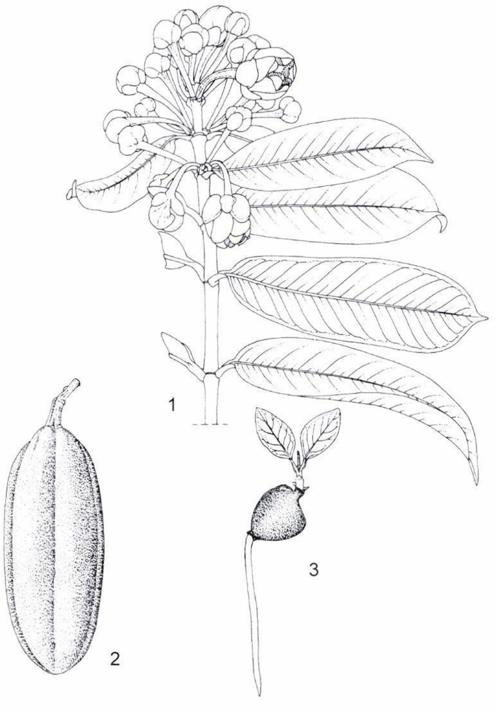
Allanblackia parviflora – wild

The wood of *Allanblackia parviflora* is pinkish beige. The grain is fairly straight, texture medium to coarse. The wood has little lustre.

The density is 660–900 kg/m³ at 12% moisture content. The rates of shrinkage during drying are moderately high: from green to oven dry 4.1% radial and 10.1% tangential. At 12% moisture content, the modulus of rupture is 103–140 N/mm², modulus of elasticity 6900–15,800 N/mm², compression parallel to grain 43–53 N/mm², cleavage 12–20 N/mm, Janka side hardness 9050 N and Janka end hardness 9500 N. The wood is easy to work and takes a smooth finish.

Adulterations and substitutes The fats from the seeds of *Allanblackia floribunda* Oliv. and *Allanblackia stuhlmannii* (Engl.) Engl. are very similar in composition to that of *Allanblackia parviflora*.

Description Evergreen, dioecious medium-sized tree up to 25(–33) m tall; bole straight, cylindrical, up to 80 cm in diameter, without buttresses; bark surface yellowish brown or reddish brown, with small, irregular scales, inner bark reddish brown with sometimes pale yellow streaks, exuding a colourless or pale yellowish sap; crown narrow, with short horizontal branches. Leaves opposite, simple and entire; stipules absent; petiole 1–1.5 cm long, grooved above; blade elliptical to narrowly obovate, 12–25 cm × 5–9 cm, base cuneate, apex acuminate, thinly leathery, glabrous, shiny above, pinnately veined with numerous lateral veins. Inflorescence a terminal raceme or panicle with strongly reduced branches or flowers single or in pairs in leaf axils. Flowers unisexual, regular, 5-merous, pinkish to reddish or white, fragrant; pedicel 1–3 cm long; sepals ovate or obovate, unequal, 6–18 mm × 4–15 mm, glabrous; petals obovate, c. 20 mm long, glabrous; male flowers with numerous stamens in 5 bundles opposite the petals, obtriangular, c. 18 mm long, anthers arranged on the internal face of the bundle, disk star-shaped with smooth or slightly folded glands; female flowers with superior, incompletely 5-



Allanblackia parviflora – 1, flowering twig; 2, fruit; 3, seedling.
Redrawn and adapted by Achmad Satiri Nurhaman

celled ovary and sessile stigma. Fruit a large, ellipsoid berry 10–50 cm × c. 15 cm, with 5 longitudinal ridges, brown warty, 40–100-seeded. Seeds ovoid, c. 3 cm × 2 cm × 1.5 cm, enclosed by a pinkish aril. Seedling with hypogeal germination; epicotyl 4–5 cm long.

Other botanical information *Allanblackia* comprises about 10 species and is restricted to tropical Africa. *Allanblackia parviflora* is sometimes considered a synonym of *Allanblackia floribunda* Oliv. However, their areas of distribution are disjunct, the latter occurring from Benin and Nigeria east to eastern DR Congo. The two species are very similar, but *Allanblackia floribunda* can be distinguished by the folded disk glands of the male flowers and longer pedicel.

Growth and development In Sierra Leone trees flower in April–June and fruits mature in January–February. In Côte d'Ivoire flowering is from December to September with a peak in March and mature fruits are found almost throughout the year. Branches are brittle and often break due to strong winds.

Ecology *Allanblackia parviflora* is most abundant in the wet evergreen forest zone, especially on slopes and away from disturbed areas. It is less common in semi-deciduous forest. It is common on strongly leached, acid soils with pH 3.8–4.1.

Propagation and planting Natural regeneration is affected by seed predation and collection. Multiplication by seed is difficult as germination is extremely slow and may take 24–30 months. Methods of multiplication using cuttings and grafting are being developed.

Management An inventory in the wet evergreen Mabi forest of Côte d'Ivoire found 150 trees per km^2 in the diameter class above 10 cm; in the very wet Yaya forest in south-eastern Côte d'Ivoire 600 trees per km^2 were recorded. In evergreen forest in Ghana it occurs at estimated densities of 200 trees of 30–80 cm bole diameter per km^2. The total number of trees in this class in Côte d'Ivoire was estimated at over 1 million (or 8 trees per ha), in Liberia the number was estimated at 4 million trees.

Efforts are underway to domesticate this species, but at present all seed is collected from wild stands or trees retained in farmland.

In production forest *Allanblackia parviflora* is considered a weed and sometimes eradicated.

Harvesting The degree of maturity of fruits on the tree can not be estimated; therefore mature fruits are left to drop to the ground and are then collected. The fruits and seeds are eaten by many wild animals and losses are great unless mature fruits are collected frequently. The harvesting season coincides with labour demands on the farm or with the harvest season for other forest products. For individual groups of trees the fruiting season is shorter and preliminary work indicates that collection of fruits from wild stands can be economical. A collection, marketing and processing chain aiming at export of the fat is being developed in Ghana.

Handling after harvest Fruits are stored under a cover of leaves to allow the fruit pulp to disintegrate. To extract the seeds, fruits are crushed between the hands and seeds are rubbed clean. To extract the fat, seeds are dried and crushed; the resulting mass is mixed with water and boiled until the fat separates and floats to the surface, from where it is scooped off. More modern hydraulic and screw press equipment is now also used.

Genetic resources *Allanblackia parviflora* is widespread and although rainforest areas are decreasing, it is not considered vulnerable.

Breeding Selection of high-yielding trees for seed collection and vegetative multiplication has started recently.

Prospects Demand for the fat of *Allanblackia* spp. is likely to remain strong. If efforts of domestication are successful, *Allanblackia parviflora* or one of the related large-fruited *Allanblackia* species may become a promising crop in the rainforest zone of Africa. Collection of seed from wild stands is possible, but its economical viability is poor, except possibly in areas where *Allanblackia parviflora* is most common.

Major references Aubréville, 1959b; Busson, 1965; de Koning, 1983; Irvine, 1961; Leung, Busson & Jardin, 1968; Saville & Fox, 1967; Van Rompaey, 2003; World Agroforestry Centre, undated.

Other references Bamps, 1969; de la Mensbruge, 1966; Ofori et al., 2006.

Sources of illustration Busson, 1965; de la Mensbruge, 1966.

Authors C. Orwa & L.P.A. Oyen

ALLANBLACKIA STUHLMANNII (Engl.) Engl.

Protologue Engl. & Prantl, Nat. Pflanzenfam. II–IV Nachtr. 1: 249 (1897).

Family Clusiaceae (Guttiferae)

Vernacular names Mkange, mkanye, mkimbo, mshambo, mwaka (Sw).

Origin and geographic distribution *Allanblackia stuhlmannii* is endemic to Tanzania, where it occurs in the Eastern Arc Mountains, extending through Iringa Region to the Southern Highlands.

Uses The seed yields an edible fat called 'allanblackia fat' or 'kanye butter'. It is used in cooking and has been used as a substitute for butter and cocoa butter, and to make candles. Recently, the international food industry has become interested in the fat as a natural solid component for margarines and similar products. The presscake is bitter and contains tannins, but is sometimes used as animal feed. The seeds are used as bait for small game. The wood is used for construction, cheap joinery, boxes, crates, beehives and water containers. It is also used as fuel. In traditional medicine, the leaves are chewed to treat cough, while the leaves, bark and roots are used to treat impotence. A seed extract is rubbed in to treat rheumatism. The fat is applied as a liniment on aching joints, wounds and rashes and small quantities are taken to treat rheumatism. Hehe people rub the fat mixed with pounded seeds of *Psorospermum febrifugum* Spach on deep cracks in the soles of the feet. The bark yields a yellow dye. Female trees of *Allanblackia stuhlmannii* are retained when land is cleared for cultivation and are possibly occasionally planted for shade in crops and for amenity. The fruit's slimy jelly-like pulp can be used in jam making.

Allanblackia stuhlmannii – wild

Production and international trade The seed and timber of *Allanblackia stuhlmannii* are of mainly local importance. The seeds were exported to Europe in the 1970s and 1980s for their fat. Recently, international demand for *Allanblackia* fat has increased sharply.

Properties Air-dried seeds contain about 50% fat. The fatty acid composition of the fat is remarkable as it consists mainly of stearic acid (45–58%) and oleic acid (40–51%). Only traces of other fatty acids are present. Its composition and resulting high melting point (35°C) makes the fat a valuable raw material that can be used without transformation to improve the consistency of margarines, cocoa butter substitutes and similar products. The approximate composition of the air-dried presscake is: water 13 g, protein 14 g, fat 7 g, carbohydrate 55 g, crude fibre 7 g, ash 8 g. The presscake is bitter and contains tannins and its suitability as cattle feed is limited.

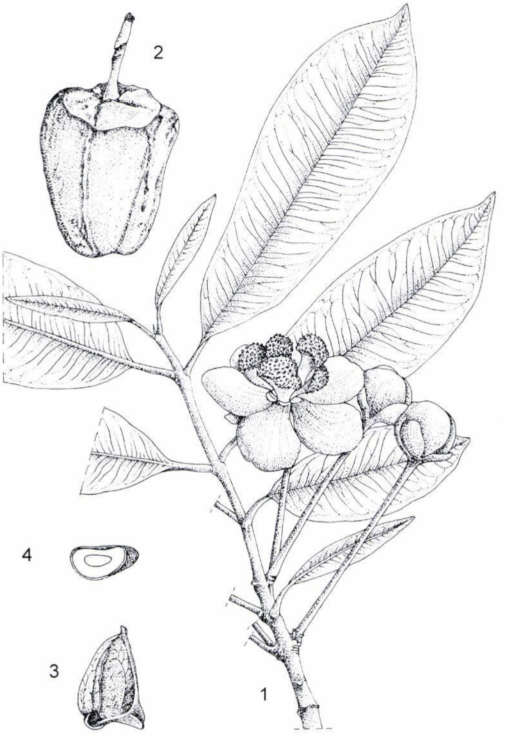
Trees of a size exploitable for timber have only a small heartwood core, a bole of 65 cm in diameter having a heartwood core of about 10 cm in diameter; the properties given below therefore refer to the sapwood. The sapwood is pale grey-brown with straight grain and medium texture. The density at 12% moisture content is about 690 kg/m^3. The heartwood is dark brown to purplish; at 10% moisture content its density is about 770 kg/m^3. The wood air dries slowly, with a moderate tendency to cup, but with little or no splitting. In kiln drying distortion is severe unless low temperatures are used. Boards of 2.5 cm thick air dry in 2 months, or kiln dry in about 12 days. Shrinkage from green to oven dry is 3.2% radial and 10.0% tangential. At 12% moisture content the modulus of rupture is 73–99 N/mm^2, modulus of elasticity 11,100–14,500 N/mm^2, compression parallel to grain 39–51 N/mm^2, compression perpendicular to grain 8 N/mm^2, shear 8–9.5 N/mm^2, cleavage 42 N/mm radial and 44 N/mm tangential, Janka side hardness 3900–5600 N and Janka end hardness 6600 N.

The wood is difficult to saw when green, but once dry it saws easily and machines well. It holds nails well. The sapwood is not durable, but is permeable to preservatives; the heartwood is very resistant.

From the wood of the roots of *Allanblackia stuhlmannii* guttiferone F, a prenylated benzophenone, was isolated. The compound is related to a group of compounds that has been investigated for its anti-HIV properties.

Adulterations and substitutes The fat from the seeds of *Allanblackia floribunda* Oliv. from Central Africa and *Allanblackia parviflora* A.Chev. from West Africa is very similar in composition to that of *Allanblackia stuhlmannii.*

Description Evergreen, dioecious, medium-sized to fairly large tree up to 35(–45) m tall; bole straight, cylindrical, slightly buttressed; bark surface smooth or rarely flaking with square scales, dark grey to black, inner bark red to pale brown with white stripes, fibrous to granular, exuding a clear sap later turning yellowish; branches drooping, hollow, longitudinally wrinkled. Leaves opposite, simple and entire; petiole 1–2 cm long; blade oblong to elliptical-oblong, 5–20 cm × 1–7 cm, base cuneate, apex shortly acuminate, leathery, dark green, pinnately veined with numerous lateral veins. Flowers solitary in leaf axils or crowded at the end of branches, unisexual, regular, 5-merous, cream to reddish, fragrant; pedicel (3.5–)6.5–8 cm long; sepals orbicular to ovate, unequal, outer ones 4–9 mm in diameter, inner ones c. 2 cm in diameter, pale yellow; petals orbicular to spatulate, 27–37 mm × 18–26 mm, glabrous; male flowers with numerous stamens grouped in 5 thick, fleshy bundles opposite the petals, c. 2 cm long, inner surface angled, anthers arranged on the 2 faces of the bundles; disk star-shaped; female flowers with superior, incompletely 5-celled ovary and sessile stigma, staminal bundles reduced to a few free, c. 4 mm long staminodes. Fruit a large oblong to globose or cone-shaped berry 16–34 cm × 15–17 cm, weighing 2.5–6 kg, red-brown, 60–140 seeded. Seeds 4-angular, c. 4 cm × 2–3 cm, one angle with a small fleshy aril; embryo small, embedded in oily endosperm. Seedling with hypogeal germination.



Allanblackia stuhlmannii – 1, twig with male flowers; 2, fruit; 3, seed; 4, seed in cross section. Redrawn and adapted by Achmad Satiri Nurhaman

Other botanical information *Allanblackia* comprises about 10 species and is restricted to tropical Africa. *Allanblackia ulugurensis* Engl. is endemic to Tanzania, where it occurs in the Udzungwa, Nguru and Uluguru Mountains, extending to Iringa Region, generally on steeper slopes and at higher altitudes than *Allanblackia stuhlmannii.* It is used for similar purposes.

Growth and development Under natural conditions, trees first flower when about 12 years old. Flowering is during the short rainy season in November–February. Pollination is done by short-tongued insects, birds and bats. Fruits take more than 1 year to develop and mature in January–March. Other reports indicate that in the Eastern Usambara Mountains fruits mature twice per year in November–March and August–October. Rodents and monkeys feed on the fruits and may disperse the seeds. Natural regeneration is currently not adequate to maintain stands.

Ecology *Allanblackia stuhlmannii* occurs on seaward slopes and valley bottoms of evergreen submontane and montane forest at 800–1200(–1600) m altitude. Average annual rainfall in its habitat is 1100–2400 mm with more than 180 rainy days. The mean annual temperature in the eastern Usambara Mountains is 18°C, maximum temperatures range from 25°C to 35°C; minima are occasionally as low as 3°C. It is found on mostly acidic clay soils derived from granite, gneiss or siliceous rock. The small isolated forest patches in the Udzungwa Mountains are drier than the rest of the habitat. *Allanblackia stuhlmannii* trees are fire-tolerant.

Propagation and planting *Allanblackia stuhlmannii* can be propagated by seed, but the seeds are recalcitrant. There are about 100 seeds per kg. Well-matured fruits are kept for about 2 weeks to allow the pulp to become soft and to make extraction of the seed easy. Fruits may be kept for up to 3 months if covered with banana leaves. Clean seeds are placed in a nursery where they take about 3 months to start to germinate, but germination may take more than 7 months to start and another 18 months to complete. The plant hormone GA_3 does not have any effect on the germination. After germination the seedlings are transferred to polythene tubes filled with soil. Mycorrhizae are necessary for successful growth of the seedlings and it is therefore important to add soil from around the base of mother trees to the substrate.

Because propagation by seed is difficult and because male and female trees are very difficult to distinguish until they flower, methods of vegetative propagation are being developed. Vegetative propagation is possible by cuttings, marcotting and grafting. Cuttings are placed a few cm deep in soil at a 45° angle in polythene tubes with at least 1 node above the substrate. Cuttings strike root in 8–12 weeks, after which sprouted and rooted cuttings are transferred to polybags. Methods of layering and budding are being developed. Initial tests with wildlings have shown good survival rates both with farmers and in experiments.

Management Female trees are often retained when clearing land for agriculture, but planting is still rare. It is estimated that 1 male tree per 10 female trees is needed to ensure adequate pollination. ICRAF, Kenya, is studying possibilities to domesticate this species and develop appropriate management techniques. A complete seed marketing chain is also being developed.

In forest reserves in the western Usambara Mountains the stocking rate of *Allanblackia stuhlmannii* trees has been estimated at 2.0 stems per ha for all diameter classes; for trees with a bole diameter of more than 80 cm it was 0.2 trees per ha.

Diseases and pests Apart from seed predators, no diseases or pests are known.

Harvesting Well-matured fruits are collected from the ground. The maturity of fruits on the tree cannot be estimated.

Yield A mature tree may yield up to 150 fruits or up to 50 kg fat per year.

Handling after harvest Seeds are extracted from the fruits by crushing them between the hands and rubbing them clean. The seeds are then dried to avoid the development of moulds before being transported to the buying centres, where seeds are graded. Fat is extracted locally by traditional methods, or seeds are dried and sold to extraction plants. Traditionally, the seeds are dried and crushed; the resulting mass is mixed with water and boiled until the fat separates and floats to the surface from where it is scooped off.

Genetic resources *Allanblackia stuhlmannii* and *Allanblackia ulugurensis* are both listed in the IUCN Red List as vulnerable because of their small and severely fragmented areas of distribution and declining habitat.

Breeding Selection of high-yielding trees for vegetative reproduction has started in Tanzania.

Prospects The international food industry has taken an active interest in the domestication of *Allanblackia* species. *Allanblackia stuhlmannii* is more easily propagated by seed than other large-fruited *Allanblackia* species tested and its cultivation is being promoted in Tanzania. If productive management techniques can be developed, and if efficient marketing structures can be established, it may become an important new crop in the humid submontane and montane equatorial areas. Its utilization as a source of timber from wild stands should be discouraged as the species is already vulnerable.

Major references Bamps, Robson & Verdcourt, 1978; Elinge & Ndayishimiye, 2003; Hamilton & Bensted-Smith (Editors), 1989; Lovett & Clarke, 1998; Lovett et al., 2006; Mbuya et al., 1994; Meshack, 2004; Ndemu, 2002; Schulman et al., 1998; Takahashi, 1978.

Other references Bolza & Keating, 1972; Bryce, 1967; Eckey, 1954; Fuller et al., 1999; Kokwaro, 1993; Maagi, Mkude & Mlowe, 1979; Neuwinger, 2000; Ruffo, Birnie & Tengnäs, 2002.

Sources of illustration Bamps, Robson & Verdcourt, 1978; Ruffo, Birnie & Tengnäs, 2002.

Authors L. Mwaura & M. Munjuga

ARACHIS HYPOGAEA L.

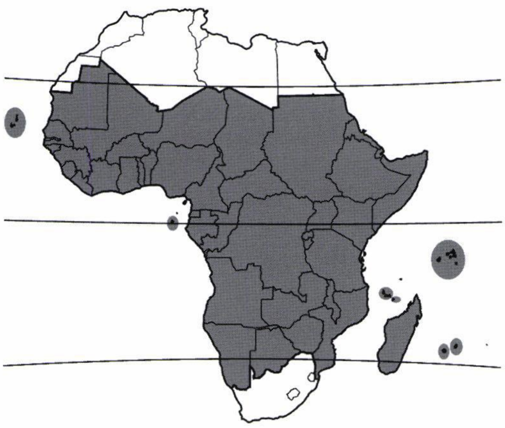
Protologue Sp. pl. 2: 741 (1753).

Family Papilionaceae (Leguminosae - Papilionoideae, Fabaceae)

Chromosome number $2n = 40$

Vernacular names Groundnut, peanut, earthnut, monkey nut (En). Arachide, cacahuète, cacahouète, pistache de terre (Fr). Amendoim, mandobi, caranga (Po). Mjugu nyasa, mnjugu nyasa, karanga (Sw).

Origin and geographic distribution Groundnut originated in the area of southern Bolivia and north-western Argentina. It is an ancient crop of the New World and was widely grown in Mexico, Central America and South America in pre-Columbian times. Domesticated groundnut had already evolved into several types before it was introduced into the Old World by Spanish and Portuguese explorers. Two-seeded types originating from Brazil were brought to West Africa, and 3-seeded types originating from Peru were taken from the west coast of South America to the Philippines, from where they spread to Japan, China, Indonesia, Malaysia, India, Madagascar and East Africa. In the late 1700s 'Spanish' groundnut types were introduced into Europe from Brazil. The first successful introduction in North America concerned small-seeded 'runner'-type groundnuts, probably originating from northern Brazil or the West Indies. Groundnut is now grown in most tropical, subtropical and temperate countries between 40°N and 40°S latitude. It is grown throughout tropical Africa and is a major cash crop in Senegal, Gambia, Nigeria and Sudan.



Arachis hypogaea – planted

Uses Groundnut seed is mainly used as food and for oil extraction. The seeds are eaten raw, boiled or roasted, made into peanut butter, confectioneries and snack foods, and are used for thickening soups or made into sauces to be eaten with meat and rice. In northern Nigeria groundnut flour is mixed with 'gari' (coarse fermented cassava meal) and made into balls that are eaten as a snack. In the United States and Argentina most of the crop is used as food, but in most other countries the primary use of groundnut is for the oil market. Worldwide, more than 50% of groundnut production is crushed into oil for human consumption or industrial use (e.g. in cosmetics). In countries such as Senegal, Gambia and Nigeria oil extraction has been an important cottage industry for years. The use of groundnut in confectionery and for oil and meal production is increasing, and there is gradual shift taking place from oil and meal to confectionery use, especially in Latin America and the Caribbean. In South America groundnut seeds are fermented into alcoholic drinks.

The presscake from oil extraction is a feed rich in protein, but it is also made into groundnut flour, which is used in many human foods. Fermented groundnut cake is eaten fried in Indonesia. The cake finds industrial application in the production of glues, sizes for paper and starches for laundering and textile manufacture. Protein from groundnut cake is made into a wool-like fibre, which can be blended with wool or rayon. Groundnut shells are used as roughage in fodder, as fuel, fertilizer, mulch, in the manufacture of particle board and building blocks, and can be used as a source of activated carbon, combustible gases, organic chemicals, reducing sugars, alcohol and extender resins.

Young groundnut pods and leaves are consumed as a vegetable; in West Africa the leaves are added to soups. The foliage is an important fodder, especially in the Sahel; it may be eaten fresh or as hay or silage. In southern India the haulms are sometimes applied as a green manure.

Groundnut has a range of uses in traditional African medicine. Pod extracts are taken as a galactagogue, and used as eye-drops to treat conjunctivis. Macerations of peeled seeds are drunk to treat gonorrhoea, macerations of the seed coats against syphilis, while macerations of the seed coats and shells are applied against ophthalmia. Sap of ground leaves and seeds is used for ear-drops against ear discharge. Leaf macerations are drunk as a diuretic. Leaf infusions are drunk against female infertility, and used for eye-drops to treat eye injuries and cataract. Plant ash with salt is applied in case of caries. Pod extracts and young plants are credited with aphrodisiac properties. The plant is also used to relieve cough and is considered emollient and demulcent; emulsions are taken to treat pleurisy, enteritis (including colitis), and dysuria.

Agglutinins (lectins) from groundnut seeds are often used in medical research for histochemical investigations.

Production and international trade According to FAO estimates, the average world production of groundnut pods in 1999–2003 amounted to about 34.4 million t/year from 24.4 million ha. The main producing countries are China (14.0 million t/year in 1999–2003, from 4.9 million ha), India (6.1 million t/year from 6.7 million ha), Nigeria (2.8 million t/year from 2.7 million ha), the United States (1.7 million t/year from 0.5 million ha), Indonesia (1.3 million t/year from 0.7 million ha) and Sudan (1.1 million t/year from 1.7 million ha). The total production in sub-Saharan Africa was 8.2 million t/year from 9.5 million ha.

Average world export of groundnut seeds amounted to 1.1 million t/year in 1998–2002. The main exporters were China (321,000 t/year), Argentina (201,000 t/year) and the United States (171,000 t/year). Export of groundnut seeds from sub-Saharan Africa was 64,000 t/year, with Gambia as main exporter (26,000 t/year). Average world export of groundnut pods in 1998–2002 was only 176,000 t/year, with China as main exporter (73,000 t/year). Exports of groundnut pods from sub-Saharan Africa were negligible.

The world production of groundnut oil in 1999–2003 was 5.1 million t/year. The main producers are China (2.0 million t/year), India (1.4 million t/year), Nigeria (480,000 t/year), Senegal (178,000 t/year) and Sudan (162,000 t/year). The production in sub-Saharan Africa was 1.2 million t/year. The world groundnut cake production in 1999–2003 was 6.9 million t/year, mainly from China (2.6 million t/year), India (1.9 million t/year) and Nigeria (750,000 t/year). The production in sub-Saharan Africa was 1.6 million t/year.

Average world export of groundnut oil in 1998–2002 was 271,000 t/year, with as main exporters Senegal (83,000 t/year) and Argentina (69,000 t/year). The total export of groundnut oil from sub-Saharan Africa was 114,000 t/year. The main importers were France (68,000 t/year), Italy (46,000 t/year) and the United States (25,000 t/year). Average groundnut cake export amounted to 280,000 t/year. Major exporters were Senegal (103,000 t/year), Argentina (51,000 t/year), India (43,000 t/year) and Sudan (35,000 t/year). Total groundnut cake export from sub-Saharan Africa was 143,000 t/year. The main importers were France (129,000 t/year) and Thailand (53,000 t/year).

Properties Mature groundnut seeds contain per 100 g edible portion (average of several types, which show little difference): water 6.5 g, energy 2374 kJ (567 kcal), protein 25.8 g, fat 49.2 g, carbohydrate 16.1 g, dietary fibre 8.5 g, Ca 92 mg, Mg 168 mg, P 376 mg, Fe 4.6 mg, Zn 3.3 mg, vitamin A 0 IU, thiamin 0.64 mg, riboflavin 0.14 mg, niacin 12.1 mg, vitamin B_6 0.35 mg, folate 240 µg and ascorbic acid 0 mg. The essential amino-acid composition per 100 g edible portion is: tryptophan 250 mg, lysine 926 mg, methionine 317 mg, phenylalanine 1337 mg, threonine 883 mg, valine 1082 mg, leucine 1672 mg and isoleucine 907 mg. The principal fatty acids are per 100 g edible portion: oleic acid 23.7 g, linoleic acid 15.6 g and palmitic acid 5.2 g (USDA, 2004).

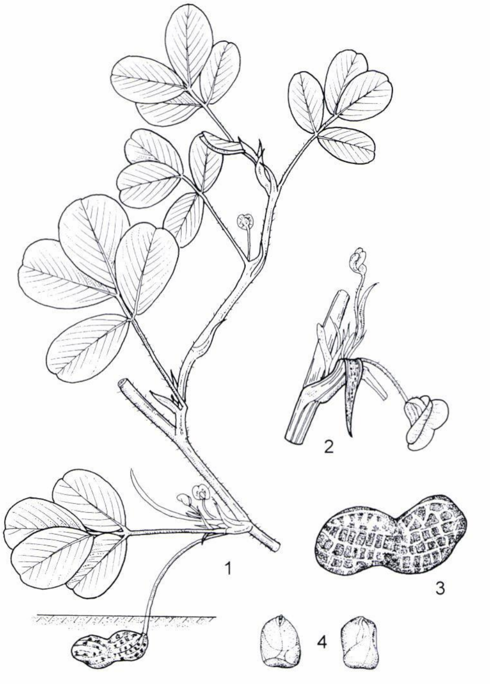
Groundnut seeds yield 42–56% oil. Groundnut oil contains 36–72% oleic acid, 13–48% linoleic acid and 6–20% palmitic acid. The ratio of oleic to linoleic acid has an important bearing on the stability of the oil; the higher the ratio, the more stable the oil and the longer its shelf life. The ratio in mature seeds can range from less than 1.0 to greater than 3.0; more than 1.3 is generally considered satisfactory by processors. The presscake contains 40–50% easily digestible protein, 20–25% carbohydrate and 5–15% residual oil.

Groundnut pods have a thick woody shell containing normally 2–3 seeds ('kernels'). The seed coat constitutes about 4–5% of the seed weight, the cotyledons 90–94% and the germ 3–4%. The major components of the seed coat are carbohydrate, cellulose and protein. Oil and protein are the main constituents of the germ and cotyledons. The germ is associated with bitter components.

An important problem in groundnut production is aflatoxin contamination by *Aspergillus* fungi. Aflatoxin has immunosuppressive effects and epidemiological studies, also in Africa, have shown a positive correlation between aflatoxin intake and the incidence of liver cancer. After industrial oil extraction, aflatoxin remains in the cake, and the refined oil is free of aflatoxin, but in case of small-scale extraction, the non-refined oil may be contaminated. Groundnut is one of the most allergenic foods known and may cause anaphylactic reactions. Groundnut seeds contain a haemostatic factor which can be useful in haemophilia. Groundnut oil is mildly laxative.

Adulterations and substitutes Groundnut oil can be substituted by other vegetable oils, e.g. from maize, soya bean and sunflower.

Description Annual herb, with erect or prostrate stem up to 70 cm long; root system consisting of a well-developed taproot with many lateral roots, up to 135 cm deep, but generally restricted to the upper layers of the soil. Leaves arranged spirally, 4-foliolate with two opposite pairs of leaflets; stipules 1.5–4 cm long, with a slender free tip, but fused to the petiole for about half their length; petiole 1.5–7 cm long; petiolules 1–2 mm long; leaflets obovate or elliptical, 1–7 cm × 0.5–3 cm, cuneate-rounded at base, rounded or emarginate and mucronate at apex. Inflorescence an axillary, 2–5-flowered spike. Flowers bisexual, papilionaceous, sessile; receptacle long and slender, pedicel-like, up to 4 cm long; calyx with 4 upper lobes joined, lower lobe free; corolla pale yellow to orange-red, rarely white, standard rounded, c. 1.5 cm × 1.5 cm, wings shorter, keel incurved; stamens (8–)10, alternately with small, globular anthers and larger, oblong anthers, joined at base; ovary superior but situated at base of receptacle tube, style free within the tube, very long, ending in a minute club-shaped stigma. Fruit an oblong or sausage-shaped pod, borne at the tip of an elongated fruit stalk ('peg') up to 20 cm long, 1–8 cm × 0.5–2 cm, surface constricted to varying degrees between the seeds and reticulately veined, 1–6-seeded. Seeds cylindrical to ovoid, 1–2 cm × 0.5–1 cm, with pointed or flattened ends, enclosed in a thin papery seed coat ranging in colour from white to deep purple. Seedling with epigeal germination; cotyledons thick and fleshy.



Arachis hypogaea – 1, branch with flowers and fruit; 2, inflorescence; 3, fruit; 4, seeds.
Source: PROSEA

Other botanical information *Arachis* comprises about 70 species, all distributed in South America. The centre of origin of *Arachis* is the Mato Grosso region of Brazil. *Arachis hypogaea* is by far the most economically important species in this genus, but several other species have been cultivated for their seeds, including *Arachis villosulicarpa* Hoehne and *Arachis stenosperma* Krapov. & W.C.Greg.

High levels of resistance to many diseases and pests of groundnut have been recorded in other *Arachis* species. Many of them are closely related to groundnut and include the other 26 species in section *Arachis*. Several diploid species have been suggested as wild progenitors of groundnut, but molecular and cytogenetic studies indicate that *Arachis duranensis* Krapov. & W.C.Greg. and *Arachis ipaensis* Krapov. & W.C.Greg. are most closely related to the progenitors of allotetraploid domesticated groundnut. *Arachis monticola* Krapov. & Rigoni is the only other tetraploid species in the section; it is very closely related to *Arachis hypogaea* and may be the direct descendant of the original hybrid between the 2 diploid progenitor species.

Hybrids between *Arachis hypogaea* and other *Arachis* species have been produced by direct hybridization and by first creating autotetraploids or allotetraploids from the diploid species before making crosses. Hybrids show high levels of sterility due to ploidy level differences and genome incompatibility.

There is considerable variation in *Arachis hypogaea* and two subspecies have been distinguished: subsp. *hypogaea* and subsp. *fastigiata* Waldron. Subsp. *hypogaea* ('runner type') is characterized by a more prostrate growth habit without flowering branches on the main stem, and with the cotyledonary lateral branches carrying alternate pairs of vegetative and reproductive secondary branches; it is usually late-maturing. It includes the 'Virginia' types groundnut. Subsp. *fastigiata* ('bunch type') is characterized by an erect growth habit with flowering branches on the main stem, and without a regular pattern in the sequence of vegetative and reproductive branches; and it is early-maturing. It includes the 'Spanish' and 'Valencia' types groundnut.

Most groundnut cultivars grown in West Africa belong to subsp. *hypogaea*; most of those in East Africa to subsp. *fastigiata*. Subsp. *hypogaea* is mainly used for food, and subsp. *fastigiata*, which has a higher oil content, as a source of oil.

Growth and development Seeds of 'Virginia' types have a dormancy period of 1–3 months, whereas 'Spanish' and 'Valencia' types are without dormancy. The optimum soil temperature for seed germination is 25–30°C. Low temperatures retard germination and development and increase the risk of seedling diseases. Upon germination, the primary root elongates rapidly, reaching 10–12 cm before lateral roots appear. As growth proceeds, the outer layer of the primary root of a seedling is sloughed off so that root hairs do not form. Branching is dimorphic, with vegetative branches and reduced reproductive branches. Secondary and tertiary vegetative branches can develop from the primary vegetative branches. Flowering may start as early as 20 days after planting, but 30–40 days after planting is more usual. The number of flowers produced per day decreases as the seeds mature. Up to 50% of the embryos may abort even under ideal environmental conditions, but this percentage becomes much higher during times of drought or other environmental stress. However, plants can produce a 'second crop' of seeds if adequate moisture becomes available again. Groundnut is self-pollinating, but outcrossing can occur when bees pollinate the flowers. Groundnut generally produces more flowers under long day conditions, but reproductive efficiency is greater under short days. Only one of the flowers in an inflorescence opens at a given time. Flowers wither within 24 hours after anthesis. Fertilization usually occurs within 6 hours after pollination, when the basal part of the ovary starts elongating into a structure called 'peg'. The embryo initiates a growth phase until it reaches an 8–16-cell stage. It then becomes quiescent during the 5–15 days required for the 'peg' to enter the soil. The 'peg' stops elongating within a day or two after soil penetration, the embryo then restarting growth. In wild *Arachis* species the 'peg' may continue to grow to a length of nearly 2 m. Seeds in 'Spanish'-type cultivars usually mature within 90–120 days after planting, whereas 'Virginia'-type cultivars take 130 days or more. Pods of the same size may differ significantly in maturity and seed weight.

Groundnut is usually effectively nodulated by N_2-fixing *Bradyrhizobium* bacteria. Because root hairs are absent, the bacteria infect the root through cracks in the epidermis near multicellular hairs at the basis of the root.

Ecology The optimum mean daily temperature for groundnut growth is 27–30°C; growth ceases when temperature drops below 15°C. Groundnut is mainly grown in areas with an average annual rainfall of 500–1000 mm; 500–600 mm of rain reasonably well distributed over the growing season allows satisfactory production. Nevertheless, groundnut is drought-tolerant and can withstand severe lack of water, though yield is generally reduced. A dry period is required for ripening and harvesting. The phenology of groundnut is determined primarily by temperature, with cool temperatures delaying flowering. In controlled environments, photoperiod has been shown to influence the proportion of flowers producing pods and distribution of assimilates between vegetative and reproductive structures (harvest index) in some cultivars. Long photoperiods (greater than 14 hours) generally increase vegetative growth and short photoperiods (less than 10 hours) increase reproduc-

tive growth. Groundnut can be grown up to 1500 m altitude.
The best soils for groundnut are deep (at least 30–40 cm), friable, well-drained sandy loams, well-supplied with calcium and a moderate amount of organic matter. It is important to maintain near to neutral soil pH levels and Ca:K ratios lower than 3.

Propagation and planting Groundnut is propagated by seed, but vegetative propagation using cuttings is possible. The 1000-seed weight ranges from 150 g to more than 1300 g. Sowing high-quality seed in a well-prepared, moist seedbed is essential for crop establishment. Groundnut seeds are often planted at a depth of 4–7 cm at a rate of 60–80 kg/ha. Groundnut pods intended for sowing are often hand-shelled 1–2 weeks before sowing. Only fully mature pods are selected. Before sowing, groundnut seed may be treated with a fungicide to control seedling diseases. In general, early sowing improves yields and seed quality. Early sown crops also suffer less risk of disease such as groundnut rosette virus. However the appropriate sowing date depends on the maturity period of the cultivar. Small-seeded 'Spanish' types are spaced at 60–75 cm between rows and 10 cm within the row. This gives an optimum plant population of 133,000–167,000 plants per ha. Large-seeded 'Virginia' types are spaced at 75 cm between rows and 15 cm within the row, giving an optimum plant population of 89,000 plants per ha. Groundnut can be grown on the flat, or on ridges as is often the case in Malawi. Groundnut grown on ridges tends to give higher yields, probably because of more loose soil favourable for pod development and easier uprooting.
In tropical Africa groundnut is grown as a sole crop or intercropped between rows of cereals such as maize, sorghum or pearl millet.

Management Groundnut does not compete effectively with weeds, particularly in the early stages of development. The crop should be thoroughly weeded within the first 45 days. Once the development of the 'peg' begins, earthing-up is kept to a minimum. Weeds at this stage are hand pulled. Pre-and post-emergence herbicides may be used to eradicate weeds, but they are too expensive for most small-scale farmers in Africa. In sound rotation systems, groundnut benefits from residual fertility; in general no additional fertilizer is given if the crop is sown on a well-managed soil previously treated with a balanced fertilizer. However, in order to ensure good crop establishment, high yield and good seed quality, a fertilizer containing Ca, such as gypsum or single superphosphate, should be applied. Calcium is absorbed directly by the pods if soil moisture is adequate. A shortage of Ca in the zone where the pods develop will result in empty pods, particularly in cultivars of the 'Virginia' type. Groundnut is normally a rainfed crop, but it is grown under irrigation in Sudan.
Groundnut should preferably not be grown in the same field more than once in 3 years to limit damage by soil-borne diseases, nematodes and weeds. It fits into a wide range of rotations and it can follow any clean-weeded crop, e.g. maize, sorghum, pearl millet, cassava, sweet potato or sunflower. To reduce the incidence of diseases and pests, groundnut should not be sown after cotton or tobacco. Groundnut does well on virgin land or immediately following a grass ley or well-fertilized crop such as maize.
The intensity of management of groundnut varies considerably around the world, depending on the economic return for the crop or the role of groundnut in the farming system. In the United States, Australia and parts of South America the crop is grown with intensive management, generally with high levels of mechanical and chemical inputs. In many countries groundnut is grown as a cash crop primarily for export.

Diseases and pests Groundnut is susceptible to a number of diseases, such as early leaf spot (*Cercospora arachidicola*), late leaf spot (*Cercosporidium personatum*, synonym: *Cercospora personata*), rust (*Puccinia arachidis*), groundnut rosette (caused by a complex of 3 agents: groundnut rosette virus (GRV), groundnut rosette assistor virus (GRAV) and a satellite RNA) and aflatoxin contamination caused by *Aspergillus* fungi. Foliar diseases of groundnut are among the most important yield-limiting factors in groundnut production. Early and late leaf spots and rust together may cause up to 70% yield losses; even where fungicides are applied significant yield reductions occur. Spraying with fungicide when the disease appears controls both leaf spots effectively. Dusting groundnut leaves with sulphur, early in the morning when there is still dew on the leaves, has been reported to control both early and late leaf spots. The use of sulphur has also been observed to increase leaf retention, thus increasing the quantity of leafy stems available for livestock feed. Cultural practices to control leaf spots include crop rotation and burning of crop residues. Cultivars with partial resistance to leaf spots have been developed. Rust generally occurs sporadically and at low severity, although it can cause crop losses up to 40% when an epidemic occurs. The cultural practices and fungicidal control measures recommended for leaf spots are also applicable to rust. Resistant cultivars are available. Groundnut rosette virus, transmitted by the aphid *Aphis craccivora*, is endemic to sub-Saharan Africa and widely prevalent in Ghana, Nigeria, Malawi and Zambia. It is the most destructive disease of groundnut leading to 30–100% yield loss. Early sowing at high plant populations controls the spread of groundnut rosette by giving complete soil coverage as quickly as possible and restricting the movement of aphids. Cultivars resistant to groundnut rosette are widely grown in Africa. In Malawi it is common practice for farmers to interplant groundnut and cowpea to control groundnut rosette. *Aspergillus* fungi can invade groundnut pods and seeds, producing toxic compounds known as aflatoxin. Contaminated produce can be poisonous to people and livestock, and cannot be exported. Aflatoxin contamination also affects groundnut seed, leading to low germination percentage and poor seedling establishment. It can occur before harvest, during field drying and curing, and in storage. Pre-harvest contamination is likely to be most serious under drought. Post-harvest contamination occurs if groundnut pods or seeds become moist and/or damaged. Various methods are used to control aflatoxin. They include avoiding mechanical damage to pods or seeds during weeding, harvesting and storage, harvesting as soon as the pods are mature, proper drying and curing, and storing in the shell at low temperature under moisture-free conditions.

Root-knot nematodes (*Meloidogyne* spp.) may cause considerable yield loss in groundnut; they can be controlled by crop rotation.

On a global scale the most important insect pests include aphids (*Aphis craccivora*), thrips (*Frankliniella* spp.), jassids (*Empoasca dolichi*), white grubs (larvae of various beetles), termites (mainly *Microtermes* sp.) and the red tea bug *Hilda patruelis*. False wireworms and millipedes seem to occur less frequently. In general, soil pests cause more damage than foliage feeders or sucking pests. However, aphids are particularly harmful because they transmit groundnut rosette virus. In Asia and Africa white grubs, termites, millipedes and ants are important pests; in the United States the lesser cornstalk borer (*Elasmopalpus lignosellus*) and the southern corn rootworm (*Diabrotica undecimpunctata*) are the main insect pests of groundnut. Pests attacking stored groundnut pods and seeds include bruchids (*Caryedon serratus*, *Callosobruchus* spp., *Acanthoscelides* spp.) and flour beetles (*Tribolium* spp.).

Parasitic plants (*Alectra vogelii* Benth. and *Striga* spp.) are recorded as causing damage to groundnut in various African countries.

Harvesting The indeterminate flowering pattern of groundnut makes proper timing of harvest difficult, even though such timing is crucial for obtaining maximum yield and quality. Harvest at the proper time ensures that the maximum number of pods have attained their greatest weight and that pods are not falling off. Methods to determine the proper time for harvesting groundnut are available, but some are environment-specific or are prohibitively expensive. Presently only the shell-out method and the hull-scrape method are widely used for groundnut maturity determination. The shell-out method is based on colour changes within the pod wall ('hull') that occur as the pod matures. The internal pod wall surface of most cultivars changes from white to brown or black blotches covering a large percentage of the area. The colour of the seed coat changes from white to dark pink or tan at the same time. A sample of plants is taken and pods opened. The percentage of pods with dark colour inside the pod wall is determined. Harvesting should begin when the percentage is 60–80, but recommendations vary. The shell-out method is widely used because it can directly be used in the field without further handling of pods, requires no equipment and provides an immediate answer. The hull-scrape method, developed in the early 1990s, is currently accepted as the most accurate means of assessing the maturity of 'runner'-type groundnuts. The method is based on the fact that the pod mesocarp (the area just beneath the pale brown coloured exterior of the groundnut pod) changes from white to yellow to orange to brown to black as the crop matures. The method requires colour charts and a pocket knife to scrape the pod surface.

Harvesting is carried out manually in most parts of Africa, as well as Asia. In the United States harvesting is normally done using a digger shaker inverter. When plants are harvested manually, they are loosened with a hoe and pulled out of the ground, after which they are turned to expose the pods to the sun to facilitate drying. When dry, the pods are ripped off the plants. With mechanical harvesting, the plants are cleanly removed from the soil and deposited in inverted windrows. Pods have to remain in the windrows until the average moisture content is 18–24%. Pods are then picked using a combine. Rainfall during windrowing may promote mould growth resulting in reduced milling quality.

Yield In tropical Africa the average yield of groundnut pods in the early 2000s was about 850 kg/ha, which is only slightly higher than the average yield in the 1970s (730 kg/ha). National average yields of groundnut pods in tropical Africa range from 300–1000 kg/ha. Average world yields of groundnut pods increased from 0.9 t/ha in the 1970s to 1.4 t/ha in the early 2000s. With good management practices and proper disease control, yields up to 5 t/ha can be achieved. On average 100 kg of pods yield 70 kg of seeds, containing 35 kg oil.

Handling after harvest Produce quality is closely related to proper harvesting date, harvesting method and drying; every step is critical to obtaining or maintaining quality. Groundnut pods are dried to an average moisture content of about 10%. Removing foreign materials early helps to maintain quality during storage. Cleaning equipment to remove the foreign material has been developed and includes sand screens and belt screens.

Groundnut pods are stored in granaries, tanks, bins, concrete silos, warehouses or in the open. In storage, ventilation is crucial to prevent moisture build up which can promote mould growth and aflatoxin production. Excessive heat should be avoided. Storage structures should be examined frequently for moisture and insect problems as these can greatly reduce quality. Seeds can be protected from mechanical damage by storage and transport in the pods. In many areas groundnut is only shelled when it is to be used or sold; in local markets unshelled pods are often offered for sale. Both mechanical and manual shelling are common.

Groundnut removed from storage is transported to shelling centres where the pods are graded, cleaned and shelled, and the seeds are separated into commercial grade sizes. Shelling operations may damage the seeds. Shelling of 100 kg of groundnut pods yields 60–80 kg of seeds. Generally groundnut seeds can be stored at 1–5°C and 50–70% relative humidity for 1 year without loss of quality. Groundnut seeds tend to absorb gases and off-flavours, which should be avoided.

Oil is extracted from groundnut seed by expeller pressing, hydraulic pressing, solvent extraction, or a combination of these methods. Expeller pressing is most widely used.

Genetic resources The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India, holds the largest collection of groundnut types, with more than 15,000 accessions, differing for many vegetative, reproductive, physiological and biochemical traits including their reactions to biotic and abiotic stresses. A duplicate sample is maintained in a regional gene bank at Niamey, Niger. Other large collections of groundnut germplasm are held in the United States (Southern Regional Plant Introduction Station, Griffin, Georgia, 9000 accessions), India (National Research Centre for Groundnut (NRCG), Junagadh, 8000 accessions), China (Institute of Crop Germplasm Resources (CAAS), Beijing, 5400 accessions; Institute of Oil Crops Research, Wuhan, 5700 accessions). In tropical Africa substantial groundnut germplasm collections are held in Senegal (Centre National de Recherche Agronomique, Bambey, 900 accessions), Uganda (Serere Agricultural and Animal Production Research Institute, Serere, 900 accessions) and Malawi (Plant Genetic Resources Centre, Chitedze Agricultural Research Station, Lilongwe, 500 accessions). The ARC Grain Crops Institute in Potchefstroom, South Africa, has a collection of 850 accessions. Core collections that have been developed are useful for developing models for future germplasm acquisition and evaluation for disease resistance. Additional collections are needed for most groundnut-producing regions, as landraces in these areas are rapidly being replaced with modern cultivars.

Breeding Groundnut breeding efforts greatly increased when the ICRISAT groundnut breeding programme was established in 1976. Diverse breeding populations are now being tested in regional programmes in sub-Saharan Africa and Asia. Most breeding programmes are conducted by public institutions. Groundnut breeding objectives have concentrated on adaptation to regional markets and production systems. All programmes aim at improving the productivity of the crop and resistance to diseases. Large-scale efforts to evaluate wild *Arachis* germplasm have resulted in identification of useful sources of resistance to many diseases. Recently there have been initiatives to

improve flavour and quality. Breeding for resistance to aflatoxin contamination has received increased attention, and the selection of short-duration cultivars with drought resistance is a high priority in many programmes. Commonly used breeding methods in groundnut are pedigree selection, bulk-pedigree selection and single-seed descent. Backcross breeding has not been used extensively as most of the economically important traits of groundnut are quantitatively inherited. The major constraints to rapid genetic enhancement include: the close linkage of disease resistance genes with loci conferring undesirable pod and seed characteristics; the later maturity, lower partitioning to seeds, and higher photoperiod-sensitivity of disease-resistant germplasm compared to agronomically elite susceptible materials; the large genotype × environment interactions for traits of economic importance; and limited gene introgression from wild *Arachis* species to cultivated groundnut.
Genetic linkage maps of groundnut have been constructed using various markers, but the saturation level is insufficient for routine application in molecular breeding. An efficient tissue culture and transformation system for groundnut has been developed and transgenic groundnut plants have been produced using biolistic and *Agrobacterium*-mediated methods.

Prospects Groundnut remains an extremely useful crop, providing food, oil, fodder and fuel to households and is also an important source of additional income as a cash crop. Important problems in groundnut cultivation in tropical Africa are low yields and its susceptibility to diseases. Many cultivars are still susceptible to early and late leaf spot and rust, as resistance tends to be linked with long duration and undesirable pod and seed characteristics. Therefore, the development of high-yielding cultivars with resistance to disease (especially leaf spots and rust) and adaptation to African production systems remains a major challenge for groundnut breeders. The application of DNA markers may allow breeders to combine resistance to biotic and abiotic stresses with improved productivity and seed quality. The use of biotechnology tools will become increasingly important for large-scale germplasm characterization and resolving some of the constraints (e.g. disease problems) in groundnut production.

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Sources of illustration Shorter & Patanothai, 1989.

Authors B.R. Ntare

BALANITES MAUGHAMII Sprague

Protologue Bull. Misc. Inform. Kew 1913: 136, 138 (1913).

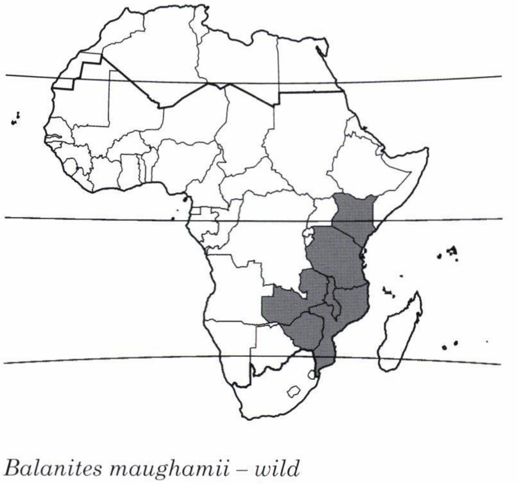
Family Balanitaceae (APG: Zygophyllaceae)

Synonyms *Balanites dawei* Sprague (1913).

Vernacular names Y-thorned torchwood, green thorn, manduro (En). Manduro, nulo (Po). Mkonga, mguguni (Sw).

Origin and geographic distribution *Balanites maughamii* occurs from south-eastern Kenya south to Swaziland and the province of KwaZulu-Natal in South Africa, with its centre of diversity in Mozambique.

Uses Oil pressed from the seed kernel is used in Limpopo Province of South Africa as a dressing for hides and skins. The fruits and seed oil are edible; the oil is used in cooking, and as a massage oil. In some regions the oil or seeds are burnt as torches, hence the common



Balanites maughamii – wild

name 'torchwood'; the wood produces a good charcoal. The timber is useful for building poles, tool handles, grain mortars, stools and for carving and turnery; in Swaziland it is used to make wagons. In southern Malawi the fruits are used to make leg rattles.

Balanites maughamii is used in magic and traditional medicine. The roots and bark are widely used in purgative medicines. Although the fruit is edible to mammals, the fruit exudate is used in fish poison and is lethal to the freshwater snails that are vectors of bilharzia and Guinea-worm. *Balanites maughamii* may contribute to the control of these diseases when it occurs near water and it has been planted for this purpose in South Africa. It has occasionally been planted as an ornamental.

Much of the information referring to the use of *Balanites maughamii* refers with certainty only to subsp. *maughamii* and may not apply to subsp. *acuta* Sands.

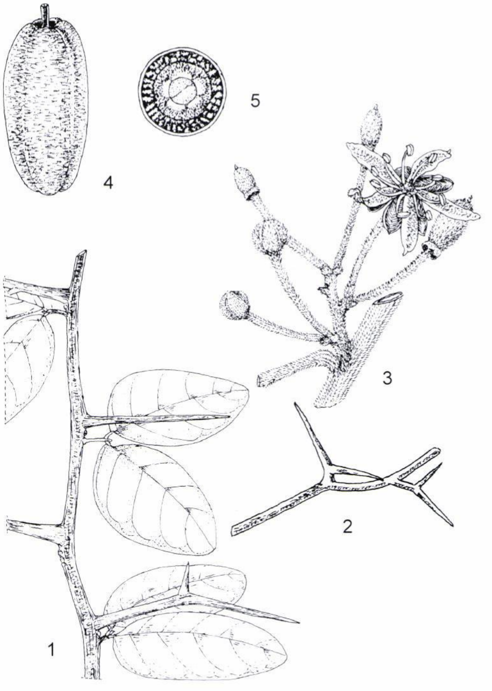
Properties The kernel contains a clear, yellow edible oil (about 60%) that is tasteless and odourless. The oil is flammable, and suitable for industrial use. The fruits have a pleasant sweet scent and taste, but later become bitter.

Balanites maughamii can yield large straight logs of a valuable hard timber. It is usually pale yellowish brown and finely textured, giving a smooth finish, which takes a high polish.

The roots have emetic properties. Extracts of the leaves and twigs have shown genotoxic effects in vitro, causing DNA damage. Stem bark extracts inhibit the malarial parasite *Plasmodium falciparum* (IC_{50} = 1.94 μg/ml) in vitro.

The use of *Balanites maughamii* for its molluscicidal properties was first proposed in the 1930s. Fruits that fell in infested water were observed to inhibit proliferation of bilharzia snail-vectors. It is postulated that yamogenin, the steroidal sapogenin to which molluscicidal activity is attributed in *Balanites aegyptiaca* (L.) Delile is present in higher concentrations in *Balanites maughamii*. The kernel and pulp of ripe fruit are toxic to snails at concentrations of 25 mg/ml, and molluscicidal activity is retained in powdered material for up to 122 days. The fruits are toxic to some frogs and fish.

Description Deciduous or semi-deciduous tree up to 20(–25) m tall, rarely a shrub; trunk straight, frequently fluted; bark smooth, yellowish brown, mottled or grey, becoming roughly fissured; crown rounded, spreading, sometimes with low branches remaining close



Balanites maughamii – 1, sterile shoot; 2, sterile shoot with forked spines; 3, inflorescence; 4, fruit; 5, fruit in cross section.
Redrawn and adapted by Iskak Syamsudin

to the trunk for some distance; branchlets usually yellow to greyish green; spines 3–6(–15) cm long, often on the upper bole and branches as well as the younger stems, frequently branched, often appearing forked. Leaves arranged spirally, 2-foliolate; stipules triangular, up to 3 mm long, sometimes corky, with brown hairs, persistent; petiole and petiolules usually densely pubescent; leaflets usually asymmetrical, elliptical to broadly ovate, rounded to obtuse, acute or shortly acuminate, leathery, glabrous or variously pubescent on both surfaces, eventually glabrescent. Inflorescence an axillary fascicle-like cyme, (1–)3–7-flowered, indumentum yellowish green to buff, sessile or with short peduncle. Flowers bisexual, 5-merous, often scented; pedicel 0.5–1 cm long; sepals ovate to obovate, c. 5 mm long, reflexed after anthesis, pubescent outside but with glabrous margins; petals oblong-lanceolate to oblanceolate, (5–)7–8(–9) mm long, reflexed after anthesis, green or greenish yellow, hairy inside; stamens 10, free; disk annular, succulent; ovary superior, densely and stiffly hairy, 5-celled, style terete or tapering. Fruit a 1-seeded drupe, oblong-ellipsoid, depressed at both ends, or ovoid, obtuse apically, 4–6(–8) cm long, ripening reddish brown, the skin firm but thin, eventually brittle, containing spongy and fibrous, dark and oily mesocarp; stone with thick endocarp. Seed ellipsoid to spindle-shaped, up to 2.5 cm long, grooved, cream-coloured.

Other botanical information *Balanites* comprises 9 species, most of them in Africa, but 1 species each in India and Myanmar. The distribution of 2 African species extends into the Arabian Peninsula, *Balanites aegyptiaca* also occurring in Jordan. *Balanites maughamii* is closely related to *Balanites wilsoniana* Dawe & Sprague which occurs from Côte d'Ivoire to Uganda, and differs in its caducous stipules, inflorescences borne above the leaf axils and silvery grey indumentum of the petiole and young growth. Within *Balanites maughamii* 2 subspecies are recognized: subsp. *maughamii* and subsp. *acuta* which are primarily distinguished by leaflet shape and pubescence. Leaflets on fertile shoots of subsp. *maughamii* are rounded or obtuse and pubescent, whereas those of subsp. *acuta* are acute to shortly acuminate and glabrous. Subsp. *maughamii* occurs throughout the southern part of the range, north to Lindi District, Tanzania, whilst subsp. *acuta* is concentrated in south-eastern Kenya and eastern Tanzania.

Growth and development Growth of *Balanites maughamii* follows the growth model of Champagnat: a shoot lengthens due to the activity of an apical bud. Initial growth is upright, but soon the shoot becomes drooping or pendulous under its own weight. A lateral bud then resumes upright growth and the pattern of growth and curvature repeats itself. Subsp. *maughamii* flowers from September to November and fruits from November to March; subsp. *acuta* flowers from November to April with the first mature fruits appearing in February.

Ecology *Balanites maughamii* occurs from sea-level to 1000 m altitude; subsp. *maughamii* generally occurs in dry open woodland, frequently along rivers, near springs and around pans, sometimes on seasonally waterlogged floodplains, typically on sandy- or clay-loam. Subsp. *acuta* is found most commonly in mixed, usually coastal, evergreen forest or coastal thicket, up to 500 m altitude. It frequently occurs on more alkaline and less well-drained soils than subsp. *maughamii*.

Propagation and planting Seed is orthodox and best germinated in the ground, as container-reared specimens tend to become chlorotic. Root suckers can be used for propagation.

Management Fruit of *Balanites maughamii* is only collected from the wild.

Genetic resources No risks of genetic erosion have been reported.

Prospects *Balanites maughamii* has been considered poorly suited to commercial exploitation, due to the difficulty of removing the kernel from the pulp and thick, fibrous shell. Modern processing methods may, however, overcome these drawbacks. Given the similarities of its fruits to those of the related *Balanites aegyptiaca*, which yield several natural products, *Balanites maughamii* probably has similar commercial potential, warranting further investigation.

Major references Kloos & McCullough, 1982; Launert, 1963; Pretorius, Joubert & Evans, 1988; Prozesky, Meyer & Louw, 2001; Sands, 2001; Sands, 2003; Sprague, 1913; Watt & Breyer-Brandwijk, 1962.

Other references Coates Palgrave, 1983; Elgorashi et al., 2002; Flynn, Turner & Dickie, 2004; Kellerman, 2004; Mander et al., 1995; Mbuya et al., 1994; Parameswaran & Conrad, 1982; Sim, 1909; van Wyk, van Oudtshoorn & Gericke, 1997.

Sources of illustration Sands, 2001.

Authors O.M. Grace & M.J.S. Sands

BRASSICA CARINATA A.Braun

Protologue Flora 24: 267 (1841).

Family Brassicaceae (Cruciferae)

Chromosome number $2n = 34$

Synonyms *Brassica integrifolia* (H.West) Rupr. var. *carinata* (A.Braun) O.E.Schulz (1919).

Vernacular names Ethiopian kale, Ethiopian mustard, Ethiopian rape, Abyssinian mustard (En). Chou éthiopien, moutarde d'Abyssinie (Fr). Figiri (Sw).

Origin and geographic distribution *Brassica carinata* is an amphidiploid with one genome from *Brassica nigra* (L.) Koch and the other from *Brassica oleracea* L. Ethiopia is the centre of genetic diversity of *Brassica carinata*, and its cultivation is thought to have started there about 4000 years BC. Truly wild types are not known, but *Brassica carinata* often escapes from cultivation. In the literature it

Brassica carinata – planted and naturalized

has been much confused with *Brassica juncea* (L.) Czern., and therefore its exact distribution in Africa is difficult to indicate. The cultivation of *Brassica carinata* as an oil crop is restricted to Ethiopia, but as a leafy vegetable it is often grown in East and southern Africa, less so in West and Central Africa.

Uses In most parts of Africa, the primary use of *Brassica carinata* is as a cooked leafy vegetable, whereas in Ethiopia, where it is called 'gomen zer' in Amarainya, the seed oil is of major importance too. Outside Africa, especially in western and southern Asia, it is occasionally grown as an oilseed crop or for mustard. The seeds are crushed and the oil is used for cooking and in the mustard industry. The oil has limitations for cooking because of high contents of glucosinolates and erucic acid. In Ethiopia it is used for oiling the baking plates of earthenware 'injera' stoves. It is also used for illumination. The seed is used in folk medicine to treat stomach-ache. People in Ethiopia use the sharp-tasting seeds as a spice to flavour raw meat. The crop is occasionally used as fodder for livestock and the seeds to feed birds. The seed cake is used as high protein food for animals, although the presence of glucosinolates is a limiting factor. Of late, there has been an interest in utilizing the oil, like other *Brassica* seed oils, as a biodiesel and for the preparation of special erucic acid derivatives.

Production and international trade Production of *Brassica carinata* for its seed is important only in Ethiopia; production in Canada and the Mediterranean region is still mainly experimental. As a leafy vegetable it is mostly grown as a kitchen garden crop, although in Tanzania, Malawi, Zambia and to a lesser extent in Zimbabwe it is also grown as a market crop. Its use as a leaf crop appears to be declining because of higher yielding leaf cabbage (*Brassica oleracea*) and leaf mustard (*Brassica juncea*). No statistical data on its production are known.

Properties There is no information on the nutritional composition of *Brassica carinata* leaves, but it is probably comparable to *Brassica juncea*. The seeds are rich in oil, containing 25–47% depending on cultivar and growing conditions; the protein content is also high, 25–45% and comparable to that of pulses. The oil consists of: erucic acid 35–44%, linoleic acid 15–22%, linolenic acid 16–20%, oleic acid 10–12%, eicosenoic acid 7–9% and palmitic acid 2–4%. Lines containing oil without erucic acid have been developed through cross-breeding with *Brassica juncea* and *Brassica napus* L. and through mutagenesis. The seeds have a high content of glucosinolates (100–200 μmoles/g), almost exclusively sinigrin, which has antioxidant but also goitrogenic properties. The phytoalexin brassilexin and several of its precursors are synthesized by *Brassica carinata* in response to attack by the blackleg pathogen *Leptosphaeria maculans*, which may explain its resistance to it.

Adulteration and substitutes The *Brassica carinata* leaf crop can be replaced by the various types of leaf cabbage (*Brassica oleracea*) or leaf mustard (*Brassica juncea*), the seed crop by *Brassica juncea*, *Brassica napus* or *Brassica nigra*.

Description Erect, annual or occasionally biennial or perennial herb up to 150(–200) cm tall, usually branched, glabrous to slightly hairy at stem and petiole bases, slightly glaucous; taproot strong. Leaves alternate, usually simple, lower ones sometimes with 1 pair of small side lobes at base; stipules absent; all leaves with short petiole; blade obovate, up to 20 cm × 10 cm, double-crenulate but upper ones often more or less entire. Inflorescence initially a rather loose umbel-like raceme but soon elongating, up to 50 cm long. Flowers bisexual, regular, 4-merous; pedicel ascending, 5–12 mm long; sepals oblong, 4–6(–7) mm long, green; petals obovate, 6–10 mm long, clawed, pale to bright yellow; stamens 6; ovary superior, cylindrical, 2-celled, stigma globose. Fruit a linear silique 2.5–6 cm × 2–3.5 mm, often somewhat constricted between the seeds, with a conical beak 2–6(–7) mm long, dehiscent, up to 20-seeded. Seeds globose, 1–1.5 mm in dia-

Brassica carinata – 1, habit of young plant; 2, flowering and fruiting branch; 3, fruit.
Redrawn and adapted by Iskak Syamsudin

meter, finely reticulated, pale to dark brown. Seedling with epigeal germination, with a strong main root and fibrous lateral roots; hypocotyl 2–3 cm long, epicotyl very short; cotyledons broadly obovate, c. 2.5 cm long, dark green.

Other botanical information Three wild *Brassica* species are found in the Mediterranean region: *Brassica nigra* (L.) Koch (black mustard) with the basic chromosome number *n* = 8 (B genome), *Brassica oleracea* L. (cabbage) with *n* = 9 (C genome) and *Brassica rapa* L. (turnip) with *n* = 10 (A genome). *Brassica carinata* is considered an amphidiploid hybrid between *Brassica nigra* and *Brassica oleracea*, with genomes BBCC, 2*n* = 34. The hybridization may have occurred on several occasions; genetic evidence indicates that in all cases *Brassica nigra* has been the female parent. *Brassica juncea* is an amphidiploid hybrid between *Brassica nigra* and *Brassica rapa* with 2*n* = 36. It is often confused with *Brassica carinata* and information can not always be attributed to either of these species with certainty. The lower leaves of *Brassica juncea* usually have more lobes and its fruit beak is longer (usually > 6 mm).

Growth and development The time from sowing to emergence of the seedling is about 5 days, depending on temperature and soil moisture. Plants develop an extensive root system, larger than in other *Brassica* species. In general, large-leaved cultivars have fewer branches than small-leaved ones. There is a difference in first flowering date between oil types and vegetable types; oil types start flowering about 10 weeks after germination, vegetable cultivars after about 12 weeks, depending on cultivar and growing conditions. Flowering of vegetable cultivars is delayed by regular harvesting of leaves or young shoots. Plants grown in dry regions flower earlier and produce ripe seeds within 4 months from sowing. Vegetable crops grown with adequate moisture produce seeds in 5–6 months. Some tall cultivars, when grown with adequate moisture, may develop new shoots after removal of the infructescences and become perennial, normally for one further season, but plants of up to 4 years old have been recorded. Most *Brassica* species are cross-pollinating, which contributes to the great diversity within species. *Brassica carinata* is an exception as it sets seed very efficiently through self-pollination without insects acting as pollinators. It does not need low temperatures for flower initiation, and seed production is therefore much easier in Africa than for most *Brassica oleracea* leaf cabbages except for Portuguese kale.

Ecology Ethiopian kale is rather versatile and can be found in highland regions up to 2600 m with a cool climate, but also in lowlands with relatively warm and dry conditions. It grows best in the dry season under irrigation when there are few pests and diseases. The crop is suited to a wide range of soils and especially the oil crop is often grown in marginal areas; the vegetable crop is mostly grown on more fertile soils. Ethiopian kale can grow from the equator to Canada and appears to be daylength neutral. It is sensitive to salt and seeds may not germinate in soils with an above average salinity level. Waterlogging is not tolerated.

Propagation and planting Propagation is normally by seed and rarely through cuttings. The weight of 1000 seeds is 3–5 g. When grown for the leaves, sowing in a nursery and transplanting are widely practised. Seedbeds are normally raised above the soil to reduce the incidence of damping off. The top layer is dug and some well-fermented manure is worked in to produce a friable soil. Seeds are drilled in the nursery in lines 15–20 cm apart. Watering in the nursery should be done with a fine rose. Farmers may cover the seedbeds with long grass or similar material to keep the surface moist and dark. When the cotyledons have spread after germination, this mulch is removed or placed next to the plantlets. Seedlings can be transplanted at the 4-leaf stage, about 5 weeks after germination. When seedlings become too tall, they may become spindly and unlikely to develop into strong plants. The field spacing is about 35–40 cm within and 50–60 cm between rows, depending on the plant size. Near Nairobi (Kenya) the space between rows is interplanted with shallot, parsley and the leafy vegetable *Crotalaria* sp. When grown as an oil crop, seeds are sown directly in lines or broadcast when a short-duration leaf crop is aimed for.

Management Ethiopian kale responds well to organic manure of up to 20 t/ha. Most farmers find it easier to incorporate chemical fertilizers in the plant beds at the rate of about 100 kg N and 30 kg P. Higher levels of nitrogen will increase proteins and enhance leaf production, whereas more phosphorous will enhance the seed production potential. Some vegetable farmers will therefore increase the initial amount to 300 kg N, whereas others give a fortnightly side dressing of 50 kg N at a time. For oilseed production, all fertilizers are incorporated at planting and no topdressing is given. For leaf production regular irrigation is necessary when it is not raining since water stress induces early flowering. When the crop is sown at the onset of the rains, attack by pests and diseases will be severe. To avoid such attacks, it is recommended that the crop be sown 5–6 weeks before rains are expected so that the crop can be transplanted at the onset of the rains.

Diseases and pests Ethiopian kale is sensitive to turnip mosaic virus (TuMV) and especially the leaf crop is vulnerable. TuMV is transmitted by a range of aphids, of which the cabbage aphid *Brevicoryne brassicae* and the green peach aphid *Myzus persicae* are the most important. Oilseed types with bluish leaves have a thicker layer of leaf wax than green-leaved vegetable types and it has been noticed that leaf wax keeps aphids at bay to some extent. Leaf wax is also associated with the level of tolerance to Alternaria leaf spot (*Alternaria brassicae*). Ethiopian kale is susceptible to black rot (*Xanthomonas campestris*), black spot (*Alternaria brassicicola*), and to damping off and seedling root rot (*Rhizoctonia solani*). Cultivar 'Nanga' from Zambia has shown tolerance to black rot. Ethiopian kale is tolerant to black leg disease *Leptosphaeria maculans* (asexual form: *Phoma lingam*). White rust (*Albugo candida*) is mainly found on vegetable cultivars, but not in the oil crop. *Xanthomonas*, *Alternaria*, *Phoma* and *Rhizoctonia* are seedborne diseases, so a reliable seed source is most important, but these diseases are also retained in the soil so appropriate crop rotation is also essential. To avoid black rot, production during the rainy season is not recommended. The best disease control is proper management rather than a spraying regime with agro-chemicals.
Diamondback moth (*Plutella xylostella*) is less problematic on Ethiopian kale than on cabbages and cauliflower. Other pests include caterpillars of the cabbage butterfly (*Pieris brassicae*) and the grubs of mustard sawfly (*Athalia proxima*), a pest that is particularly important at the seedling stage. Other pests are the cabbage and mustard aphid (*Hyadaphis pseudobrassicae*, synonym: *Lipaphis erysimi*), cabbage weevil (*Lixus* sp.), flea beetles (*Phyllotreta* spp.), and hurricane bug (*Bagrada cruciferarum*).

Harvesting There are several ways to harvest this vegetable. Plants from seeds that were broadcast at high density can be harvested by uprooting the whole plant 6 weeks after sowing. This method is normally used when the land is needed for another crop. For a conventional crop, the first harvest takes place about 5 weeks after transplanting. Leaf harvesting is best done once in 2 weeks with 50% defoliation. Small-leaved cultivars are often collected in the form of shoots rather than as individual leaves.
Seed crops are harvested when the fruits turn brown. Infructescences are cut and placed on a tarpaulin or similar sheet, where they are allowed to dry without risk of seed shattering. The crop is then threshed and winnowed.

Yield The farmer can expect an average leaf and shoot yield of 35 t/ha, but at research stations leaf yields of 50–55 t/ha have been reported, depending on production season and cultivar. In India and Canada farmers may get seed yields of 1200–1800 kg/ha in a good year.

Handling after harvest The leaves are rather perishable and wilt or become yellow when left on the shelf for more than a day. Farmers therefore harvest small quantities at a time. To retain freshness, the leaves are kept moist inside a bag that is left in the shade or in a cool place. When the product is offered as whole plants with roots, traders place the roots in water and plants can thus be kept for a few days.

Genetic resources The genetic diversity in *Brassica carinata* based on molecular DNA markers is much less than in *Brassica juncea*. In spite of the comparatively small variation in *Brassica carinata*, there are many landraces for both the oilseed and the leafy vegetable types, differing in earliness, plant structure, leaf size, shape and structure, seed yield, and glucosinolate and erucic acid levels in the seed. There is a need for further collection, conservation and evaluation of this diversity before farmers start using new cultivars at the expense of their traditional landraces. A collection is maintained at the Centre for Genetic Resources (CGN), Wageningen, Netherlands. Working collections are available at research institutes in Ethiopia, Tanzania, Zambia and Zimbabwe.

Breeding In Africa some breeding work has been done and several selections have been made in Tanzania, Zambia and Zimbabwe. Selection criteria are leaf size, late bolting, reduced susceptibility to major diseases and pests, and high yield. Well-known cultivars are 'White Figiri', 'Purple Figiri', 'Lushoo', 'Mbeya Green' and the large-leaved 'Lambo' from Tanzania, 'RRS-V' from Zimbabwe, 'Chibanga' and 'NIRS-2' from Zambia. 'TAMU Tex Sel' is a vegetable cultivar released in Texas (United States). In Zambia, Ethiopian kale has been crossed with Portuguese cabbage and with *Brassica nigra*. More breeding work has taken place on cultivars used for oilseed, mainly in Canada, India and Italy. Low erucic acid and glucosinolate content and high seed yield are major selection criteria.

Prospects Ethiopian kale is a leafy vegetable and oil crop that is fully adapted to African conditions and has a high potential. There are many different landraces, allowing the breeder ample scope for advancement. Seed production by farmers themselves is easy, but the availability of reliable and healthy commercial seed would also benefit farmers. If no action is taken soon, this species will gradually disappear, and be replaced by new cultivars of especially *Brassica juncea* and loose-leaved types of *Brassica oleracea*, for which more research has been done and which receive more attention from breeders.

Major references Alemayehu & Becker, 2002; Getinet, Rakow & Downey, 1996; Getinet et al., 1997a; Getinet et al., 1997b; Maundu, Ngugi & Kabuye, 1999; Mingochi & Jensen, 1988; Mnzava & Msikita, 1988; Mnzava & Olsson, 1990; Msikita & Mnzava, 1988; Schippers, 2002.

Other references Cardone et al., 2003; Cowley, 1970; del Río, de Haro & Fernández-Martínez, 2003; Edwards, 1991; FAO, 1988; Gildemacher, 1997; Gómez-Campo (Editor), 1999; Jonsell, 2000; Mathai, 1984; Mnzava, 1986; Pearson & Bock, 1976; Pedras, Loukaci & Okanga, 1998; Seegeler, 1983; SEPASAL, 2003; Stephens, 1994; Stephens, Saldana & Lime, 1975; Westphal & Marguard, 1981.

Sources of illustration Jonsell, 2000; Jonsell, 1982a.

Authors N.A. Mnzava & R.R Schippers

BRASSICA JUNCEA (L.) Czern.

Protologue Consp. pl. charc.: 8 (1859).

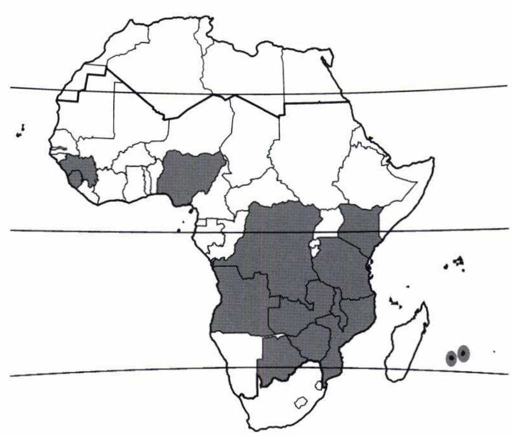
Family Brassicaceae (Cruciferae)

Chromosome number $2n = 36$

Synonyms *Sinapis juncea* L. (1753).

Vernacular names Brown mustard, Indian mustard, leaf mustard (En). Moutarde brune, moutarde de Sarepta, moutarde de Chine, moutarde frisée (Fr). Mostarda vermelha, mostarda indiana (Po). Haradali, mastadi (Sw).

Origin and geographic distribution *Brassica juncea* is an amphidiploid with *Brassica nigra* (L.) Koch ($2n = 16$) and *Brassica rapa* L. ($2n = 20$) as parents. Several regions in western and central Asia have been assumed to be the centre of origin of *Brassica juncea*. Brown mustard has been cultivated in Asia and



Brassica juncea – planted and naturalized

Europe for thousands of years for its leaves and seeds. Presently, vegetable types of *Brassica juncea* are cultivated throughout southern and eastern Asia. Variation is greatest in China. Brown mustard is grown as a leafy vegetable in West and southern Africa, known as 'laulau' in Nigeria, 'mpiru' in Malawi and 'tsunga' in Zimbabwe. In many African countries it has been introduced and became naturalized. However, its exact distribution in Africa is difficult to indicate because of confusion with other *Brassica* species, especially *Brassica carinata* A.Braun. Oilseed types are particularly important in southern Asia, China, North America and Europe, but are not or only rarely found in Africa. *Brassica juncea* is important as a source of mustard in Europe and North America, and it is occasionally planted for this purpose in Africa, e.g. in Réunion and Mauritius.

Uses *Brassica juncea* has many uses: it yields a seed oil, crushed seed is used in the production of mustard and it has a variety of vegetable uses. It is also used as forage and medicinally.

In Africa and many parts of Asia the leaves are eaten as a vegetable; they are often shredded, cooked and served as a side dish with the staple food. Older leaves and leaves affected by drought are very bitter. When they have to be used, consumers renew the cooking water once. Young tender leaves, called 'mustard greens' are used in salads, mixed with other salad greens. In Asia brown mustard leaves are used in pickles or offered as frozen or canned vegetables. Sprouted seeds are used as a garnish or to add a spicy note to salads. In East Asia a variety of vegetable types have been developed that are comparable to that of *Brassica oleracea* L. 'Tai Tau Choi' has an enlarged root and is prepared and eaten like turnips, while 'Cha Tsoi' has peculiar swollen stems with knobby bulges that are preserved in brine and pressed flat until most of the sap is removed.

In Asia, Europe and America, *Brassica juncea* is grown mainly for its seed used in the fabrication of brown mustard or for the extraction of vegetable oil. It has been introduced for this purpose locally in Africa, e.g. in the Mascarene Islands. In much of Europe *Brassica juncea* has replaced *Brassica nigra* as the main source of commercial mustard seed. Its mustard is spicier than the yellow type made from *Brassica nigra*. Mustard oil is one of the major edible oils in Bangladesh, India and Pakistan, appreciated for its special taste and pungency. In adjacent parts of the former Soviet Union it is used as a substitute for olive oil. In Western countries its use as edible oil is restricted because of the high erucic acid content. The oil is also used as hair oil and as lubricant. The oil of cultivars bred for extra high erucic acid content is used for industrial purposes. A peculiar use of mustard oil is to retard the fermentation process when making cider from apples. The seeds are also used in birdseed mixtures. The remaining seed meal is high in protein, but the high glucosinolate content makes it unacceptable for human or for monogastric-animal consumption.

Brown mustard is reported to have anodyne, aperient, diuretic, emetic and rubefacient properties. It is a folk remedy for arthritis, foot ache, lumbago and rheumatism. In China the seed is used as medicine against tumours. Ingestion may impart a body odour repellent to mosquitoes. Leaves applied to the forehead are said to relieve headache. The leaves are eaten in soups to treat bladder inflammation or haemorrhage. In Korea the seeds are used to treat abscesses, colds, lumbago, rheumatism and stomach disorders. Brown mustard oil is used against skin eruptions and ulcers. In Tanzania the roots have been given to cows to promote milk production.

Production and international trade Statistics on the production and trade of seed oil and mustard of *Brassica juncea* are difficult to find as they are often combined or confused with those of rape seed (*Brassica napus* L. or *Brassica rapa* L.). Brassica oil is the third-most important vegetable oil after only soya bean and oil palm. Brown mustard as a vegetable is only marketed locally even in those parts of Asia where it is an important vegetable. In Africa it is mainly encountered in southern Africa and is quite rare elsewhere. In Zambia and Zimbabwe, where it is referred to as 'rape', it is very popular, but no reliable statistics are available on the area under cultivation, production or produce traded.

Properties Brown mustard leaves contain per 100 g edible portion: water 90.8 g, energy 109 kJ (26 kcal), protein 2.7 g, fat 0.2 g, carbohydrate 4.9 g, total dietary fibre 3.3 g, Ca 103 mg, Mg 32 mg, P 43 mg, Fe 1.46 mg, Zn 0.2 mg, vitamin A 10,500 IU, thiamin 0.08 mg, riboflavin 0.11 mg, niacin 0.80 mg, folate 187 μg, ascorbic acid 70 mg. Dry mustard seed contains per 100 g edible portion: water 6.9 g, energy 1964 kJ (469 kcal), protein 24.9 g, fat 28.8 g, carbohydrate 34.9 g, Ca 521 mg, Mg 298 mg, P

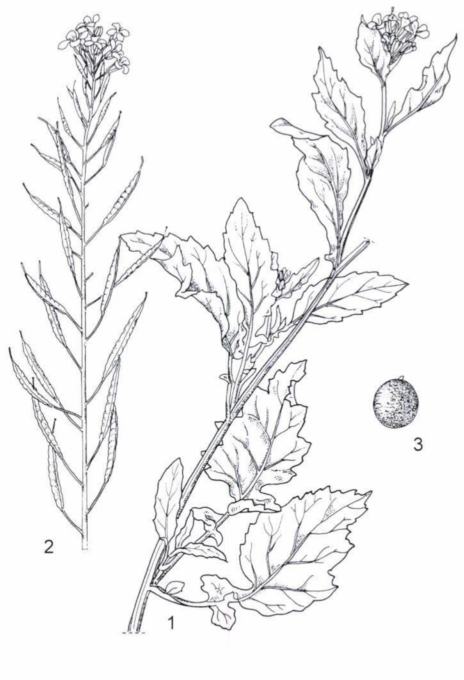
841 mg, Fe 10.0 mg, vitamin A 62 IU, thiamin 0.54 mg, riboflavin 0.38 mg, niacin 7.9 mg, ascorbic acid 3 mg (USDA, 2003).

The seeds and leaves contain the glucosinolate sinigrin. Their pungency develops when cells are damaged and sinigrin is hydrolyzed by the enzyme myrosinase to form allyl isothiocyanate. The seed also contains sterols of which the most important ones are brassicasterol, campesterol and sitosterol. The oil content of the seed is 28–45% with an average of about 35%. The oil is similar to that of other *Brassica* species and is made up of erucic acid 25–55%, oleic acid 8–33%, linoleic acid 12–21%, linolenic acid 8–14%, eicosenoic acid 6–12%, palmitic acid 2–4%, stearic acid 0.8–1.5%, arachidic acid 0.5–1.2%, palmitoleic acid 0.2–0.5%, nervonic acid 0–2%, behenic acid 0–1% and lignoceric acid 0–1%. Eicosenoic acid and erucic acid are long-chain fatty acids that have antinutritional and toxic properties. Cultivars yielding oil low in eicosenoic acid and erucic acid have been developed. Their fatty acid composition is: palmitic acid 56%, stearic acid 25%, arachic acid 10%, behenic acid 6% and lignoceric acid 3% (USDA 2002). They are generally recognized as safe for human consumption. Together with cultivars of *Brassica napus* and *Brassica rapa*, yielding similar oil, they are known in Canada as 'canola'. The seed cake remaining after oil extraction contains about 37% crude protein.

Experiments with rats suggest that brown mustard might be beneficial in attenuating the damage caused by oxidative stress involved in diabetes and its complications.

Adulterations and substitutes Mustard leaves are often erroneously called 'rape leaves', but rape (*Brassica napus*) is a distinct vegetable and oil crop. Brown mustard as leafy vegetable can easily be replaced by leaf cabbages (special cultivars of *Brassica oleracea*, *Brassica carinata* and *Brassica napus*), although these lack the typical taste of brown mustard.

Description Erect, annual to biennial herb up to 160 cm tall, often unbranched, sometimes with long ascending branches in upper part, almost glabrous to scattered hairy, slightly glaucous; taproot sometimes enlarged (root mustard). Leaves alternate, pinnately lobed but upper ones often simple; stipules absent; all leaves with short petiole; blade ovate to lanceolate or with up to 2 side lobes on each side and a large end lobe, up to 30 cm × 10 cm, margin irregularly toothed. Inflorescence initially an umbel-like raceme but soon strongly elongating, up to 60 cm long. Flowers bisexual, regular, 4-merous; pedicel ascending, 5–12 mm long; sepals oblong, 4–6 mm long, green; petals obovate, 6–10 mm long, clawed, bright yellow; stamens 6; ovary superior, cylindrical, 2-celled, stigma globose. Fruit a linear silique 2.5–7.5 cm × 2–3.5 mm, often constricted between the seeds, with a conical beak usually longer than 6 mm, dehiscent, up to 20-seeded. Seeds globose, 1–1.5 mm in diameter, finely reticulate, pale to dark brown.



Brassica juncea – 1, flowering branch; 2, flowering and fruiting branch; 3, seed.
Source: PROSEA

Other botanical information *Brassica juncea* is a highly variable species which has been cultivated for centuries as a vegetable and oil plant, and is also a widespread weed. *Brassica juncea* cultivars have only slightly glaucous, often dark green and more or less hairy leaves, distinct from the bluish green, glabrous leaves of the other leaf brassicas. In Africa it has been much confused with *Brassica carinata*, but the lower leaves of the latter species are simple or have up to 1 side lobe on each side, and its fruit beak is shorter (usually < 6 mm).

Several authors have proposed cultivar classifications for *Brassica juncea*. These have little relevance for Africa, where farmers use mostly local cultivars. Only occasionally is seed imported from Western seed companies, e.g. 'Florida Broad Leaf'.

Growth and development Seed germinates within 5 days after sowing at 20–25°C. Under good conditions plants grow rapidly and leaves are harvestable after 3 weeks when plants have developed 6–8 fully expanded leaves, but harvesting will start later when larger leaves are demanded for sale. Under tropical African conditions, flowering occurs early as low temperatures are not required for flower induction. Water stress or low soil fertility promote early flowering. *Brassica juncea* is self-fertile, but bees may effect cross-pollination. Fruits develop rapidly and the seeds can be ready for harvesting within 4 weeks from flowering.

Ecology Brown mustard is reported to tolerate annual precipitation of 500–4000 mm and temperatures of 6–37°C and is therefore suited to the tropical lowlands as well as relatively cool conditions. It grows best on fertile, well-drained loamy soils with a pH of 5.5–6.8, rich in organic matter. At high temperatures it will quickly flower and yields are lower, but production is still possible. For seed production, brown mustard is tolerant of adverse conditions including moisture stress, high or low pH, salt and insect damage.

Propagation and planting Brown mustard can be sown directly or transplanted. Direct sowing is mainly used when time is a limiting factor and where there is a market that will accept smaller leaves. This system is frequently used in Zambia in wet areas called 'dambos'. The weight of 1000 seeds is 1.7–2 g. The seeds need to be mixed with sand and broadcast thinly to avoid the need for removing too many seedlings later on. The first harvest can be in the form of thinned-out seedlings, collected after about 35 days from sowing. Transplanting is common and seedlings are raised in 1 m wide nursery beds with fertile finely-tilled soil. Seed beds should be prepared by loosening the soil and incorporating up to 50 kg of well-fermented manure per 10 m^2. Seed is sown in drills 25–30 cm apart and seedlings are thinned to a spacing of 5–10 cm. Seedlings need to be adequately watered. They are ready for transplanting after 20–30 days when they have 3–4 true leaves, and are planted at a spacing of 30–50 cm between rows and 20–40 cm in the row, depending on the size of the plant required. When grown as an oil crop, seeding is at a rate of 4–6 kg/ha. Plant density may vary as brown mustard has a considerable capacity to compensate for an irregular plant stand.

Management The uptake of minerals by brown mustard is high and manure application to the field at a rate of 30 t/ha is recommended. When no manure is available, it can be replaced by a fertilizer gift of about 500 kg/ha NPK 18–12–12, depending on soil fertility. Top dressing of N-fertilizer is practised a few weeks after transplanting. For seed production fertilizer applications may be lower. Weeding is required during the early growth stages of leaf mustard and ample watering is necessary to promote rapid growth. Early flowering can occur during hot weather with high temperatures. In several parts of the United States *Brassica juncea* is considered a noxious and invasive weed

Diseases and pests A devastating disease of brown mustard during the rainy season is bacterial soft rot (*Erwinia carotovora*), for which there is no adequate control. Another bacterial problem is black rot caused by *Xanthomonas campestris*, a disease that is both soilborne and seedborne. Amongst the fungal diseases, the most important is Alternaria black spot (*Alternaria brassicae* and *Alternaria brassicicola*). Turnip mosaic virus (TuMV) is also noticed quite frequently on brown mustard.

The most destructive pest is diamondback moth (*Plutella xylostella*), especially during the dry season. Other pests are cabbage web worm (*Hellula undalis*), caterpillars of the mustard leaf webber (*Crocidolomia binotalis*), aphids and flea beetles (*Phyllotreta* spp.) and several nematodes. In cold weather brown mustard has few pests, but warmer weather will bring on aphids and other insects.

Field sanitation, rotation with unrelated crops and the use of pathogen-free seeds considerably reduce the impact of pests and diseases. However, under conditions of subsistence production little is done to control pests and diseases.

Harvesting Harvesting of leaves starts about 4 weeks after transplanting. Leaves may be cut once weekly during the vegetative phase until the crop loses its tenderness and leaves become stiff. When the crop starts developing inflorescences, it becomes more economical to replant. In some cases young plants are harvested whole with their roots attached, espe-

cially when grown under closer spacing. In Africa leaves of 15–30 cm long are preferred for marketing.
For seed production, plants should be harvested before fruits are fully ripe to reduce shattering of the seeds. Harvesting is usually done early in the morning. Plants are tied into bundles and dried in the sun for 4–10 days.

Yield The leaf yield of *Brassica juncea* ranges from 8–35 t/ha, with 20 t/ha as average on better farms. In Zimbabwe, this crop performs better during the winter, with average yields of 20–30 t/ha. Seed yields of brown mustard in India range from 900–1200 kg/ha with an oil content of 30–38% and in the United States seed yields are about 1100–1500 kg/ha.

Handling after harvest Under hot conditions, leaves wilt soon after harvest and are therefore sold as soon as possible. Where facilities are available, it is recommended that the product be cooled to near 0°C immediately after cutting, and that it be kept as cool as possible during transport and marketing. This can be done by placing ice between the leaves, which will also keep the humidity high. The humidity can also be kept high by packing the leaves in polythene bags or plastic film.
In Zimbabwe farmers dry the leaves in the sun for use during the off-season. Dried leaves offered as broken pieces and packed in polythene bags are frequently encountered at markets in Harare and elsewhere in Zimbabwe. Extraction of oil from the seed is by rotary mill, expeller or hydraulic processes. Mustard is made by mixing ground seeds with water, spices and vinegar.

Genetic resources Large germplasm collections of *Brassica juncea* are maintained at the Australian Temperate Field Crops Collection, Horsham Victoria, Australia, the Institute of Crop Germplasm Resources (CAAS), Beijing, China, the All India Coordinated Research Project on Rape & Mustard, Haryana University, Hisar, Haryana, India and the N.I. Vavilov All-Russian Scientific Research Institute of Plant Industry, St Petersburg, Russian Federation. Smaller working collections are held in many other countries. A working collection of brown mustard with African landraces is present at the Horticultural Research Centre, Marondera, Zimbabwe. The diversity found in farmers' fields in Africa is considerable and there is a need to collect and evaluate this material before this potentially valuable resource disappears with the introduction of improved varieties.

Breeding Many African farmers use their own landraces of farm-saved seed. *Brassica juncea* can be reproduced by means of self-pollination, allowing for a rapid purification of new selections. East-West Seed Company in Thailand has developed cultivars especially for tropical conditions, e.g. 'Mayur' harvestable 30–35 days after sowing or 21–25 days after transplanting, and 'Laguna' with bolting tolerance at high temperatures and harvestable 40–45 days after sowing. 'Suehlihung No.2' is a cultivar from Taiwan that is resistant to soft rot and viruses. It can be grown year-round in Taiwan and be harvested 20 days after transplanting. The cultivar 'King Mustard' produces large and tender green-purple leaves.

Prospects There is a good potential for improving current landraces of this excellent vegetable which can be grown in humid hot lowland areas like the coastal regions of West Africa and the cooler regions of southern Africa. Many people prefer brown mustard and other loose-leaved *Brassica* types over white cabbage and when healthy seed of improved cultivars becomes available, the demand for this crop will increase. Prospects for *Brassica juncea* as an oil crop or for mustard production in tropical Africa are limited.

Major references Chen et al., 1997; Chen, 1982; Hemmingway, 1995; Holland, Unwin & Buss, 1991; Knowles et al., 1981; Opeña, 1993; Pryde & Doty, 1981; Schippers, 2000; Toxopeus, 2001; USDA, 2002.

Other references Bettencourt & Konopka, 1990; Duke, 1983b; Floridata, 2002; Gladis & Hammer, 1992; Jonsell, 1982b; Larkcom, 1991; Leung, 1980; Maity, Sengupta & Jana, 1980; Oplinger et al., 1991; Patel, Parmar & Patel, 1980; Perry, 1980; Prakash & Hinata, 1980; Tindall, 1983; van Epenhuijsen, 1974; Yokozawa et al., 2003.

Sources of illustration Toxopeus, 2001.

Authors R.R. Schippers & N.A. Mnzava

CARTHAMUS TINCTORIUS L.

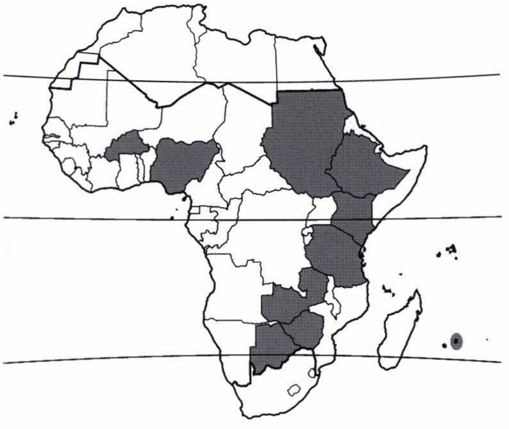
Protologue Sp. pl. 2: 830 (1753).

Family Asteraceae (Compositae)

Chromosome number $2n = 24$

Vernacular names Safflower, false saffron (En). Carthame, safran bâtard (Fr). Açafroa, saflor, açaflor (Po). Kartamu, alizeti ya miba (Sw).

Origin and geographic distribution *Carthamus tinctorius* is known only from cultiva-



Carthamus tinctorius – planted

tion and probably originated in the Middle East. Other centres of diversity are Afghanistan, Ethiopia and India. *Carthamus tinctorius* has long been domesticated, initially for the orange dye obtained from the flowers for which it was already grown in Egypt in 2000 BC. Its use as an oil crop probably came later, but also dates back to pre-Christian times. The 'Revenue Laws' 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 and grown extensively, particularly along the Chang Jian and in Sichuan. From China safflower was introduced into Japan, where it became an important source of cooking oil. From the Middle East the crop also spread westward into Europe and the Americas. Sudan, Ethiopia, Kenya and Tanzania are the main producers in tropical Africa.

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 mainly in cooking and for making salad dressings and margarine. Cultivars with a high oleic acid content 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. In India it has been used traditionally to make 'roghan wax' used in the batik industry.

Safflower has long been grown for the dye extracted from the flowers. Depending on the dyeing procedure and the addition of other colorants 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 colorant it is a substitute or adulterant for true saffron and flowers are commonly mixed with rice, bread, pickles and other food to give them an attractive orange colour.

The seed cake is used as animal feed. The cake from undecorticated seeds (botanically the fruit) containing matairesinol-glucoside is only suitable for ruminants. After removal of the bitter compounds, the cake from decorticated seed would be excellent feed for monogastric animals too, but decortication is generally too costly. Safflower meal and flour from decorticated seed are used in the production of high-protein human diet supplements. The flour can be added to wheat flour to make breads and pies. The hulls have been used to make potting mixtures for nurseries, packing and insulation materials, and as filler for bricks.

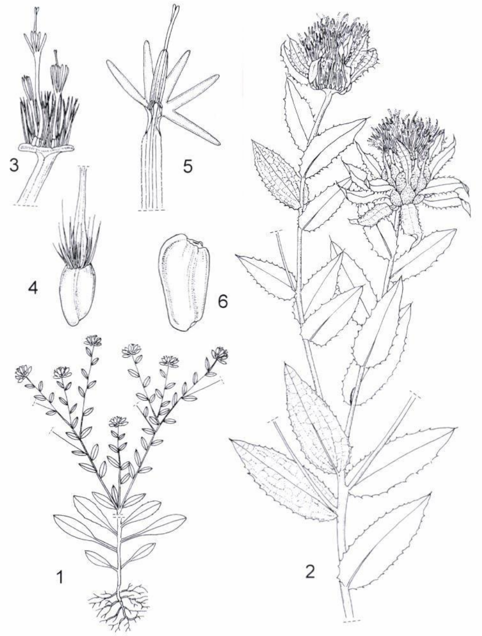
In Asian countries the young leaves are eaten as a vegetable, the seeds are used in cooking and the fruits as bird feed. Safflower herbage is valuable as green fodder and may be stored as hay or silage. The straw is also used as fodder.

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. In Mauritius the flowers are used to treat jaundice, while the seeds are considered laxative. The sap is believed to reduce salivation. The oil is applied to treat scabies. Some cultivars are grown as ornamentals, and safflower is also popular as a cut-flower, fresh or dried.

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. In recent years production has increased again to about 800,000 t in 2005. 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 30–40% hull and 60–70% kernel (botanically the seed). The kernel may contain 35–60% oil. The proportion of hull was higher in the past and a handicap to commercial production, but the recently introduced thin-hulled types may hamper mechanical harvesting and processing. The kernel contains a drying oil. Two types of cultivars yielding different oils are recognized: oleic safflower oil and linoleic safflower oil. The fatty acid composition of the former is: palmitic acid 5–6%, stearic acid 1.5–2%, oleic acid 74–80%, linoleic acid 13–18% and traces of linolenic acid and longer chain fatty acids; the fatty acid composition of linoleic safflower oil is: palmitic acid 5–8%, stearic acid 2–3%, oleic acid 8–30%, linoleic acid 67–83(–89)% and also traces of linolenic acid and longer chain fatty acids. Safflower types producing oil with an intermediate fatty acid composition also occur. 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, the residual cake of undecorticated safflower 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. The high fibre content limits the value of undecorticated cake as livestock feed, but removing the hulls is costly. Undecorticated meal can only be used to supplement a grain, lucerne or silage ration to fatten cattle. It cannot be fed to pigs, except in small quantities, nor to poultry. However, hulled seedmeal can be given to pigs.
The flowers of safflower contain two major pigments: the water-soluble, yellow carthamidin and the formerly important dye carthamin, a flavanone which is orange-red and soluble in alkaline solutions. Flowers contain 0.3–0.6% carthamin. Flavonoids, glycosides, sterols and serotonin derivatives have been identified from the flowers and seeds, including matairesinol, one of the main lignan precursors in dietary fibre.

Description Erect, much-branched, glabrous,



Carthamus tinctorius – 1, plant habit; 2, flowering branch; 3, detail of head; 4, lower part of flower; 5, upper part of flower (opened); 6, achene.
Source: PROSEA

annual herb, up to 180 cm tall; root system well developed, brownish grey, taproot thick and fleshy, penetrating up to 3 m deep, horizontal lateral roots thin, occurring mainly in the upper 30 cm; stem cylindrical, solid with soft pith, woody near the base, grooved, greenish white. Leaves arranged spirally, sessile, simple; stipules absent; blade oblong to ovate-lanceolate, 4–20 cm × 1–5 cm, margins more or less spiny toothed, glossy dark green. Inflorescence a terminal, urn-shaped head, 2.5–4 cm in diameter; involucral bracts numerous, arranged spirally, outer ones oblong, constricted above the base, 3–7 cm × 0.5–1.6 cm, hairy outside, pale green, upper part leafy and spinescent, inner bracts lanceolate, 2–2.5 cm × 1–4 mm, apex bearing a spine; receptacle flat to conical, with abundant, whitish bristles 1–2 cm long and 20–80 bisexual flowers and a few sterile marginal ones. Flowers tubular, sessile, regular, 5-merous, c. 4 cm long, glabrous, mostly orange-red becoming dark red during flowering, sometimes yellow; corolla with 18–22 mm long tube and spreading, narrowly oblong to linear lobes 7 mm × 1 mm; stamens with filaments 1–2 mm long, anthers c. 5 mm long, fused; ovary inferior, ellipsoid, 3.5–4.5 mm long, 1-celled, style slender, c. 30 mm long, glabrous, stigma c. 5 mm long, bifid, yellow, with short hairs. Fruit an often obliquely obovoid achene 5.5–8 mm × 3–5 mm, 4-angled, glabrous, glossy white but often pale brown near the top, innermost fruits in a head often with pappus of bristles c. 6 mm long. Seed without endosperm. Seedling with epigeal germination; taproot strong; hypocotyl greenish white; cotyledons leaflike, obovate, c. 6 cm × 1.5 cm, greyish pale green; first leaves lanceolate with tapering base; juvenile plants with leaf rosette.

Other botanical information *Carthamus* comprises about 15 species. Section *Carthamus* comprises *Carthamus tinctorius* and its 5 closest relatives, all annual species from western Asia with $n = 12$.

Because *Carthamus tinctorius* has been cultivated over a wide area since ancient times, and because cross-pollination is fairly common, variability in safflower is large. The morphological differences are most obvious in branching (height, density), leaves (presence or absence of rosette leaves, more or less spiny leaves), involucral bracts (form, pubescence, spiny or not), inflorescences (number and size of heads), flower colour (reddish, orange, yellow, white), and achenes (size, presence or absence of pappus).

Growth and development Safflower generally lacks seed dormancy and can germinate in the head if rainfall occurs at harvest time. After germination, the seedling enters the rosette stage, characterized by slow growth, production of a rosette of leaves 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, which allows them to overwinter. Cultivars in Ethiopia do not form rosettes, but form a stem immediately. Safflower is generally a long-day plant. Flowering is normally initiated by approximately 14 hours of daylight, but this can be modified by temperature, high temperatures accelerating flowering. Salinity may also accelerate the onset of flowering. Cultivars differ in sensitivity to daylength and daylength-neutral cultivars 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 and branch. After the completion of growth of secondary branches and the formation of flower heads (75–100 days after sowing), flowers start to appear in the heads. Flowering begins in the head of the main axis, followed by the main branches; secondary and tertiary branches follow sequentially. Flowering normally begins at the head's margin, proceeds towards the centre 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.

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 between 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 is 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 it favours 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 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 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. The 1000-seed weight is 40–80(–100) g. Most seed drills are suitable for sowing safflower, but should be calibrated. 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 are 10–15 kg/ha in very drought-prone regions to 30 kg/ha under higher rainfall conditions. Under irrigation and when cultivars with minimum branching are grown, 40–60 kg/ha is used.

Wide rows, 35–60(–90) cm with close in-row spacing, generally give 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.

Management Safflower is readily integrated into mechanized small grain production. During the rosette stage, safflower is a poor competitor with weeds. Mechanical weeding of young safflower is difficult, and pre-planting harrowing should aim at maximum weed reduction. 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.

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 should be 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. Rainfed crops 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 and in Ethiopia safflower cultivation is closely associated with the distribution of teff (*Eragrostis tef* (Zuccagni) Trotter) and barley (*Hordeum vulgare* L.) with which it is mostly intercropped, Elsewhere, intercropping is not common because the yields are low as a result of 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; the most serious and widespread is leaf blight caused by *Alternaria carthami*. Root rots caused by *Fusarium oxysporum* and *Phytophthora* spp. including *Phytophthora cryptogea* and *Phytophthora*

drechsleri are widespread and very damaging. *Phytophthora drechsleri* is especially serious in surface-irrigated safflower and its incidence and severity are 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. However, the safflower fly *Acanthiophilus helianthi* can be very damaging and virtually preclude safflower growing. Pesticide use is often uneconomical and it is always necessary to balance control costs against allowable damage. Early planting and growing short-duration cultivars help reduce damage by evading infestation. *Condica capensis* (synonym: *Perigea capensis*) attacks at all stages of development and is common in India, Pakistan and South-East Asia. Bollworm (*Helicoverpa* spp.) and black cutworm (*Agrotis ipsilon*) occur in all countries that grow safflower and are of varying importance.

Harvesting Harvesting of safflower usually begins 35–40 days after maximum flowering, when plants are quite dry but not brittle, involucral bracts on heads turn brown and fruits have a moisture content below 8%, preferably 5%. While harvesting is done manually in many areas, 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 flowers are washed and later dried.

Yield The average seed yield of safflower grown under rainfed, intensive cultivation has increased steadily to 1500 kg/ha and nearly twice this under irrigation. Average yields in Ethiopia and India are about 500 kg/ha. Yields of straw are larger than those of small grain crops and may reach 5 t/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 carthamidin 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 done, including work on related species considered valuable sources of genetic material. Evaluation of germplasm collections showed large variability in agronomically important characters, including spininess, seed yield per plant, flower heads per plant, hull percentage, crop duration, rosette period, dry matter production and days to maturity. Resistance to the pest *Acanthiophilus helianthi* has not yet been found. The ARS-GRIN Western Regional Plant Introduction Station, Pullman WA, United States maintains a germplasm collection of 2300 accessions of *Carthamus tinctorius* and many related species. The Institute of Oil Crops Research, CAAS, Wuhan, Hubei, China holds 2300 accessions, the Regional Station Akola, NBPGR, Akola, Maharashtra, India 2000 accessions.

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 being reported. There is a major need to expand safflower's adaptation through genetic research and breeding.

Prospects In industrialized countries where research has linked health and diet, demand for unsaturated oils has increased, thereby creating a growing market for such oils as health foods. This may lead to an increasing demand for and production of safflower. Poten-

tial yield levels, yield stability and improved pest control need research attention. The large genetic diversity gives ample scope to develop improved cultivars.
The use of dyes from natural sources in food products is gaining popularity because of possible harmful effects from synthetic colourings.

Major references Fernández-Martinéz, del Rio & de Haro, 1993; Firestone, 1999; Hanelt, 1963; Jaradat & Shahid, 2006; Li & Mündel, 1996; López González, 1990; Oyen & Umali, 2001; Seegeler, 1983; Vilatersana et al., 2005; Weiss, 2000.

Other references Ashri, 1971; Bassil & Kaffka, 2002; Bradley et al., 1999; Garnatje et al., 2006; Hanelt, 1961; Knowles & Ashri, 1995; Modestus, 1992; Riungu, 1990; Stern & Beech, 1965; Verma et al., 1997; Vilatersana et al., 2000; Weiss, 1971; Yau, 2005; Zang et al., 1997.

Sources of illustration Oyen & Umali, 2001.

Authors L.P.A. Oyen & B.E. Umali
Based on PROSEA 14: Vegetable oils and fats.

CEPHALOCROTON CORDOFANUS Hochst.

Protologue Flora 24(1): 370 (1841).

Family Euphorbiaceae

Origin and geographic distribution *Cephalocroton cordofanus* occurs naturally in northern Nigeria, and from eastern Sudan east to Ethiopia and Eritrea, and south to north-eastern Tanzania.

Uses The seeds, locally called dingili seeds, are eaten in eastern Sudan. They are rich in a highly unsaturated oil, which is occasionally extracted and used in cooking.

Properties The seeds contain 42% oil, the kernel about 56%. The oil has a pleasant odour and taste. It consists chiefly of cis-12:13-epoxyoleic acid (62%) along with saturated acids (7%), oleic acid (10%), linoleic acid (17%) and 12:13-dihydroxyoleic acid (4%).

Botany Monoecious, perennial much-branched shrub up to 3 m tall; taproot stout; bark dark grey; all parts covered with stellate hairs, young parts somewhat viscid. Leaves alternate, simple; stipules irregularly cleft with filiform segments, c. 2 mm long; petiole 1–2.5 cm long; blade broadly ovate-oblong to elliptical-ovate, (0.5–)1.5–4(–6) cm × (0.5–)1–2.5(–4) cm, base rounded or shallowly cordate, apex acute to rarely obtuse, margins entire to toothed, papery, 5–7- veined from the base. Inflorescence a terminal raceme, with male flowers in a dense terminal globose cluster and 1–4 female flowers at base of peduncle; peduncle 2–6 cm long; bracts up to 3 mm long. Flowers unisexual, regular; petals absent; male flowers with pedicel up to 5 mm long and with 4 glabrous, elliptical-ovate sepals c. 2 mm × 1–1.5 mm, white to pale greenish white, stamens 4–5, free, filaments c. 5 mm long, bright yellow, pistillode cylindrical, 2-lobed; female flowers sweet-scented, with pedicel up to c. 1.5 cm long and with 6 sepals, bipinnately lobed, c. 5 mm long, strongly enlarging in fruit, lobes linear, with side lobes, often flushed purplish red, ovary superior, c. 2 mm in diameter, 3-lobed and 3-celled, styles 3, fused at base, c. 7 mm long, cleft into many lobes, lime-yellow to ochre. Fruit a deeply 3-lobed capsule c. 12 mm in diameter, hairy, 3-seeded. Seeds ovoid to nearly globose, c. 7.5 mm × 6 mm, smooth, evenly greyish or dark brown flecked and mottled, somewhat shiny.
Cephalocroton comprises 3 species in tropical Africa and South Africa. It is closely related to *Adenochlaena* (1 species from Madagascar and the Comoros and 1 from Sri Lanka) and *Cephalocrotonopsis* (1 species from Socotra), which are commonly included in *Cephalocroton*.

Ecology *Cephalocroton cordofanus* usually occurs on sandy soils, less often on clayey soils (including black cotton soil), in dried-out river beds, in seasonally waterlogged, open grassland and in mixed open bushland, up to 1200 m altitude.

Management The seeds are mainly collected from the wild, but occasional cultivation has also been reported.

Genetic resources and breeding *Cephalocroton cordofanus* occurs only sparsely in its wide area of distribution. However, there are no indications that it is threatened by genetic erosion.

Prospects The presence of epoxy and hydroxy fatty acids in high concentrations make the oil an interesting raw material in chemistry. The physiology which leads to these high concentrations deserves research attention.

Major references Bharucha & Gunstone, 1956b; Gilbert, 1995; Mansfeld, 1986; Morris & Holman, 1961; Radcliffe-Smith, 1987.

Other references Bharucha & Gunstone, 1956a; Eckey, 1954; Gilliland, 1952; Govaerts, Frodin & Radcliffe-Smith, 2000; Henry & Grindley, 1943; Radcliffe-Smith, 1973; Radcliffe-Smith, 2001.

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COCOS NUCIFERA L.

Protologue Sp. pl. 2: 1188 (1753).
Family Arecaceae (Palmae)
Chromosome number $2n = 32$
Vernacular names Coconut palm (En). Cocotier (Fr). Coqueiro (Po). Mnazi (Sw).

Origin and geographic distribution *Cocos 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 palm to remain viable after floating long distances at sea ensured wide natural dispersal in the Indo-Pacific region long before domestication may have started in South-East Asia. The domesticated coconut palm has a robust stem and large fruits, which cannot survive long periods of floating at sea because of thinner husks and shells and quicker germination. Initial dissemination of the domesticated coconut palm coincided with migrations of South-East Asian peoples to the Pacific and India, which started 3000 years ago. Where wild coconut palms already occurred, there was opportunity for introgression with domesticated types, as they remained compatible. Polynesian, Malay and Arab navigators played an important role in further dispersal of coconut into the Pacific, Asia and East Africa. Coconut palm 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. Coconut palm is planted throughout lowland tropical Africa, mainly along the coast in more humid areas.

Uses Coconut palm has been called the 'tree of life', because of its value as provider of so many useful products. For domestic oil extraction a mixture of grated fresh endosperm from the fruit and water is boiled until floating oil can be skimmed off. For industrial production the endosperm is first dried to copra before it is 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 low grades is processed into soap, detergents, cosmetics, shampoos, paints, varnishes and pharmaceutical products. Remnant fatty acids and alcohols and their methyl esters find application as components of emulsifiers and surfactants. The press cake or copra meal is a good livestock feed.

Coconut milk or cream pressed from the mix of freshly grated endosperm with water has been a traditional ingredient in many African and especially Asian food and bakery products. It is now also marketed in pasteurized and homogenized canned or powdered form. 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. Shredded or thinly sliced and desiccated fresh coconut endosperm is a favourite side dish and ingredient in many confectionery, bakery and snack food products.

Water in the cavity of young coconuts provides a cool and sweet-tasting, popular refreshment. It is now also commercially preserved without altering its typical flavour. The tender, jelly-like endosperm of young coconuts is a delicacy consumed directly or grated and mixed with food. The haustorium or apple which fills the cavity of germinating coconuts is also edible. The liquid endosperm of mature coconuts can be used to produce a fermented gelatinous dessert called 'nata de coco' in the Philippines.

The shell (endocarp) covering the seed 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 (mesocarp) yield, after retting, 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 alcoholic beverage called 'arak'.

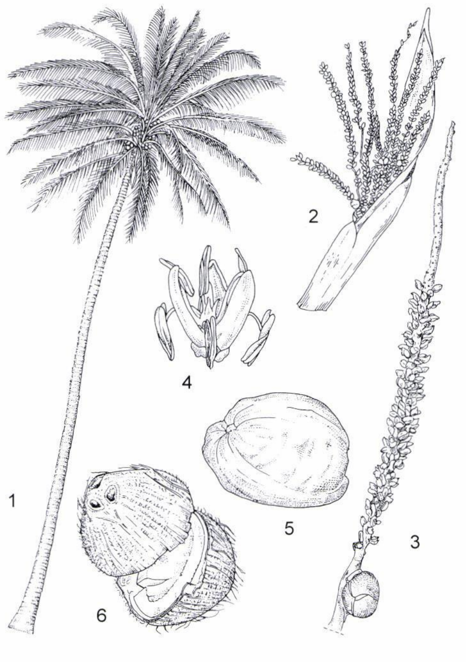
The leaves are used to thatch roofs; the leaflets are plaited into mats, baskets, bags and hats; immature leaflets are made into traditional decorations and small bags or containers for food; the midribs of the leaflets are formed into brooms. The palm heart, which consists of the

white, tender tissues of the youngest, unopened leaves at the stem apex, is considered a delicacy. Young coconut 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 wood is needed if it is to be used for construction or any outdoor use. Coconut palm wood is also suitable for furniture, household utensils and tool handles.
Medicinal uses have been attributed to coconut palm. The roots are considered antipyretic and diuretic. Milk of young coconut is diuretic, laxative, antidiarrhoeic and counteracts the effects of poison. The oil is used to treat diseased skin and teeth and mixed with other medicines to make embrocations.
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.

Production and international trade Average annual world production in 2002–2004 was estimated at about 58,000 million coconuts, equivalent to 10.5 million t of copra, from 11.8 million ha in 93 countries. The copra of about 55% of all coconuts is commercially extracted to produce annually some 3.3 million t oil and 1.8 million t coconut meal, the remaining coconuts being processed domestically or sold as young coconuts for drinking. Coconut palm is mainly a smallholder crop and only about 6% of the total area consist of estates. Asia and the Pacific account for 86% of world production, Latin America and the Caribbean for 10% and Africa for 3% (6% of planted area). The major producers are Indonesia (30% of world production), the Philippines (23%) and India (17%). Estimated areas planted with coconut palm in Africa are: Tanzania 310,000 ha, Mozambique 70,000 ha, Ghana 55,000 ha, Nigeria 50,000 ha, Madagascar 33,000 ha and Côte d'Ivoire 30,000 ha.
With about 2.1 million t of oil traded annually, coconut palm is the 7th most important supplier of vegetable oil in the global market. It has a special position in the market together with palm-kernel oil as a major source of lauric oil. The Philippines exports 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 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%. Fresh endosperm contains 35–52% water; high-quality copra has 63–68% oil, no more than 6% water and less than 1% free fatty acid. The proximate composition of dried copra per 100 g edible portion is: water 3 g, energy 2761 kJ (660 kcal), protein 7 g, fat 65 g, carbohydrate 24 g, fibre 16 g, Ca 26 mg, Mg 90 mg, P 206 mg, Fe 3 mg, Zn 2 mg, vitamin A 0 mg, thiamin 0.06 mg, riboflavin 0.1 mg, niacin 0.6 mg, vitamin B_6 0.3 mg, folate 0 mg, ascorbic acid 1.5 mg. The fatty acid composition of coconut oil is: caproic acid 0.6%, caprylic acid 7.5%, capric acid 6%, lauric acid 45%, myristic acid 17%, palmitic acid 8%, stearic acid 3%, oleic acid 6%, linoleic acid 2% (USDA, 2006). More than 90% of the fatty acids are saturated. Lauric acid is an easily digestible source of energy and a precursor of the antimicrobial 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 carbohydrate 2%; powdered coconut milk: fat 60%, protein 7% and carbohydrate 27%; dried and powdered skim milk: fat 6%, protein 24% and carbohydrate 25%; spray-dried coconut protein powder: protein 59%. Presscake contains: fat 6%, protein 21%, carbohydrate 49% and crude fibre 12%.
Coconut palm wood, known as 'cocowood' in trade, has a basic 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 unbranched palm tree up to 30 m tall, with a terminal crown of leaves; roots mostly in the top 1.5 m of soil, normally c. 6 m × 1 cm but in optimum soil conditions up to 30 m long; stem cylindrical, erect, often curved or slanting, up to 40 cm in diameter but the swollen base up to 60 cm, pale grey, conspicuously ringed with scars of fallen leaves. Leaves arranged spirally, pinnately compound, 4.5–6(–7) m long, 25–35 unfolded leaves per plant; 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 1–2 m long, in axils of leaves,



Cocos nucifera – 1, tree habit; 2, young inflorescence; 3, inflorescence branch; 4, male flower; 5, fruit; 6, opened stone ('nut').
Source: PROSEA

enclosed by a large bract when young, consisting of up to 40 spirally arranged spikes, each bearing 200–300 male flowers and 1–few female flowers in basal parts. Flowers unisexual, regular, 3-merous; male flowers 1–3 together, sessile, 0.5–1.5 cm in diameter, 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, almost orbicular, almost equal, persistent and enlarging in fruit, with large 3-celled ovary, 3 sessile triangular stigmas and 3 nectaries near ovary base. Fruit a globose, ovoid or ellipsoid drupe, indistinctly 3-angled, 20–30 cm long, weighing up to 2.5 kg, 1-seeded; 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 ('husk') fibrous, 4–8 cm thick, pale brown; stone (called 'nut') ovoid, 10–15 cm in diameter, endocarp ('shell') 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. Seed with a thin brown testa closely appressed to endocarp and adhering firmly to firm, white, oil-rich endosperm ('meat'), 1–2 cm thick, embryo 0.5–1 cm long, with large cavity in centre of seed.

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

Up to now, cultivated coconut palm has been classified into 2 groups: tall types and dwarf types. More than 95% of all cultivated coconut palms belong to the tall type. Cultivars of the tall type are: 'Malayan Tall', 'Rennell Island Tall', 'Vanuatu Tall', 'Jamaican Tall', 'West African Tall' and 'East African Tall'. The dwarf type is rare, but can be found in different ecotypes. Characteristics of the dwarf type are: weaker growth and slow height increment; slender stem with almost no thickened base; 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 tall types by its very short internodes and short rigid leaves; the medium-sized types such as 'Malayan Dwarf' from Indonesia, 'Gangabondam' from India and 'King' from Sri Lanka; and the small dwarf cultivars in various countries. Dwarf types are also differentiated based on the colour of leaf petiole of young palms: green, yellow and red (orange or golden).

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

Growth and development Mature fruits of most coconut palm 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 germination 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 pinnately compound.

Cultivars of the tall type produce about 10 leaves during the first year, those of the dwarf type about 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 tall types and hybrids and 20–22 leaves for dwarf types. Since a leaf of a tall coconut 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, and premature fruit 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 types yield earlier and more than tall types. First flowering in tall types occurs after 5–7 years, in dwarf types after 2 years, and in dwarf × tall hybrids 3–4 years after germination. Growing conditions have great influence on these aspects. Coconut palm trees can be more than 100 years old, but highest yields are usually obtained at 10–20 years of age for tall types and a few years earlier in dwarf types and hybrids. In coconut plantations in coastal Tanzania yields slowly increase until the trees are 20 years old, yields increase at a faster rate until age 40 and start declining at age 50. It is recommended to replant when the palms are 60–70 years old.

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 types or 1 week in dwarf types after the enveloping bract has opened, and the stigmas of the last female flower turn brown 5–12 days later. Female flowers are nectariferous and sweet scented. Pollination is both by insects and by wind. Each female flower remains receptive for 2–3 days.

Tall types are generally allogamous because the male and female phases do not overlap, while in dwarf types 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 physiological causes. Fruits are mature 11–12 months after anthesis, but may not drop until 15 months old.

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 coconut palm is planted in areas below 500 m altitude, it may thrive at altitudes up to 1000 m, although low temperatures will affect growth and yield.

Generally, coconut palm grows in areas with evenly distributed annual rainfall of 1000–2000 mm and high relative humidity, but it can still survive in drier regions if there is adequate soil moisture. The semi-xerophytic leaves enable coconut palm to minimize water loss and withstand drought for several months.

Coconut palm thrives in a wide range of soils, from coarse sand to clay, provided they have adequate drainage and aeration. Coconut palm is halophytic and tolerates salt in the soil well. Coconut palm 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 palm will in general not produce more than 100–150 seed-nuts per year. Although 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 constraint to practical methods of large-scale clonal propagation so far. 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 5–8 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 palm 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 6–7 m × 6–7 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. Many growers prefer wider spacing to prevent inter-tree competition. As the open crowns also transmit a fair portion of incident light coconut palm is well suited to intercropping. It is occasionally grown with cocoa and coffee. Although this usually results in lower copra yields, the combined income from well-fertilized coconut palm and intercrop is much higher than that from coconut palm alone. Coconut palm is also grown in mixed cropping systems with other crops such as rubber, mango, cashew, citrus and banana. Pastures are sometimes established under the palms for use in mixed husbandry. Green manures are also 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.

Management Weeding is essential, especially for young coconut palms. Fertilizing is required, especially on soils that have been cultivated for many years, but smallholders seldom apply fertilizers due to limited financial resources. If nutrient deficiencies largely limit growth and yield, responses to organic and inorganic fertilizer application and other cultural practices such as cover crops and green manuring can be observed within one year. Potassium and chloride are the major nutrients needed by coconut palm, followed by nitrogen, phosphorus and sulphur. Leaf analysis is an accepted and quick guide to the fertilizer requirements of the palm. The annual crop nutrient removal of one ha of coconut palm, yielding 7000 nuts (1.0–1.3 t copra), 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. Organic fertilizers have additional benefits of improving texture, water-holding capacity, cation exchange capacity and microflora of the soil, but generally cannot adequately compensate for crop nutrient removal, K in particular. An example of recommended inorganic fertilizer application per year and per palm is a mixture of 0.4 kg N, 0.3 kg P_2O_5, 1.2 kg K_2O, 0.2 kg S and 0.9 kg Cl, applied 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. 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. Serious threats to global coconut production are the lethal yellowing disease in the Caribbean and lethal yellowing-like diseases, such as the Kalimantan and Natuna wilts and Sulawesi yellows (Indonesia), Malaysian wilt, Socorro wilt (Philippines), Tatipaka disease and root wilt (India), leaf scorch decline (Sri Lanka), Awka disease (Nigeria), Cape St. Paul wilt (Ghana), Kaincopé disease (Togo), Kribi disease (Cameroon) and lethal disease (Kenya, Tanzania and Mozambique). The causal agent in each case is a related but distinct phytoplasma, as confirmed by molecular diagnostic assays. Generally, the symptoms of yellowing diseases are browning and collapse of spear leaves (leaves of full length, but still folded), yellowing of mature leaves, collapse of roots, premature nut fall, death of bud and later, of the tree. The probable vector of lethal yellowing disease is a plant hopper (*Myndus crudus*), but in all other cases implicated insect vectors have not yet been confirmed unambiguously. Blast disease and dry bud rot in coconut palm nurseries in Tanzania are probably also caused by a phytoplasma. Control measures include eradication of affected palms, plant quarantine and host resistance. Tall palms are generally susceptible. 'Malayan Dwarf' is highly tolerant of lethal yellowing disease, while 'Pemba Red Dwarf' shows resistance to lethal disease of East Africa.

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. Coconut palm in Guam is 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* that is favoured by high humidity. It causes rotting of the spear leaf and 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 *Ceratocystis paradoxa* (*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* (*Drechslera incurvata*) are widespread fungal diseases. Leaf spot diseases caused by *Cercospora* spp. and *Helminthosporium* spp. in nurseries and young plantings in East Africa can be controlled by copper fungicides or mancozeb (e.g. Dithane M45).

Numerous insect pests attack coconut palm. Several species of rhinoceros beetle are pests of coconut; the dominant species in Africa is *Oryctes monoceros*. Its larvae tunnel through the apical bud leaving characteristic triangular cuts in opened leaves. When the growing point is attacked, the palm dies. Control measures include removal of beetles from feeding tunnels, keeping the plantation free from dead stems, which are breeding grounds for the beetle, and trapping with an aggregation pheromone to reduce beetle populations. Other *Coleoptera* that inflict serious damage to coconut palm are *Promecotheca* spp., *Brontispa longissima* and *Rhynchophorus* spp. in Asia and the Pacific. Many caterpillars feed on the leaves, such as *Hidari irava*, *Tirathaba* spp., *Setoria nitens*, *Parasa lepida* and *Artona catoxantha* (*Brachartona catoxantha*) in Asia and *Latoia pallida* and *Latoia viridissima* in West Africa. *Bacillus thuringiensis* formulations can provide effective control in some cases. Coreid bugs (*Pseudotheraptus wayi* in East Africa and *Pseudotheraptus devastans* in equatorial Africa) attack flowers and young fruits, causing premature nut fall or deformed coconuts. Weaver ants (*Oecophylla longinoda* in Africa and *Oecophylla smaragdina* in Asia and the Pacific) are the most important natural enemy and stimulating their colonization of palms provides an effective method of biological control of this pest. Damage by termites (*Macrotermes bellicosus* in West Africa, *Allodontermes morogorensis* in East Africa) of seedlings in the nursery or newly planted fields should be prevented by timely nest destruction or chemical control with endosulfan or carbosulfan.

Harvesting Fruits of coconut palm can be harvested 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 coconuts is easier, but there are more losses due to rat attack and theft. Some coconuts 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 (30–50 fruits/palm). Well managed plantations of selected local tall coconut palm may yield 3–4 t copra/ha (90–130 fruits/palm). Plantations of dwarf coconut palm in Malaysia produce about 1.5–2 t copra/ha and even 3.5 t copra/ha under favourable conditions. Dwarf × tall hybrids combine the high number of fruits produced by the dwarf type with the larger fruit size from the tall one and usually have a higher yielding potential than the parents. Experimental yields of more than 6 t/ha of copra have been obtained in Côte d'Ivoire and the Philippines.

Handling after harvest Harvested coconuts are stored in a protected place until the husks are completely dry. Dried coconuts are husked manually by striking and twisting them on a steel point that is placed firmly in the ground. Husking machines have been developed but have not been a success. After husking, 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. The crude oil is subsequently cleaned by filtration, refined (chemically or by steam) to reduce its free fatty acid content, bleached (bleaching earth) to remove pigments and finally deodorized (stripping by steam) to produce a colourless cooking oil. The press cake, which still contains 6–10% oil, is ground to a meal and also pelletized if exported. In traditional extraction, coconut cream obtained from grated fresh kernel is boiled gently until the oil floats to the surface.

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

Genetic resources Local coconut palm 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 maintained 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 coconut palms 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 Philippine 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 Instituto Nacional de Investigaciones Agrícolas, Irapa (INIA) in Venezuela, the National Centre for Agricultural Research (CNRA) in Côte d'Ivoire 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 embryos and pollen will enable the safe and inexpensive long-term storage of 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 palm 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 palm are: yield of copra and its components (number of fruits, copra content per fruit), early production, disease resistance and drought tolerance. Selection for endosperm thickness is a minor factor of selection, whereas 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 ecotype, but has not been a criterion for formal selection as yet.

The genetic variance in 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 sub-populations (dwarf and tall types) are now used in some breeding programmes to increase substantial transgressive hybrid vigour for yield in new cultivars. Molecular (e.g. microsatellite) markers have been recently developed in coconut palm to accurately assess genetic relationships 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 Côte d'Ivoire 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, 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 enough seed yearly for planting 50–60 ha. 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: the 'KB' and 'KHINA' series in Indonesia; the 'PCA 15' series in the Philippines and 'PB' series (e.g. 'PB121') from Côte d'Ivoire.

Prospects Some of the latest dwarf × tall hybrid cultivars of coconut palm 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 modified soya bean and brassica oilseed. On the other hand, as a smallholder crop in the coastal areas of the tropics, coconut palm 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 export trade. However, this will require astute marketing, more research into the economic viability of smallholder production systems (e.g. replanting, intercropping and biological control of diseases and pests) and into novel processing technologies for local industries to manufacture diversified products of coconut palm suitable for the international market.

Major references Batugal & Rao (Editors), 1994; Bourdeix et al., 1997; Haas & Wilson (Editors), 1985; Harries, 1995; Harrison & Jones, 2003; Lebrun et al., 2003; Ohler (Editor), 1999; Ohler & Magat, 2001; Perera et al., 2003; Rethinam, 2004; Schuiling et al., 1992.

Other references Adkins et al., 2002; Arancon Jr, 1997; Child, 1974; Menon & Pandalai, 1958; Mwinjaka et al., 2000; Oehlschlager, 2004; Perry, 1980; Tsai & Harrison, 2003.

Sources of illustration Ohler & Magat, 2001.

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CRAMBE HISPANICA L.

Protologue Sp. pl. 2: 671 (1753).

Family Brassicaceae (Cruciferae)

Chromosome number $2n$ = 30, 60, 90

Synonyms *Crambe abyssinica* Hochst. ex R.E.Fr. (1914).

Vernacular names Crambe, Abyssinian mustard, Abyssinian kale, colewort (En). Crambé, crambé d'Abyssinie, chou d'Abyssinie (Fr).

Origin and geographic distribution *Crambe hispanica* occurs naturally in Mediterranean Europe, Morocco and the Middle East. Its native distribution extends into the highlands of Ethiopia, Eritrea, Uganda, Kenya, Tanzania, Rwanda and easternmost parts of the DR Congo. In Ethiopia it is traditionally grown on a small scale as a medicinal plant and minor oil crop. Crambe was first tested as an oil crop in the former USSR in the 1930s. From there, interest in crambe as a new, alternative crop spread to Sweden and Poland and later to other parts of Europe, North America and China. Thus, crambe is being developed as a cool-temperate oil crop although it occurs naturally in the subtropics and tropics.

Uses Crambe is grown for its seed oil which is rich in erucic acid. Crambe oil is used industrially as a lubricant and cooling agent. Erucic acid is easily modified and its chemical derivatives are valuable raw materials in the the production of lubricants (erucamide), plasticizers, surfactants, corrosion inhibitors, rubber additives, nylons, paints, hydraulic and dielectric fluids, pharmaceuticals and cosmetics. The presscake, although rich in glucosinolates, can be used as a feedstuff for ruminants. The presscake is also applied as a fertilizer. Glucosinolates extracted from the seed are being tested pharmaceutically. In Ethiopia the fruits are used in traditional medicine to treat snake bites. The leaves are eaten in Kenya.

Crambe hispanica – wild

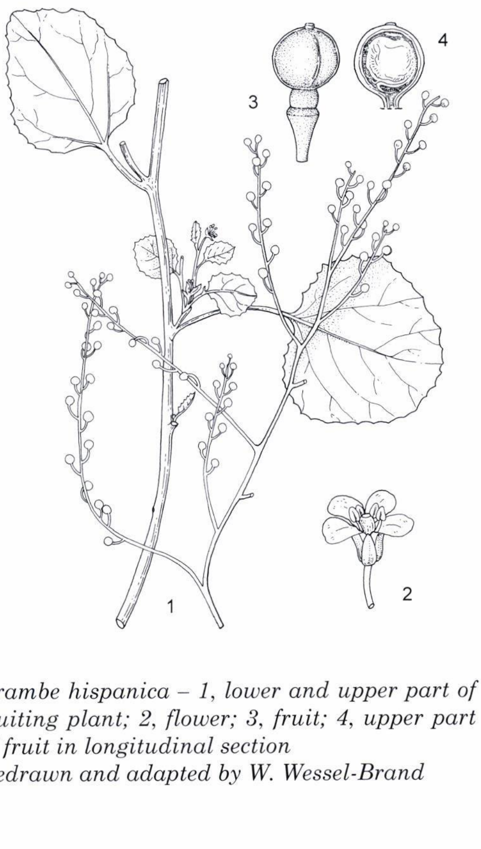
Production and international trade Few data on production and trade of crambe are available. Soon after its introduction as an oil crop in Poland it was cultivated there on 25,000 ha, but no recent data are available. In the United States production increased rapidly to 25,000 t seed from 22,500 ha in 1993, but then declined rapidly again; the main centre of production of crambe is North Dakota. Difficulties in organizing commercial oil extraction and lack of government support have contributed to the decline. More comprehensive recent statistics are not available.

Properties The approximate composition of 100 g of crambe fruit is: water 7 g, crude fat 33 g, protein 17 g, crude fibre 14 g, N-free extract 23 g and ash 5 g. Hulls make up about 30% of the weight of the fruit. Crambe oil has the highest content of erucic acid (50–60%) of all crops; other fatty acids include oleic acid (about 17%), linoleic acid (about 9%) and linolenic acid (about 5%). Nearly all erucic acid in crambe oil is esterized with C-atoms 1 or 3 of the glycerol moiety. It can be selectively hydrolyzed, yielding almost pure erucic acid.

The approximate composition of defatted seed cake made from whole seed is per 100 g dry matter: protein 28 g, crude fibre 22 g, N-free extract 40 g and ash 8 g; 100 g seed cake made from dehulled seed contains approximately: protein 50 g, crude fibre 7 g, N-free extract 36 g and ash 10 g. Crambe cake contains about 5% glucosinolates, which are nitrogen and sulphur containing organic compounds that release cyanogenic acid on decomposition. The main glucosinolate (over 90% of the total) is epiprogoitrin (2-hydroxy-3-butenyl glucosinolate), a stereoisomer of progoitrin which occurs in rapeseed. Glucosinolates and their derivatives are toxic or appetite suppressing to animals, but ruminants exhibit a degree of tolerance. In the United States, the Food and Drug Administration allows the addition of 5% crambe meal to cattle feed. Methods of detoxification have been developed, but the small amounts of epiprogoitrin remaining in detoxified meal may still be toxic or appetite suppressing to monogastric animals, especially pigs. However, from tests with mice it was concluded that crambe may exert protective effects against tumour formation and growth.

Adulterations and substitutes The oils of *Brassica napus* L. and *Brassica rapa* L. (rapeseed oil) both contain large amounts of erucic acid. Cultivars especially rich in erucic acid have been bred. Their erucic acid content is lower than that of crambe, but their yields are higher and they are better adapted to warm temperate climates.

Description Annual, much-branched herb; stem erect, furrowed, up to 1.5(–2) m tall, branched in upper parts, base often prickly hairy, upper parts with scattered hairs or glabrous. Leaves alternate, pinnately lobed, variable in shape and size along the stem, 4–15 cm long, densely to sparsely hairy on both surfaces; stipules absent; petiole of lower leaves up to 20 cm long, grooved above, hairy, upper leaves sessile or shortly petiolate; terminal lobe large, ovate or kidney-shaped, margins irregularly toothed, lateral lobes in 1–2 pairs, elliptical, much smaller, usually 0.5–2 cm long, sometimes absent, upper leaves frequently undivided, acutely ovate to rhombic. Inflorescence a terminal, umbel-like raceme, usually branched, up to 40 cm long, sparsely hairy or glabrous, 20–50-flowered. Flowers bisexual, regular, 4-merous; pedicel up to 1 cm long, jointed; sepals elliptical, 1.5–3 mm long, green; petals spatulate, shortly clawed with limb expanded, 2.5–6 mm long, white; stamens 6, 4 long and 2 short, 2–3 mm long; ovary superior, consisting of 2 segments, only upper segment developing a seed. Fruit a 2-parted silique, lower part very short, up to 1 mm long, upper part globose to ellipsoid, 2–3 mm in diameter, straw-coloured, smooth, shiny, indehiscent, 1-seeded. Seed globose, greenish brown to yellowish brown or brown, 1–2.5 mm in diameter. Seedling with epigeal germination.



Crambe hispanica – 1, lower and upper part of fruiting plant; 2, flower; 3, fruit; 4, upper part of fruit in longitudinal section
Redrawn and adapted by W. Wessel-Brand

Other botanical information *Crambe*, with about 35 species, is one of the largest genera of the tribe *Brassiceae*. *Crambe hispanica* is included in the section *Leptocrambe* DC., together with 4 other species from the Mediterranean and East African region. In the literature it is generally referred to as *Crambe abyssinica*. The differences (kidney-shaped to cordate terminal lobe of the lower leaves and upper fruit part without ribs in *Crambe hispanica* versus obovate to ovate-rhomboid terminal lobe and slightly 4-ribbed upper fruit part in *Crambe abyssinica*) are considered insufficient to distinguish *Crambe abyssinica* as a separate species. However, it is distinguished as a subspecies: subsp. *abyssinica* (Hochst. ex R.E.Fr.) Prina. Two other subspecies are distinguished: subsp. *hispanica* from the eastern Mediterranean region, and subsp. *glabrata* (DC.) Cout. from the western Mediterranean region.

Growth and development Crambe has orthodox seeds with usually about 4 months dormancy. Once the dormancy is broken, the seeds take 1–2 weeks to germinate at temperatures of 10–20°C. Germination is retarded below 8°C and inhibited below 5°C. Early growth is rapid. Plants reach the 2-leaf stage 6–12 days after germination and the 6-leaf stage after 15–27 days. Inflorescences develop from the 10–13th node upwards. Flowering starts 33–42 days after germination. Crambe is mainly self-pollinated, but about 15% cross-pollination occurs. Leaf growth virtually stops soon after flowering and the onset of anthesis generally coincides with maximum leaf area index and biomass accumulation rate. Early senescence of the foliage is a major factor in the low yield capacity of crambe, especially because the surface area of the fruits is small and can intercept only at most 25–35% of incident radiation. Physiological maturity is reached after about 80 days.

Ecology Little is known about the natural occurrence of *Crambe hispanica* in tropical

Africa. It is found on grassland and waste ground, and as a weed in agricultural fields at 1200–2600 m altitude. Although young seedlings are tolerant of –5.5°C for a few hours, frost is generally not tolerated. The best temperature range for vegetative growth is 10–25°C, but higher temperatures are well tolerated. Crambe can be grown up to 2500 m altitude in the tropics, provided a frost free period of 90 days is assured. For commercial production, an annual rainfall of 800–1500 mm is required. Once established, crambe tolerates periods of drought as long as soil moisture is adequate during the flowering and fruit setting stages. A dry period prior to fruit maturity is beneficial. Crambe is more tolerant of drought than maize, soya bean and mustard crops. Crambe grows best on well-drained fertile loamy soils of pH 6.0–7.5. Soils with poor internal drainage should have good surface drainage. Soil crusting can seriously affect germination and seedling growth. Crambe is moderately tolerant of salinity.

Propagation and planting Crambe is propagated by seed. The weight of 1000 seeds is about 7 g. Seed rates vary from 10–25 kg/ha. A fine, firm seedbed is required for even germination and vigorous seedling growth. Seed is placed at a depth of 2 cm. Wind erosion should be avoided or controlled as drifting soil easily damages seedlings.

Management Fertilizer recommendations for crambe have not yet been developed. Rates recommended for *Brassica* oilseed crops can be used. A high plant density is the best way to control early weeds in crambe. However, weeds may develop later in the maturing crop and cause difficulties with harvesting and moisture content of the seed. Crambe is very sensitive to herbicides and is easily affected by herbicide drift.

Diseases and pests The main disease of crambe in North America is *Alternaria brassicola*. Control is possible by treating seed with a fungicide or with hot water (60°C for 20 minutes). Other potential diseases are *Fusarium* wilt, *Sclerotinia* white mould and *Pythium* rot. Susceptibility to tobacco mosaic virus (TMV) and turnip mosaic virus (TuMV) has been reported. Seedlings may be attacked by flea beetles and aphids. Grasshoppers seem to avoid them when alternative sources of food are available.

Harvesting When crambe fruits approach maturity, the leaves turn yellow and drop; a few days later the fruits and small branches turn straw-coloured. When the last seed-bearing branches have turned colour, the crop is ready to harvest. Timely harvesting is important to avoid excessive shattering. Swathing may be necessary in an unevenly ripened crop. However, early swathing results in a low erucic acid content of the oil.

Yield In the United States, commercial yields of crambe seeds are 1300–2000 kg/ha, but up to 3500 kg/ha has been obtained in trial plantings.

Handling after harvest Transport costs of crambe seed are high because of its low bulk density. Hulling of crambe fruit is possible but more difficult than in fruits of *Brassica* oil crops, and is hard to carry out in the field. Hulling is not necessary for oil extraction, but gives the presscake a higher value as cattle feed. Before oil extraction the fruit is crushed and heated. The heating process should be carefully controlled as it has major effects on the palatability and toxicity of the presscake. Subsequently the oil is extracted by mechanical pressing followed by solvent extraction or by solvent extraction alone. Heat treatment or extraction with water of the presscake may improve its quality by reducing its content of antinutritional and toxic substances. However, the treated presscake is still only suitable for ruminants.

Genetic resources Genetic variability in cultivated forms of crambe is limited. However, crosses with wild types of *Crambe hispanica* and several other *Crambe* species yield viable seed, and experimental crosses with *Brassica juncea* (L.) Czern. have given hybrid seedlings through embryo rescue techniques. Substantial collections of *Crambe* germplasm, including *Crambe hispanica*, are maintained at the Victorian Institute of Dryland Agriculture, Horsham, Victoria, Australia and the USDA National Seed Storage Laboratory, Ft. Collins, Colorado, United States.

Breeding The potential yield of erucic acid from crambe is still low in comparison with other crops such as *Brassica napus* L. The main objective of breeding programmes is therefore to increase yields. Factors limiting potential yield include photosynthetic efficiency during the grain filling stage. Inheritance of seed yield, however, has been found to be low. Cultivars released include: 'Meyer', 'BelAnn' and 'BelEnzian' in the United States, 'Galactica' in the Netherlands and 'Charlotte' and 'Carmen' in France.

Prospects Great steps have been made in the development of crambe as an industrial oil crop for temperate regions. It fits well in crop rotations and can be grown using common practices. However, other crops yielding erucic acid and technologies to separate erucic acid from their oils are also being developed. Advantages of crambe are that it is more tolerant of heat and drought, resistant to flea beetles and it can be combine-harvested without swathing. However, only if research can increase the yield potential of crambe sufficiently to compete with other crops can it become a viable choice for farmers. As there are no indications of day-length sensitivity, it could become a suitable crop for the highlands of tropical Africa.

Major references Endres & Schatz, 1993; Erickson & Bassin, 1990; Francois & Kleiman, 1990; Jonsell, 1982b; Lazzeri et al., 1994; Mastebroek, Wallenburg & van Soest, 1994; Mulder & Mastebroek, 1996; Wang & Luo, 1998; Wang et al., 2000; Weiss, 2000.

Other references Barrett, Klopfenstein & Leipold, 1998; Carlson et al., 1996; Kmec et al., 1998; Lessman, 1990; Prina, 2000; Seegeler, 1983; Warwick & Gugel, 2003.

Sources of illustration Maire, 1965; Prina, 2000.

Authors L.P.A. Oyen

ELAEIS GUINEENSIS Jacq.

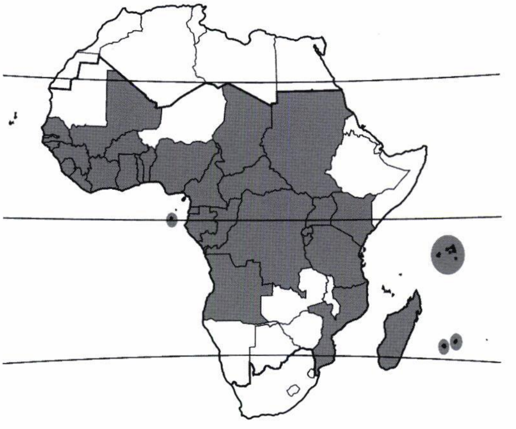
Protologue Select. stirp. amer. hist. : 280 (1763).

Family Palmae (Arecaceae)

Chromosome number $2n = 32$

Vernacular names Oil palm, African oil palm (En). Palmier à huile (Fr). Dendezeiro, palmeira do azeite, palmeira do dendê, palmeira andim (Po). Mchikichi (Sw).

Origin and geographic distribution *Elaeis guineensis* is indigenous to the tropical rainforest belt of West and western Central Africa between Guinea and northern Angola (11°N to 10°S). The greatest genetic variation is found in south-eastern Nigeria and western Cameroon and there is also fossil evidence that the Niger delta is its most likely centre of origin. The abundance of oil palm groves throughout the forest zone is attributed to early domestication. In Nigeria alone, such groves of wild and semi-wild oil palms cover an estimated 2.5 million ha. Isolated groves of semi-wild oil palms are found in Senegal (16°N) and southern Angola (15°S), along the shores of Lake Kivu and



Elaeis guineensis – wild and planted

Lake Tanganyika, along the coast of East Africa, and even on the west coast of Madagascar (21°S). 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 population.

The semi-wild oil palm groves of north-eastern Brazil have a West-African origin through the slave trade of the 16th–18th centuries. They gradually spread to other regions of tropical America and the original description of the oil palm was based on a specimen growing in Martinique. The introduction of oil palm into South-East Asia started with four seedlings planted in the Botanic Garden of Bogor (Indonesia) in 1848. Offspring of these palms formed the basis for the oil palm plantation industry, which developed gradually from 1911 in Indonesia, initially in the Deli district in Sumatra, and from 1917 in Malaysia.

The 19th century trade in palm oil and kernels between West Africa and Europe depended entirely on the produce of the semi-wild palm groves. In response to demands for more and better quality palm oil, commercial plantations started to be established in Africa after 1920 (e.g. in DR 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 took off during 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. Côte d'Ivoire, Cameroon, Ghana). Smaller oil palm industries are developing in the Philippines, Solomon Islands, China (Hainan), India and Sri Lanka.

Uses Two types of oil are extracted from the fruits of *Elaeis guineensis*: palm oil from the mesocarp and palm-kernel oil from the endosperm, in a volume ratio of approximately 9 : 1. Palm oil is used for a large variety of edible products, such as cooking oils, margarine, vegetable ghee, shortenings, frying and bakery fats, and for preparing potato crisps, pastry, confectionery, ice-cream and creamers. Unrefined red palm oil is an essential ingredient of the West African diet, while boiled and macerated fruits are used to prepare a nutritious soup, served after removal of the seeds, fibre and part of the oil. About 10% of all palm oil, the inferior grades in particular and also refining residues, is used to manufacture soaps, detergents, candles, resins, lubricating greases, cosmetics, glycerol and fatty acids. Palm oil is employed in the steel industry (tin plating and sheet-steel manufacturing) and epoxidized palm oil is a plasticizer and stabilizer in PVC plastics. Palm oil and more particularly its methyl- or ethyl-ester derivatives have potential as biofuel 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, 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 making 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 such as surface-active agents, plastics, lubricants and cosmetics. The presscake or palm-kernel meal is a valuable protein-rich livestock feed.

In addition to oil, the processing of 1 t of fruit bunches yields about 240 kg empty bunches, 140 kg fibres and 60 kg of shells, which are commonly used as fuel for the boilers of the palm oil mill. The shells are much appreciated by local blacksmiths as high calorific fuel for their furnaces; they are also polished and carved into ornamental rings and beads. The empty bunches, fibre and also the effluent (0.5 t sludge for each t of milled fruit bunches) may also be converted into products such as organic fertilizers.

In West Africa it is common practice to produce palm wine by tapping the unopened male inflorescences, or the stem just below the apex of felled oil palms. In Nigeria in particular, tapping of wine from oil palm is a major industry, as it is also from raffia palm (*Raphia hookeri* G.Mann & H.Wendl.). The palm heart (soft tissue 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 palm, 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 material for paper and board production, but this has not yet attracted much commercial interest.

Traditional medicinal uses in Africa are numerous. Preparations made from the palm heart are used to treat gonorrhoea, menorrhagia, and perinatal abdominal pain, and are considered laxative, anti-emetic and diuretic. Leaf sap is used in preparations against skin affections, roots as analgesic. The oil is an excipient for herbal ointments.

Oil palm is sometimes planted as a garden ornamental and along avenues.

Production and international trade World production of palm oil increased from 1.3 million t in 1960 (78% from Africa) to 12.1 million t in 1980 (83% from South-East Asia) and it almost doubled again in the subsequent two decades. It continued to increase substantially, from 25.4 million t (from 10.5 million ha) in 2001 to 34.8 million t (from 12.6 million ha) in 2005, largely as a result of further expansion of oil palm cultivation in South-East Asia. Palm oil is expected to overtake soya bean oil as the most important vegetable oil within the next few years. In 2005, South-East Asia produced 89%, Africa 5% and tropical America 6% of total palm oil supply.

The largest producers of palm oil in 2005 were Indonesia with 15.0 million t (3.6 million ha), Malaysia with 14.8 million t (3.6 million ha), Nigeria with 900,000 t (3.3 million ha), Thailand with 800,000 t (300,000 ha) and Colombia with 700,000 t (200,000 ha). Other African countries with significant palm oil production are Côte d'Ivoire with 360,000 t in 2005 (140,000 ha), DR Congo with 200,000 t (250,000 ha), Cameroon with 150,000 t (57,000 ha), Ghana with 120,000 t (112,000 ha); minor producers are Angola (58,000 t), Guinea (50,000 t), Liberia (42,000 t), Sierra Leone (36,000 t), Benin (35,000 t) and Togo (7000 t).

In Nigeria about 20% of annual palm-oil output is produced by the formal plantation and smallholder sector, which covers only 250,000 ha. The remaining 80% comes from low-yielding semi-wild palm groves, which may explain the very low national average yield figures. On the other hand, actual production may be underestimated, as the considerable trade of palm fruits and oil on local markets probably remains largely unrecorded in formal agricultural statistics.

Palm oil is by far the most important commodity (45%) in the world trade of vegetable oils and fats. World trade in palm oil amounted to 25.7 million t in 2005 or 75% of total production. Malaysia exported about 90% and Indonesia 70% of their production, together 92% of the internationally traded palm oil. About 50% of the internationally traded palm oil is imported by China, India and other Asian countries, another 18% by the 25 countries of the European Union, but only 2% by the United States. Imports of palm oil by countries in tropical Africa amounted to 1.0 million t in 2005, and included palm-oil producing countries such as Nigeria (210,000 t) and Ghana (130,000 t).

In 2005, world palm-kernel oil production was 4.2 million t (Malaysia 1.79 million t, Indonesia 1.75 million t and Nigeria 260,000 t) and palm-kernel meal 5.0 million t, with 47% of the oil and 80% of the meal traded internationally.

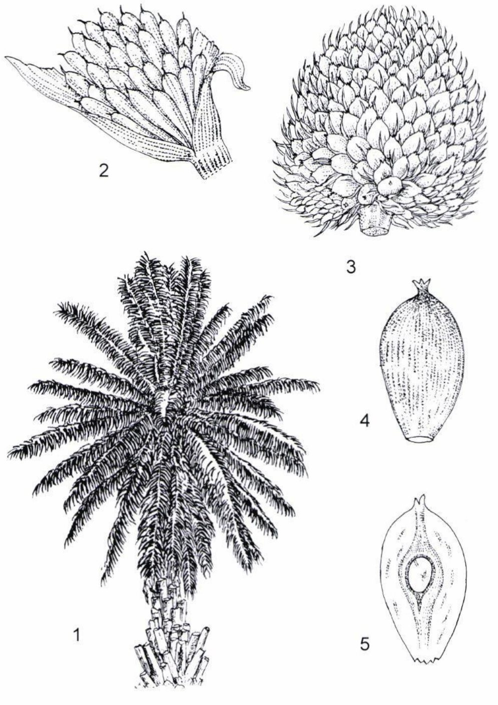
Properties Industrially extracted fresh fruit bunches of the most commonly planted oil palm cultivars ('Dura' × 'Pisifera' hybrids producing thin-shelled 'Tenera' fruits) yield per 100 kg 20–28 kg palm oil and 4–8 kg kernels, the latter yielding 2–4 kg palm-kernel oil. Per 100 g, the mesocarp of mature fruits 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, oil 48–52 g, protein 7–9 g, carbohydrate 30–32 g and crude fibre 4–5 g.

Palm oil varies in colour from pale yellow to dark red; its melting point ranges from 25°C to 40°C and it has an energy value of 3700 kJ (884 kcal) per 100 g. It consists of triglycerides with the following fatty acids: myristic acid 1–2%, palmitic acid 43–50%, stearic acid 2–4%, oleic acid 34–41% and linoleic acid 4–9%. Palm olein is produced by subjecting palm oil to a process of 'winterization' which involves slow cooling of the oil and removal of solidified fraction by filtration. The process partially removes the saturated fraction, and palm olein contains less palmitic acid (<35%) and more oleic acid (>45%). Palm oil for edible purposes should contain less than 3% free fatty acids (FFA). 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 up to 850 mg/kg. Carotenoid content is reduced to zero and the tocopherol content to half during refining of the oil.

Palm-kernel oil has a pale yellow colour and is almost white when solid. Its melting-point range is 23 to 30°C. The fatty acid composition of palm-kernel oil is similar to coconut oil: caprylic acid 3–4%, capric acid 3–7%, 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%. Per 100 g, palm-kernel cake or meal contains: water 8–11 g, crude protein 19–22 g, carbohydrate 42–49 g, crude fibre 11–15 g.

Although crude palm oil contains about 50% saturated fatty acids, it behaves nutritionally much like an unsaturated oil and does not increase LDL-cholesterol levels in the blood. This can be explained by the predominant composition of the triglycerides, with saturated fatty acids on the outer 1- and 3-positions and an unsaturated fatty acid on the 2-position. Hydrolysis during pancreatic digestion leads to free saturated fatty acids and 2-monoglycerides with unsaturated fatty acids, which are easily absorbed by the intestinal wall. Much of the saturated fatty acids give rise to insoluble calcium salts that cannot be absorbed and are excreted.

Description Unbranched, monoecious tree up to 30 m tall; 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 for anchorage for more than 1.5 m, roots with pneumatodes under very moist conditions; bole erect, cylindrical, up to 75 cm in diameter, but thicker at the swollen, often inverted cone-like basal part, rough and stout due to adhering petiole bases during the first 12–15 years, slender looking and smooth in older palms; crown with 40–50 leaves. Leaves arranged spirally, pinnately compound, up to 8 m long, 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 1–2 m long, channelled above,



Elaeis guineensis – 1, tree habit; 2, male inflorescence; 3, infructescence; 4, fruit; 5, fruit in longitudinal section.
Redrawn and adapted by Iskak Syamsudin

bearing spines; leaflets 250–350 per leaf, irregularly inserted on the rachis, linear but single fold, 35–65 cm × 2–4 cm, pulvinus at base, with thick wax layer on upper and semi-xeromorphic stomata on lower surface. Inflorescence axillary, short and condensed, unisexual, branching to 1 order; peduncle 30–45 cm long; inflorescence tightly enclosed in spindle-shaped or ovate bracts before anthesis; male inflorescence ovoid, 20–25 cm long, with branches 10–20 cm long, each with 700–1200 closely packed flowers; female inflorescence globose, 25–35 cm long, with thick and fleshy branches, each in the axil of a spiny bract, with 10–25 spirally arranged flowers and a terminal spine. Male flowers 3–4 mm long, perianth consisting of 6 small segments, with 6 stamens and rudimentary pistil; female flowers in shallow cavities accompanied by two rudimentary male flowers and subtended by a spiny bract, with 2 bracteoles, 6 tepals c. 2 cm long, a superior, 3-celled ovary and sessile 3-lobed, creamy-white stigma. Infructescence (fruit bunch) up to 50 cm long and 35 cm wide, weighing 4–60(–90) kg, with 500–3000 tightly packed fruits. Fruit a globose to elongated or ovoid drupe 2–5 cm long, weighing 3–30 g, apex with persistent woody stigma; exocarp smooth, shiny, orange-red when ripe with violet-black pigmented apex, innermost smaller and irregularly shaped fruits often without pigmented apex; mesocarp fibrous, yellow-orange, oily; endocarp (shell) stony, dark brown, with longitudinal fibres drawn out into a tuft at base, and 3 germ pores at apex, usually 1-seeded. Seed (kernel) with dark brown testa, endosperm solid, oily, grey-white, embedding a c. 3 mm long embryo opposite one of three germ pores.

Other botanical information *Elaeis* comprises only two species: the African *Elaeis guineensis* and the tropical American *Elaeis oleifera* (Kunth) Cortés ex Prain (synonyms: *Corozo oleifera* (Kunth) L.H.Bailey, *Elaeis melanococca* Gaertn.), the latter distributed from southern Mexico to the central Amazonian region. Due to low oil yield, *Elaeis oleifera* is of little economic importance, except in its natural area of distribution. However, it has a range of characters that are potentially useful in oil palm breeding, including resistances to some important pests and diseases, slow stem growth and high unsaturated fatty acid content of the mesocarp oil. *Elaeis oleifera* and *Elaeis guineensis* are inter-fertile and hybridization to transfer such characters is in progress. For some time an oil palm with smaller fruits found in Madagascar was considered a separate species (*Elaeis madagascariensis* Becc.), but is now thought to fall within the normal variability range of *Elaeis guineensis*.

Classification within *Elaeis guineensis* is based primarily on variation in fruit characteristics. One with considerable economic consequences is the distinction between 3 types based on shell thickness, which is determined by a single gene: 'Dura', homozygous, with a thick endocarp (2–8 mm at cross-section of fruit), 'Tenera', heterozygous, with a thin endocarp (0.5–4 mm), and 'Pisifera', homozygous, without a lignified endocarp.

Within the 'Dura' and 'Tenera' types, 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% by fruit weight) than 'Dura' (20–65% by fruit weight). The original palms introduced in Java (Bogor) in 1848 were of the 'Dura' type, and their offspring is generally referred to as 'Deli Dura'. 'Pisifera' is usually unproductive because female inflorescences abort before developing into fruit bunches, but it is used as male parent in crosses with 'Dura' palms to produce pure stands of 'Tenera' palms.

Other classifications are based on fruit characteristics under monogenic control and include presence or absence of

- anthocyanin in the upper fruit exocarp (absent in the 'Virescens' type, present in 'Nigrescens'; recessive);
- carotene in the mesocarp (absent in the 'Albescens' type; recessive);
- additional carpels in the fruit (present in the 'Poissoni' (mantled) type; recessive).

The 'Idolatrica' oil palm has entire leaves (recessive).

Growth and development After harvesting oil palm seeds are dormant. Germination starts with the appearance of a white button at one of the germ pores of the endocarp, 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 haustorium. Subsequent leaves gradually change from lanceolate to pinnate over a period of 12–14 months, when the seedling may have 18—24 leaves. Leaves on seedlings have no spines and are less xeromorphic than adult leaves. The base of the stem becomes swollen and adventitious primary roots develop from it. In the first 3–4 years, lateral growth of the stem dominates, giving the palm a broad base up to 60 cm in diameter. After that, the stem starts growing in height, 20–75 cm per year, at a 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° resulting in a spiral of 8 leaves per full turn. 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 and 9^{th} leaves. 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, with a surface area of 2–10 m^2, takes some 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 lifespan of oil palm plantations 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 in 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 sex differentiation in oil palm is not 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 oil palm to survive under adverse climatic conditions by reducing the 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, the African oil palm weevil (*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 fragrance during anthesis. Fruits ripen within 4.5–6 months after pollination. Fruit ripening on the bunch proceeds from top to bottom and from outer to inner fruits. Ripe fruits become detached. Oil formation in the kernel takes place between 2.5 and 3.5 months after pollination, but in the mesocarp it starts only in the 4^{th} month and does not reach its peak until the fruit is fully ripe.

Ecology Oil palm is a heliophile plant of the humid tropical lowlands. It is most common at the edges of swamps and along river banks, where competition from faster growing tree species is limited. It reaches its maximum photosynthetic activity only under bright sunshine and unrestricted water availability. Under such conditions palms have a single unopened leaf at any time, while several of 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 about 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 (at elevations exceeding 400 m or latitudes above 10°), growth and productivity are severely reduced. Oil palm is also affected by excessively high temperatures, because of progressively lower photochemical efficiency above 35°C.

Oil palm can grow on various soils such as latosols developed over various 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 per cm of 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 oil palm is fairly tolerant of short periods of flooding.

Propagation and planting Freshly harvested, cleaned and dried seeds of oil palm with 14–17% moisture content lose viability within 9–12 months at tropical ambient temperatures (c. 27°C). High seed viability (>85% germination) can be maintained for 24–30 months in air-conditioned stores at 18–20°C and at seed moisture contents of 21–22%. Longer storage of valuable oil palm germplasm by cryopreservation of seeds, kernels, excised embryos or somatic tissues is now also possible. To break dormancy and induce rapid germination, seeds of oil palm require a heat treatment of 39–40°C for 60–80 days, followed by cooling and rehydration. However, in-vitro grown excised embryos start elongating within 24 hours. The 1000-seed weight of 'Dura' (thick-shelled) seed is 4–12 kg and for 'Tenera' (thin-shelled) seed 2–3 kg.

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 'Pisifera'. The fruits are of the 'Dura' type, but the palms raised from such seeds 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 seed can be transported over long distances (300 seeds in a polythene bag and several bags carefully packed in a box) before planting in a pre-nursery in mini polybags (8 cm × 20 cm, 200 gauge black polyethylene). Transplanting into the nursery takes place at the 2-leaf stage and large polybags (40 cm × 60 cm, 500 gauge black polyethylene) are used. 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 of oil palm through somatic embryogenesis, starting from young root or leaf explants, were first developed in the late 1970s. 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 widescale application of clonal propagation in oil palm will 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 strongly 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 crop species used are *Calopogonium muconoides* Desv., *Centrosema pubescens* Benth. and *Pueraria phaseoloides* (Roxb.) Benth., often in mixtures of 2 or 3 species, while *Calopogonium caeruleum* (Benth.) Sauvalle is sometimes planted alone. Except in regions with no distinct dry season, the best time of 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 minerals. There is experimental evidence for a progressive reduction of dry matter production with higher densities, but also that fruit yield is more affected than vegetative growth. Hence, maximum yields are reached at a planting density that is lower (140–160 per ha) than the density that gives maximum total dry matter production. Oil palm is commonly planted 9 m apart in a triangular pattern giving 143 plants/ha.

Management The interrows in oil palm fields have to be slashed regularly, especially in fields with young palms. Clean weeding is practised around palms, manually or by applying herbicides to prevent competition from the cover crop. It 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 and ground cover. As the canopies close in mature plantations, the legume cover is gradually replaced by a natural vegetation, often consisting of a mixture dominated by 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. Intercropping of oil palm with annual food crops during the first 4 years after planting is common practice among small farmers in West Africa.

Considering the importance of moisture supply, oil palm benefits from irrigation in areas where the dry season is severe or long. Substantial areas of oil palm are under irrigation in southern India and Colombia, where the cost of irrigation is compensated by high yields.

The root system of young palms is not yet sufficiently developed to exploit a large volume of soil. Complete fertilizer applications are beneficial during the first three years after planting to boost vegetative growth and early production. Recommendations in Nigeria are: 0.1–0.6 kg N, 0.3–1.4 kg P and 0.4–1.2 kg K per palm per year, with rates increasing from field planting to 3 years. Nutrient status of adult palms varies considerably with soil and climatic conditions, history of the land before planting, and with the levels and number of years of production. On fertile land cleared from dense secondary forest, oil palm may not show yield responses to fertilizers for several years. The gross annual uptake of nutrients of adult oil palms grown on a marine clay in Malaysia and yielding 25 t of fruit bunches was per palm: 1.4 kg N, 0.2 kg P, 1.8 kg K, 0.6 kg Ca and 0.4 kg Mg. 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. In combination with the results of local fertilizer trials, foliar analysis (sampling a few leaflets from leaf 17) is a reliable diagnostic tool in oil palm to determine types and rates of fertilizer applications for mature oil palms long before deficiency symptoms become apparent. Significant responses to phosphorus and magnesium are less common, but these elements are often included in fertilizer applications as a precautionary measure. The demand for micronutrients is less well established for oil palm. Composted waste products from the palm oil mills (empty bunches, fibre and sludge) forms a considerable source of nutrients, which can partly replace inorganic fertilizers, while simultaneously improving physical and biological soil quality.

Oil palm is a fairly labour-intensive crop and optimum plantation management requires about one field worker per 4 ha. The need for increased mechanization of field operations becomes evident in regions with a labour shortage, e.g. in Malaysia. Most field maintenance operations can be mechanized, but economically viable methods for mechanically removing the ripe bunches from the palms have not yet been developed.

Diseases and pests Nursery seedlings are affected by a number of fungal diseases, which, however, can be controlled by cultural and fungicide treatments. The most important ones 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* (synonym: *Macrophomina phaseolina*) and *Pythium* spp.). Crown disease is a physiological disorder causing leaf distortion in 2–4-year old palms, particularly of Deli origin, and having a severe effect on early development and yield. Breeding for crown-disease free oil palm is possible, as susceptibility is inherited by a single recessive gene.

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 met with some degree of success. 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 land previously under coconut or 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 replanting and removal of diseased palms from plantations. Lethal bud rot (often with little leaf symptoms) and sudden wither are two serious diseases of oil palm in Central and South America. The causes are uncertain, but a promising method of control is planting with resistant *Elaeis oleifera* × *Elaeis guineensis* hybrids. Strict plant quarantine measures (e.g. seed treatment) are taken to prevent the inadvertent introduction of diseases such as *Fusarium* vascular wilt and *Cercospora* leaf spot into South-East Asia or tropical America.

The leaf miner (*Coelaenomenodera lameensis* (synonym: *Coelaenomenodera elaeidis*) is a serious oil palm pest of West Africa, regularly causing heavy defoliation in Côte d'Ivoire, Ghana, Benin, Nigeria and western Cameroon. Control is effected by a combination of regular monitoring of larvae and adults to determine optimum timing for insecticide spray application (e.g. thiocyclam). Biological control by indigenous or exotic egg and larval parasites is under study. Another important pest in Africa is the palm weevil *Rhynchophorus phoenicis* often in combination with the rhinoceros beetle (*Oryctes monoceros*), which burrows into the cluster of central spear leaves and thereby predisposes the palms to a secondary attack by the palm weevil. Pheromone-based mass trapping of *Rhynchophorus phoenicis* and manual collection of the weevils can be an effective method of pest control. Insects pests causing occasional damage are the African spear borer (the moth *Pimelephila ghesquierei*) and weevils (*Temnoschoita* spp.) on young palms in Central and West Africa (e.g. DR Congo) in particular, and leaf-eating nettle and slug caterpillars (*Parasa pallida*, *Parasa viridissima*). In South-East Asia, where the range of insect pests differs from that in Africa, techniques of integrated pest management in oil palm plantations are well-advanced. They include close monitoring, biological control and spraying with narrow-spectrum insecticides to prevent major epidemics. Occasional outbreaks of bagworms (*Cremastopsyche pendula*, *Metisa plana*, *Mahasena corbetti*), nettle and slug caterpillars (*Darna trima* and *Setora nitens*) occur notably in Sabah and Sumatra. The rhinoceros beetle (*Oryctes rhinoceros*) of Asia and the Pacific has readily adapted to oil palm. Destruction of breeding sites and good ground cover generally ensure adequate control. Other occasional pests in South-East Asia are the oil palm bunch moth (*Tirathaba mundella*), root-feeding cockchafers (*Adoretus* and *Apogonia* spp.) and grasshoppers (e.g. *Valanga nigricornis*). In West Africa, young palms need protection by a wire collar against the rodent *Thryonomys swinderianus* (cutting-grass rat, greater cane rat or agouti) during the first year after field planting. Rats can cause considerable damage on maturing fruit bunches. Control is carried out by baiting. Barn owl (*Tyto alba*) is also used in Malaysia to prey on rats and nest boxes are placed in the plantation.

Harvesting Harvesting of bunches generally starts in West Africa 3–3.5 years after planting, in South-East Asia already after 2.5 years. In the estate sector 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 and because the first bunches have a low oil content. Bunches ripen throughout the year and harvesting rounds are usually made at intervals of 7–10 days. Bunches are cut when they have reached optimum 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. Bunches are cut from the stalk with a chisel in young palms, while in tall palms a 'Malayan knife' that consists of a sickle on a long bamboo or aluminium pole is used. In Africa very tall and smooth-stemmed palms are climbed with a climbing rope and the bunches are removed with a cutlass. Loose fruits must be gathered from the ground because they also yield oil. Bunches are transported to collection sites along the road and from there direct to the mill by road or rail track (Asia) for processing.

Yield World average yields per ha in 2005 were 2.8 t palm oil and 0.7 t palm kernels (45% oil and 55% meal). National averages for palm-oil yields per ha are, for example: Nigeria 0.3 t (plantations 1.9 t), DR Congo 0.7 t, Ghana 1.1 t, Côte d'Ivoire and Cameroon 2.6 t, Colombia 3.9 t, Malaysia 4.1 and Indonesia 4.2 t. Oil palm is extremely responsive to environmental conditions and annual yields therefore vary greatly. The course of yield over time, however, shows 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 factory oil extraction rates of 22% ('Tenera' type) this represents palm oil yields of 5.2–7.1 t/ha. In West Africa, where climatic conditions are less favourable (with a substantial dry season), maximum annual bunch yields of 12–16 t are obtained or 2.6–3.5 t of palm oil per ha, which is nevertheless still much higher than for any other oil crop.

Handling after harvest Palm oil mills, large or small, process fresh fruit bunches (FFB) to oil and kernels through the following stages:
- sterilizing the FFB 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 the fruits from the bunches;
- digesting the fruits and reheating of the macerated mix of pulp and nuts (stones);
- 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 tanks before transport for further refining and processing.

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

On the one hand, there are industrial mills with capacities to process 20–60 t FFB/hour for large oil palm plantations and their smallholder 'outgrowers'; on the other hand, a range of small plants with oil extraction efficiencies similar to those of large mills (>92%) have been developed over the past 50 years for the smallholder oil palm sector, which operates independently of the estate sector and in West Africa produces mainly for the domestic markets. The capacity varies from 1–2 t FFB/hour in a highly mechanized plant with a double-shafted continuous screw press, to 0.5 t FFB/hour or less by a unit with 1–2 manually operated hydraulic presses with ancillary equipment for sterilization, digestion and clarification.

The traditional method of edible oil extraction in West Africa, still applied in remote villages, includes boiling of the fruits, pounding and boiling again until the floating oil can be skimmed off. Palm oil for soap manufacturing is manually extracted from macerated fruits, which have been allowed to ferment in pits for several days. Oil extraction efficiency of the traditional methods is low (<50%) and free fatty acid content high (6–10%) even in edible palm oil.

Genetic resources Almost all present oil palm planting materials in Malaysia, Indonesia, elsewhere in South-East Asia and tropical America, have been developed from the genetically very narrow 'Deli Dura' population and one source of 'Pisifera' (the 'Djongo Tenera' palm from Yangambi in DR 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 Senegal to Angola and even in Tanzania and Madagascar during the period 1984–1994. It also collected *Elaeis 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 DR Congo) maintained on 400 ha of field trials at the research station near Kluang, Johore (Malaysia). Another large field collection of more than 1000 accessions is maintained by NIFOR near Benin City (Nigeria). The National Centre for Agricultural Research (CNRA, formerly IRHO) in Côte d'Ivoire 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 collections of genetic resources.

Oil palm germplasm collected in 1966 in the Bamenda Highlands of Cameroon and in 1977 along Lake Tanganyika, both at altitudes of about 1000 m, are being tested in the cooler uplands of Ethiopia and other countries of East Africa in an effort to extend oil palm cultivation beyond its natural ecosystem of the tropical lowlands. Results are still to be published. 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' trees 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 (1960–1970s) carried out in large breeding programmes of NIFOR in Nigeria and Ghana, CNRA in Côte d'Ivoire and the Oil Palm Genetics Laboratory (OPGL, now MPOB) in Malaysia have 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 moderate to low 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 'Pisifera' in Asia by introgression with 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 stem (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 the case with fruit quality components (mesocarp, shell and kernel content) and fatty acid composition of the palm oil, thus allowing effective phenotypic selection of parents for these characters.

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 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, e.g. by preselection at the nursery stage. New complementary biotechnological approaches are being explored. The MPOB in Malaysia has initiated major research projects on genetic transformation in oil palm. Objectives include resistance to herbicides and diseases (e.g. *Ganoderma*) and changes in the fatty acid composition of 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 oil palm.

Prospects World demand for vegetable oils is rising sharply, from 100 million t in 2005 to an estimated 150 million t in 2020, as the world population continues to grow and the standards of living increase in many developing countries. The role of oil palm as a supply of relatively inexpensive and versatile edible oil is, therefore, expected to become ever more prominent. With best practices for cultivation and processing, it can produce 4–6 times more oil/ha than any of the other oil crops, in an economically and environmentally sustainable manner. Extrapolations from crop-growth models suggest that the physiological potential for oil yield of 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. The main drawback of oil palm is the difficulty of cost-effective mechanization of harvesting. Hence, availability and cost of labour may well become limiting factors in producing countries with improving standards of living.

Well-established oil palm plantations provide an ecosystem that has some of the characteristics of humid tropical forests. Recent studies have shown that the net carbon sequestration by a mature oil palm ecosystem is higher than that of humid tropical forests. The negative publicity on palm oil as being an 'unhealthy tropical vegetable oil' has been repeatedly proved unjustified by scientific evidence. On the other hand, much needs to be done at national and regional levels, particularly in South-East Asia, to restore the reputation of the oil palm as an ecologically sustainable plantation crop, as this has been severely tarnished in the past decade by poorly controlled expansion causing air pollution and unnecessary destruction of tropical forests. The 'Roundtable on Sustainable Palm Oil', initiated by stakeholders of the Malaysian palm oil industry in 2003, appears to be a move in the right direction in this respect.
In West Africa the smallholder sector of palm oil producers, processors and traders is increasingly overtaking the privatized formal plantation sector in becoming the main supplier for the ever-growing domestic markets. Sustainable palm oil production needs to be redefined here, as the best management practices applied in the estate sector may be incompatible with the socio-economic priorities of the smallholders and their families.

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Other references Aisagbonhi et al., 2004; Ataga, 1993; Ataga, Okwuagwu & Okolo, 1999; Blaak & Sterling, 1996; Breure, 1987; Caliman et al., 2005; Cheyns & Raffleau, 2005; Corley, Hardon & Wood (Editors), 1976; Gunstone, Harwood & Padley, 1986; Hardon, Rajanaidu & van der Vossen, 2001; Hartley, 1988; Hayati et al., 2004; Index Mundi, 2005; Lamade & Bouillet, 2005; Omont, 2005; Pioch & Vaitilingom, 2005; Sparnaaij, 1969; Turner, 1981; van der Vossen, 1974; Wood, 1968.

Sources of illustration Dransfield & Beentje, 1995; Hardon, Rajanaidu & van der Vossen, 2001.

Authors C.D. Ataga & H.A.M. van der Vossen

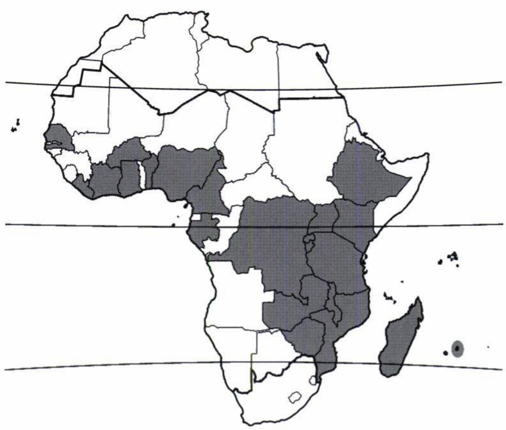
Based on PROSEA 14: Vegetable oils and fats.

GLYCINE MAX (L.) Merr.

Protologue Interpr. Herb. amboin. 274 (1917).
Family Papilionaceae (Leguminosae - Papilionoideae, Fabaceae)
Chromosome number $2n = 40$
Synonyms *Glycine hispida* (Moench) Maxim. (1873).
Vernacular names Soya bean, soybean (En). Soja, soya (Fr). Soja (Po). Soya (Sw).

Origin and geographic distribution Soya bean was domesticated in the north-east of China around the 11th century BC. From there, it spread to Manchuria, Korea, Japan and other parts of Asia. Soya bean was introduced into Korea between 30 BC and 70 AD, and it was mentioned in Japanese literature around 712 AD. It reached Europe before 1737. Soya bean was introduced into the United States in 1765 and into Brazil in 1882. It is unclear when soya bean first reached tropical Africa. There are reports of its cultivation in Tanzania in 1907 and Malawi in 1909, but it is likely that soya bean was introduced during the 19th century by Chinese traders who were active along the east coast of Africa. Nowadays, soya bean is widely cultivated in tropical, subtropical and temperate regions throughout the world. The slow distribution outside Asia is explained by the absence of soya bean specific rhizobia in the soils of other regions; the crop only developed in the United States at the beginning of the 20th century, following the discovery of the nodulation process by scientists.

Uses In tropical Africa dry soya bean seeds are boiled for use in relishes, or used in the preparation of milk substitutes and flour. A popular use of soya bean milk in Nigeria is to



Glycine max – planted

make a tofu-like product that is deep fried and sold as a snack or breakfast food. The flour is used as a component of bread or mixed with maize flour to make a fortified porridge ('ugali', 'sadza'). In West Africa soya bean flour is used to thicken soup and to replace a traditional flour that is made from the seed of egusi melon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai). 'Okara' is the pulp and bran left over from making soya milk; this cake is used in almost all the same ways as soya bean flour. Soya bean seeds are dry roasted and used directly as a snack or as a coffee substitute. The seed is also milled into flour and mixed with maize meal to serve as a relief food during famine. In Asia soya bean is used in the preparation of a variety of fresh, fermented and dried food products like milk, tofu, tempeh, miso, yuba, soya sauce and bean sprouts (soya bean sprouts are meant here, and not mung bean sprouts, which are more common in Western countries, and which are often called 'germes de soja' in French). Immature soya bean seeds are eaten as a vegetable.

Soya bean seed is processed to extract oil for food and for numerous industrial purposes; the crop is currently the world's most important source of vegetable oil. The edible oil enters the market as cooking oil, salad oil, margarine and shortening. Soya bean lecithins are used as emulsifier in the food industry, in pharmacy, and in the industrial production of decorating materials, printing inks and pesticides. Soya bean oil is the main commercial source of α-tocopherol (natural vitamin E) and contains stigmasterol, which is used for the commercial synthesis of steroid hormones and other pharmaceutical products. The cake remaining after oil extraction is rich in protein and is an important animal feed. Uses of soya bean proteins in food include defatted flours and grits, concentrates, isolates, textured flours and textured concentrates (commonly used as meat extender). The protein is also used in the production of synthetic fibres, glues and foams.

Soya bean is also grown as fodder and as green manure; it is suitable for haymaking and silaging. The leafy stems remaining after pod removal can also be used as fodder.

Production and international trade According to FAO estimates, the average world production of soya bean seeds is 173 million t/year from 77 million ha (mean of 1999–2003). The main producing countries are the United States (73.5 million t/year in 1999–2003, from 29.4 million ha), Brazil (39.0 million t/year from 15.1 million ha), Argentina (26.4 million t/year from 10.2 million ha), China (15.4 million t/year from 9.0 million ha), India (5.9 million t/year from 6.3 million ha), Paraguay (3.4 million t/year from 1.3 million ha) and Canada (2.3 million t/year from 1.0 million ha). South Africa produced 188,000 t/year from 121,000 ha. The soya bean production in tropical Africa in 1999–2003 was 790,000 t/year from 895,000 ha, the main producers being Nigeria (439,000 t/year from 601,000 ha), Uganda (139,000 t/year from 124,000 ha) and Zimbabwe (119,000 t/year from 62,000 ha).

Average world export of soya bean seeds amounted to 47.4 million t/year in 1998–2002, the main exporters being the United States (25.4 million t/year), Brazil (12.3 million t/year) and Argentina (4.7 million t/year). Export of soya beans from tropical Africa was only 27,000 t/year, with Zimbabwe as main exporter (11,000 t/year). The main importer was China (11.0 million t/year). Soya bean import in tropical Africa was 37,000 t/year. Average world export of soya bean oil in 1998–2002 was 8.2 million t/year, with as main exporters Argentina (3.0 million t/year), Brazil (1.5 million t/year) and the United States (0.9 million t/year). The export of soya bean oil from tropical Africa was negligible. The main importers in 1998–2002 were China (975,000 t/year), India (837,000 t/year), Iran (701,000 t/year) and Bangladesh (522,000 t/year). Soya bean oil import in tropical Africa in 1998–2002 amounted to 338,000 t/year, the main importing countries being Senegal (83,000 t/year), Angola (39,000 t/year), Mauritius (25,000 t/year), Madagascar (22,000 t/year) and Zimbabwe (22,000 t/year). Average soya bean cake export amounted to 40.8 million t/year, with as major exporters Argentina (13.6 million t/year), Brazil (10.8 million t/year) and the United States (6.4 million t/year). Soya bean cake export from tropical Africa was 30,000 t/year, mainly from Zimbabwe (14,000 t year) and Zambia (12,000 t/year). The main importers were countries of the European Union. Tropical Africa imported 72,000 t/year.

Soya bean is grown by smallholders in many countries of West, East and southern Africa, though normally as a minor food crop. Commercial soya bean production on large farms and estates is common in Zambia and Zimbabwe, and also in South Africa.

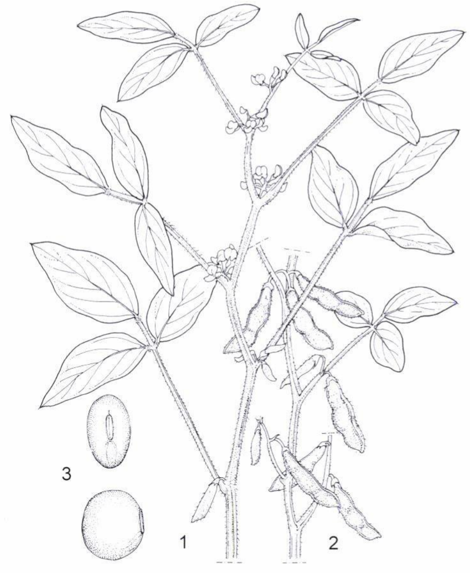
Properties The composition of mature raw soya bean seeds per 100 g edible portion is: water 8.5 g, energy 1742 kJ (416 kcal), protein

36.5 g, fat 19.9 g, carbohydrate 30.2 g, dietary fibre 9.3 g, Ca 277 mg, Mg 280 mg, P 704 mg, Fe 15.7 mg, Zn 4.9 mg, vitamin A 0 IU, thiamin 0.87 mg, riboflavin 0.87 mg, niacin 1.6 mg, vitamin B_6 0.38 mg, folate 375 μg and ascorbic acid 6.0 mg. The essential amino-acid composition per 100 g edible portion is: tryptophan 530 mg, lysine 2429 mg, methionine 492 mg, phenylalanine 1905 mg, threonine 1585 mg, valine 1821 mg, leucine 2972 mg and isoleucine 1770 mg. The principal fatty acids are per 100 g edible portion: linoleic acid 9925 mg, oleic acid 4348 mg, palmitic acid 2116 mg, linolenic acid 1330 mg and stearic acid 712 mg (USDA, 2004). Soya bean seeds have a protein content higher than any other pulse. The seeds have a high lysine content; the limiting amino-acid is methionine. Mature soya bean seeds are not easily digested, contain toxic compounds and have an unpleasant taste. Therefore they must be soaked and cooked for a long time before being edible, or be processed by techniques such as roasting, fermentation or sprouting. Heat-labile antinutritional factors of soya bean are trypsin inhibitors, haemagglutinins, goitrogens, antivitamins and phytates, and heat-stable ones are saponins, oestrogens, flatulence factors and lysinoalanine.

Yield of meal from soya bean seeds is 80% and of oil 18%. The meal contains about 50% protein. The average fatty acid composition of commercial soya bean oil is: linoleic acid 54%, oleic acid 22%, palmitic acid 10%, linolenic acid 10% and stearic acid 4%. Soya bean oil is rich in vitamin E and contains 1.1–3.2% lecithins. Soya bean seeds are always heat-treated before oil extraction, because of the presence of antinutritional compounds. Soya bean oil tends to become rancid when exposed to air or light, due to the instability of the linolenic acid. The protein and oil concentrations of soya bean are negatively correlated, and efforts to raise both simultaneously have been unsuccessful. The oil content tends to increase with increasing temperature during growth, whereas the protein content tends to decrease.

Consumption of soya bean is associated with decreased risk of atherosclerosis and cardiovascular disease, although the exact mechanisms are not clear. There are also indications that soya bean has a positive effect on bone health. The relation between soya bean consumption and reduced risk of cancer is more uncertain.

Description Usually erect, bushy annual herb up to 2 m tall, sometimes viny; taproot branched, up to 2 m long, lateral roots spreading horizontally to a distance of up to 2.5 m in the upper 20 cm of the soil; stem brownish or greyish pubescent. Leaves alternate, 3(–7)-foliolate; stipules broadly ovate, 3–7 mm long; petiole 2–20 cm long, especially in lower leaves; leaflets ovate to lanceolate, 3–15 cm × 2–6(–10) cm, base cuneate or rounded, apex acute to obtuse, entire, glabrous to pubescent. Inflorescence an axillary false raceme up to 3.5 cm long, often compact, densely hairy, (2–)5–8(–35)-flowered. Flowers bisexual, papilionaceous; pedicel up to 3 mm long; calyx tubular, with 2 upper and 3 lower lobes, hairy; corolla 5–7 mm long, white, pink, purple or bluish, standard obovate to rounded, c. 5 mm long, glabrous, wings obovate, keel shorter than the wings; stamens 10, 9 fused and 1 free; ovary superior, style curved with head-shaped stigma. Fruit a slightly curved and usually compressed pod 2.5–8(–15) cm × 1–1.5 cm, hairy, dehiscent, (1–)2–3(–5)-seeded. Seeds globose to ovoid or rhomboid, 6–11 mm × 5–8 mm, yellow, green, brown or black, or blotched and mottled in combinations of those colours; hilum small, black, brown or yellow. Seedling with epigeal germination; cotyledons thick and fleshy, yellow or green; first leaves simple and opposite.



Glycine max – 1, flowering branch; 2, fruiting branch; 3, seeds.
Source: PROSEA

Other botanical information *Glycine* comprises about 20 species distributed in the tropics and subtropics of Asia and Australia. It is divided into 2 subgenera: *Glycine* (perennials) and *Soja* (annuals), with the latter including 2 species: *Glycine soja* Sieb. & Zucc. (wild types, occurring in eastern Asia) and *Glycine max* (cultivated types). *Glycine soja* is considered the wild ancestor of *Glycine max*. The 2 taxa hybridize easily and may also be considered a single species with 2 subspecies, *Glycine max* (L.) Merr. subsp. *max* and subsp. *soja* (Sieb. & Zucc.) Ohashi.

Numerous cultivars are recognized in tropical Asia that vary in time to maturity, size, plant habit, colour, content of oil and protein in the seed, and uses to which they are put. For oil production, yellow seeds are preferred. For immature seeds to be used as a vegetable, types with large yellow or green seeds are preferred. Hay and fodder cultivars usually have brown or black seeds and the plants often twine. In tropical Africa the older cultivars that originated from Asia tend to be tall and indeterminate in growth habit, take comparatively long to mature (about 120 days) and are 'promiscuous' in their ability to nodulate with rhizobia indigenous to African soils. These cultivars can be contrasted with soya bean cultivars that have emerged from breeding programmes and tend to be short-statured, determinate, and relatively fast-maturing (70–90 days).

Growth and development Soya bean seedlings emerge within 5–15 days after sowing; a seedbed temperature of 25–33°C is optimal. Flowering starts from 25 days to more than 150 days after sowing, depending on daylength, temperature and cultivar. Flowering can take 1–15 days. Soya bean is normally self-pollinated and completely self-fertile with less than 1% cross-pollination. Pollen is normally shed in the morning, before the flowers have completely expanded. At higher altitudes with lower temperatures, flowers are usually cleistogamous. The time from flowering to pod maturity is 30–50 days. The total crop cycle from sowing to maturity is 65–200 days. Development to maturity is usually shorter with short days than with long days. The number of pods per plant varies from a few to more than 1000.

Although older literature indicates that soya bean is nodulated exclusively by slow-growing rhizobia (*Bradyrhizobium* spp.; initially called 'cowpea-type rhizobia') it is now well established that the fast-growing *Sinorhizobium fredii* can also form effective nodules with the crop. Soya bean genotypes differ enormously in their ability to nodulate with indigenous rhizobia in soils. The ability to nodulate spontaneously and prolifically with indigenous rhizobia is known as the 'promiscuous' character, compared with the 'specific' character of soya bean types that normally require inoculation with a specific type or with a few specific types of rhizobia in order to grow well. However, it has now been established that all soya bean genotypes nodulate to some extent with indigenous rhizobia, but the diversity of strains with which they can nodulate determines the extent of their promiscuity. Rates of N_2-fixation in soya bean are greatest in the more luxuriant and late maturing genotypes. Studies conducted in Nigeria have measured a N_2-fixation rate of 126 kg of N per ha for an uninoculated late-maturing soya bean line.

Ecology Soya bean is grown from the equator to latitudes 55°N or 55°S, at altitudes from close to sea level up to 2000 m. Although the crop grows well under a wide range of temperatures, the optimum temperature for growth and development is in general around 30°C. Both excessively high (>32°C) and low (<20°C) temperatures can reduce floral initiation and pod set. Soya bean requires at least 500 mm water during the growing season for a good crop; water consumption under optimal conditions is 850 mm. Drought stress during flowering reduces pod-set but drought during pod-filling reduces yield even more. Soya bean can tolerate brief waterlogging but weathering of seed is a serious problem under humid conditions. Soya bean is considered a quantitative short-day plant, but some cultivars are insensitive to photoperiod. The response to photoperiod interacts strongly with temperature, and given the relatively small variation in daylength in the tropics, temperature is the major factor influencing the rate of phenological development. The photoperiod sensitivity means that types brought directly into tropical Africa from North America will often flower and set seed before they have fully developed, restricting their yields.

Soya bean grows well on most soils, except very coarse sands. The optimum pH is 5.5–7.5, and soya bean is sensitive to soil acidity, in particular to aluminium toxicity. Where soya bean has not grown previously, or where P is limiting, symbiotic N_2-fixation may be inadequate to meet the N requirement of the plants.

Propagation and planting Soya bean is propagated by seed. The 1000-seed weight is 100–250 g. The seed can be sown before the start of the rainy season, or when the soil is moist. Seed rates are 40–120 kg/ha. Soya bean is sown in rows (20–)40(–75) cm apart. Within the rows, 2–3 seeds are sown in hills spaced at 7.5–10 cm intervals, at a depth of 2–5 cm. With intercropping, sowing rates are less than for sole cropping. In traditional agriculture the land is prepared by hand or animal traction before sowing. Soya bean is grown mainly on the flat, but sowing on hills or ridges may be practised where the soil is heavy, the water table high, or rainfall heavy. Small-scale farmers in tropical Africa grow soya bean as a sole crop or in mixed cropping with maize, sorghum or cassava.

Management Soya bean is usually weeded 1–3 times during the first 6–8 weeks after planting, after which its canopy should be sufficiently developed to suppress weeds. Irrigation is uncommon except for dry season production. Basal fertilization with 20–25 kg P per ha is often required for adequate symbiotic N_2-fixation and general growth. Soya bean is commonly grown in rotation with cereals, such as maize, rice, sorghum, wheat and finger millet, whereby all fertilizer may be applied to the cereal.

Diseases and pests Various fungal diseases affect soya bean. Soya bean rust (*Phakopsora pachyrhizi* and *Phakopsora meibomiae*) is a devastating disease that can reduce yields by as much as 90%. It is widespread; in tropical Africa it is recorded from Sierra Leone, Ghana, Nigeria, DR Congo, Uganda, Tanzania and Zambia. Partial resistance has been found in various cultivars; fungicides may reduce damage. Red leaf blotch (*Dactuliochaeta glycines*, synonym: *Pyrenochaeta glycines*) is confined to Africa; it is economically important in Zambia and Zimbabwe, where yield losses of up to 50% have been recorded. Seeds are not infected, but the fungus can survive in the soil for many years. Tolerant cultivars have been developed in Zimbabwe. Frogeye leaf spot (*Cercospora sojina*, synonym: *Passalora sojina*) occurs worldwide. It is primarily a leaf disease, but it may also affect stems, pods and seeds. It survives on stored seeds and crop residues and is spread by wind. Control measures include seed treatment (e.g. with thiram), deep-ploughing of crop residues, crop rotation and application of fungicides. Resistant cultivars are available. Purple seed stain and leaf blight are caused by *Cercospora kikuchii*, also occurring worldwide. Recommended control measures are crop rotation, the use of clean seed, ploughing back of crop residues, spraying with fungicides and the use of tolerant cultivars. Among the bacterial diseases of soya bean, bacterial blight (*Pseudomonas syringae* pv. *glycinea*, synonym: *Pseudomonas savastanoi* pv. *glycinea*) is common wherever soya bean is grown. Control practices of this foliar disease include the use of resistant cultivars, the use of clean seed, crop rotation and burying of crop residues. Bacterial pustule (*Xanthomonas campestris* pv. *glycines*, synonym: *Xanthomonas axonopodis* pv. *glycines*) is also widespread. It is seed-transmitted and survives on crop debris. Control measures are similar to those of bacterial blight. Virus diseases of soya bean include soya bean mosaic virus (SMV), cowpea mild mottle virus (CPMMV) and bean yellow mosaic virus (BYMV), but these are of little importance in tropical Africa.

Soya bean cyst nematode (*Heterodera glycines*) and root-knot nematodes (*Meloidogyne* spp.) can cause severe damage, especially on sandy soils. Therefore, soya bean should not be grown continuously or in rotation with other susceptible crops, such as tobacco. Soya bean cultivars resistant to nematodes are available.

The most widespread and probably most serious pest of soya bean in tropical Africa is the southern green stink bug or soya bean green stink bug (*Nezara viridula*), of which the nymphs and adults feed on soya been seeds. Control is by using insecticides. The most important leaf-eating pest is probably the soya bean looper (*Xanthodes graellsii*). Bean flies (mainly *Melanagromyza sojae* and *Ophiomyia centrosematis*) can cause complete yield loss. Soya bean seedlings are occasionally damaged by cutworms (*Agrotis* spp.). No major storage pests are recorded from Africa, except rodents.

Harvesting Mature seeds of early-maturing soya bean cultivars can be harvested 65 days after planting; late maturing cultivars may need more than 150 days. In tropical Africa the plants are generally allowed to dry in the field and the whole plants (above ground) are collected by hand when most leaves have turned yellow and fallen, and when the pods have turned brown. The moisture content of the seeds at harvesting should be 14–15%. Pods of older cultivars have a tendency to shatter in the field when drying and plants need to be harvested on time to prevent major loss of yield. Combine-harvesting is used on large farms and estates. Soya bean seed for vegetable use is harvested when the pods are still green but the seeds fill the pod.

Yield Average world soya bean yields are 2.25 t/ha; those in the United States 2.5 t/ha. Under smallholder farming conditions in tropical Africa yields are often as low as 0.5 t/ha due to a combination of poor soil conditions and poor management. However, yields of more than 2 t/ha have been recorded on smallholder farms in Zimbabwe and Nigeria, particularly when farmers are growing soya bean as a cash crop to sell in urban food markets or for processing for oil and feed. The average yield of commercial, large-scale farmers hovers around 2 t/ha. Under optimal growing conditions yields of more than 4.5 t/ha have been recorded in Zimbabwe. In Nigeria and most of West Africa the yield potential of soya bean is about 3 t/ha.

Handling after harvest The whole plants are dried in the sun. They are then threshed by beating with sticks. The seeds are winnowed, cleaned and prepared for store or market. For on-farm storage a seed moisture content of 10–12% must be maintained. Deterioration of seed in storage is a major problem in the humid tropics and is attributable to poor storage conditions and pests. In the savanna region of West Africa producers have developed appropriate seed handling methods that ensure good seed germination when they save their own seeds.

Genetic resources The largest germplasm collections of soya bean are held in China (Institute of Crop Germplasm Resources (CAAS), Beijing, 23,600 accessions; Nanjing Agricultural University, Nanjing, 13,000 accessions), the United States (USDA-ARS Soybean Germplasm Collection, Urbana, Illinois, 18,400 accessions) and Taiwan (Asian Vegetable Research and Development Centre (AVRDC), Shanhua, 12,500 accessions). In tropical Africa substantial germplasm collections are held in Zimbabwe (Crop Breeding Institute, Harare, 2250 accessions), Nigeria (International Institute of Tropical Agriculture (IITA), Ibadan, 1800 accessions), Rwanda (Institut des Sciences Agronomiques du Rwanda (ISAR), Butare, 550 accessions) and Kenya (National Genebank of Kenya, Crop Plant Genetic Resources Centre, KARI, Kikuyu, 130 accessions). Genebank accessions have been successfully used for the improvement of resistance to diseases and pests, plant morphology and seed composition. The genetic variation of soya bean cultivars is rather narrow. For instance, about 80% of the genepool of the soya bean cultivars grown in the United States can be traced to only 7–10 introductions from the same geographical area. It is therefore considered necessary to broaden the genetic base of cultivated soya bean by using wild relatives.

Breeding Breeding work on soya bean in tropical Africa aims at the development of improved cultivars with high and stable seed yield, resistance to major diseases and pests, tolerance to aluminium toxicity, resistance to lodging and pod shattering, promiscuous nodulation, improved seed longevity and acceptable seed colour, oil and protein content. A breeding programme at IITA has focused since the early 1980s on combining the yield potential of cultivars bred in North America with the 'promiscuous' or 'naturally-nodulating' ability of landraces from Asia to form nodules and fix nitrogen without inoculation in African soils. This breeding programme has produced a series of excellent multi-purpose cultivars that combine a leafy growth habit with appropriate seed type and high yield potential. These cultivars are liked by smallholder farmers because they provide biomass for forage or to improve soil fertility in addition to having high seed yields. They are being actively promoted in many countries in East and West Africa at present. In southern Africa similar benefits of a largely unimproved cultivar, 'Magoye', were recognized. 'Magoye' is a leafy, indeterminate cultivar, relatively resistant to stresses and mid-season drought, that grows better on poor soils than some of the improved cultivars, nodulating well with indigenous rhizobia. Despite its smaller, yellow seed, and susceptibility to some diseases such as bacterial pustule, this makes it an attractive cultivar for use by smallholder farmers in southern Africa.

Research at IITA has identified soya bean breeding lines that favour the germination of *Striga hermonthica* (Delile) Benth., a parasitic weed that infects maize, sorghum and pearl millet, and one of the major constraints to production of these crops in Africa. The probable cause of this effect of soya bean is the presence of root exudates. The inclusion of these soya bean cultivars in crop rotations stimulates *Striga* germination and reduces infestation levels in following sorghum, maize or pearl millet crops as a result of the decline of *Striga* seed numbers in the soil. After germination the *Striga* plants are unable to infest the soya bean crop, and die without producing seed. A 3-year trial conducted in Benin showed that 2 seasons of soya bean followed by maize reduced *Striga* *hermonthica* emergence by about 80–90% and increased maize yield from 1.5 t/ha to 3 t/ha. Similar results have been obtained in farmers' fields in Nigeria. As soya bean becomes more popular in areas where maize, sorghum and pearl millet are grown, the amount of damage caused by *Striga hermonthica* should become significantly less.

A number of private seed companies are involved in breeding soya bean in southern Africa, with particular emphasis on cultivars suitable for mechanized production. The companies are targeting a number of traits including high seed yield, resistance to lodging, resistance to pod shattering, rapid stem dehydration, seed quality and resistance to diseases (particularly red leaf blotch and frogeye leaf spot). New cultivars are 'Solitaire', 'Soma', 'Soprano' and 'Viking', all of which have some resistance to frogeye leaf spot. These cultivars are all specific in their nodulation ability and require inoculation with the appropriate rhizobia. Inoculants for soya bean are produced, sold and used on a large scale in both Zimbabwe and South Africa.

Soya bean is a leading crop in the field of genetic transformation. In 2001 the world area under transgenic herbicide-tolerant soya bean was estimated at 33 million ha; it was grown in the United States, Argentina, Canada, Mexico, Uruguay, Romania and South Africa. Genetic linkage maps have been constructed for soya bean on the basis of various markers (RFLP, SSR, RAPD, AFLP), and several moderate- to high-density genetic maps are now available. In-vitro regeneration of soya bean is possible through organogenesis and somatic embryogenesis.

Prospects Soya bean is a relatively new crop in tropical Africa. It has long been thought that soya bean was not a suitable food crop for the region, because of the long cooking time needed and the unacceptable taste. However, the importance of the crop in tropical Africa has grown rapidly during the past decades. Especially Nigeria witnessed a rapid expansion in soya bean production in the smallholder farming sector in the savanna zone during the 1990s. The driving force for this expansion was the use of soya bean in the preparation of many traditional foods and the introduction of soya tofu which rapidly became one of the most popular snacks in markets in the region and is widely used by the food processing industry. In some areas, the low world prices may depress opportunities for local producers to respond to increased local demand for soya bean. Soya bean can play an increasingly important role in diversifying cereal-based farming systems in tropical Africa. Apart from being a source of residual nitrogen for subsequent cereal crops in crop rotations, the new multi-purpose cultivars bred by IITA provide the additional benefit that they help to reduce *Striga hermonthica* damage on maize, sorghum and millet, thus representing a major opportunity to provide sustainable crop rotations for smallholder farmers. It is therefore very likely that soya bean production will expand in many tropical African countries in the future.

Major references Boerma & Specht, 2004; Carsky et al., 2000; Dashiell & Fatokun, 1997; Hymowitz, 1995; Javaheri & Baudoin, 2001; Mpepereki et al., 2000; Sanginga et al., 2003; Shanmugasundaram & Sumarno, 1989; Sinclair, 1998; Singh, Rachie & Dashiell (Editors), 1987.

Other references Akem & Dashiell, 1996; Aljanabi, 2001; Dashiell & Akem, 1991; FAO, 1998; Giller, 2001; Hanelt & Institute of Plant Genetics and Crop Plant Research (Editors), 2001; Hume, Shanmugasundaram & Beversdorf, 1985; ILDIS, 2005; James, 2002; Mackinder et al., 2001; Musiyiwa, Mpepereki & Giller, 2005; Rehm & Espig, 1991; Sanginga, Thottappilly & Dashiell, 2000; Sanginga et al., 1997; Sanginga et al., 1999; Shannon & Kalala, 1994; Thulin, 1989; Tindall, 1983; USDA, 2004; Weiss, 2000.

Sources of illustration Shanmugasundaram & Sumarno, 1989.

Authors K.E. Giller & K.E. Dashiell
Based on PROSEA 1: Pulses.

GUIZOTIA ABYSSINICA (L.f.) Cass.

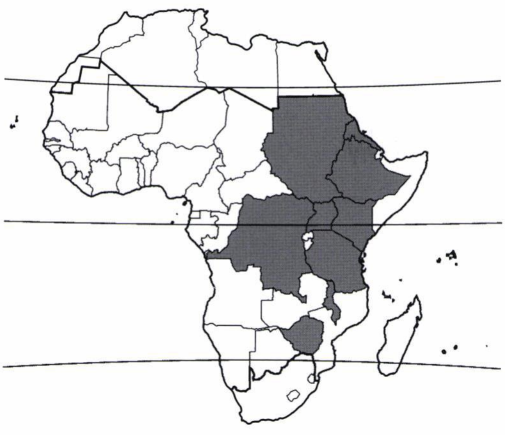
Protologue Dict. Sci. Nat. 59: 237, 248 (1829).

Family Asteraceae (Compositae)

Chromosome number $2n = 30$

Vernacular names Niger seed, niger, ramtil (En). Noug, niger, Guizotia oléifère (Fr). Níger, verbesina da India (Po).

Origin and geographic distribution Niger seed originated in Ethiopia, and its wild ancestor is presumably *Guizotia schimperi* Sch.Bip. It was probably domesticated before 3000 BC in the highlands of Ethiopia, where it is still cultivated as an oilseed crop. From there, traders brought it to India before the Christian era and probably during the same period it spread



Guizotia abyssinica – planted

to other countries in East Africa. Niger seed is now grown extensively in Ethiopia, India and Nepal and on a smaller scale in parts of montane, eastern and southern Africa, Bangladesh, Bhutan and Pakistan and the West Indies. In the 19th century it was also grown in Europe where it still occurs as a casual and it is currently grown on a small scale in the United States.

Uses Niger seed (name refers to both the fruit and the whole plant) is a valued source of edible oil in Ethiopia, where it is called 'noug'. In Ethiopia it is the prime supplier of edible oil in most regions, accounting for about half of the total production of vegetable oil. In India it is mainly a substitute for or extender of sesame oil and contributes only 2% in the national edible oil production. Niger seed is prepared into chutneys, condiments and porridge, mixed with pulses to make snack foods and ground to produce flour and beverages. In Ethiopia slightly roasted seeds are ground with salt and mixed with roasted cereals to prepare snacks, locally called 'litlit' and 'chibito', which are presented during coffee ceremonies. In Western countries niger seed is an important component of birdseed mixtures. Apart from cooking, the oil is utilized in illumination, medicine and cosmetics, 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. In Ethiopia the straw is used as fuel for cooking. Niger seed is grown as a green manure. The seed cake, having about 70% in-vitro digestibility, is the most widely used protein supplement in animal feed in Ethiopia.

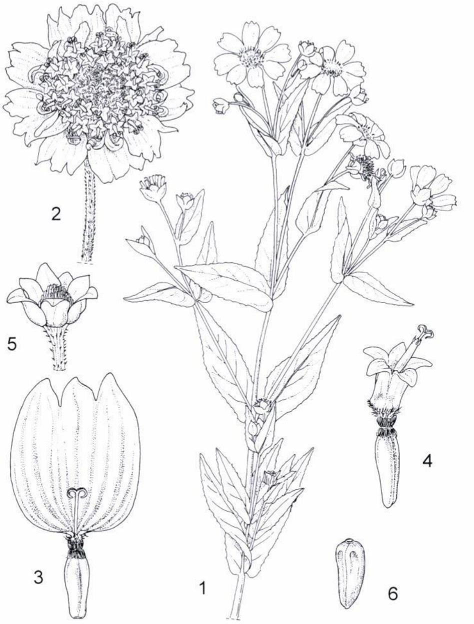
Production and international trade Statistical data on the production of niger seed vary greatly. The production is concentrated in Ethiopia and India, which had a combined annual production of about 350,000 t in the 1990s. In recent years there have been wide variations in the annual production of niger seed in Ethiopia, which was estimated to be 84,000 t in 2002, 85,000 t in 2003 and 114,000 t in 2004. This fluctuation also accounts for the fluctuating exports (from nil to 20,000 t per year) to Europe (especially Italy) and Japan. Niger seed production in India is declining; in 1990 it was estimated at 200,000 t, in 2000 at 120,000 t.

Properties The composition of niger seed per 100 g (portion for oil extraction) is: water 4.1–7.8 g, energy 2033 kJ (483 kcal), protein 17.0–17.7 g, fat 31.9–36.2 g, carbohydrates 34–40 g, fibre 13.4–13.6 g, Ca 400–540 mg, P 690–910 mg, β-carotene 0 mg, thiamin 0.0–0.94 mg, riboflavin 0.3–0.9 mg, niacin 0.5–6.4 mg (Leung, Busson & Jardin, 1968). The oil content varies between 25% and 45% of seed weight for unimproved types and between 50% and 60% for selected strains. In Ethiopia the average oil content of niger seed is 45%.

The major fatty acids in Ethiopian niger seed oil are palmitic acid 7.6–8.7%, stearic acid 5.6–7.5%, oleic acid 4.8–8.3% and linoleic acid 74.8–79.1%. 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°C and –15°C. While Ethiopian niger seed oil contains over 70% linoleic acid, Indian oil contains only 45–70% linoleic acid and 15–40% oleic acid. Niger seed oil is slow drying, clear, pale yellow, odourless or with a faint sweet fragrance and has a nutty taste.

Niger seed cake contains per 100 g: water 8.8 g, energy 1475 kJ (352 kcal), protein 21.7–23.2 g, fat 4.9–6.9 g, fibre 24.6–28.9 g, Ca 123–681 mg, P 680–2353 mg (Leung, Busson & Jardin, 1968). Seed cake from India tends to have a higher protein and 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 subsequent crops.

Description Stout, erect annual herb up to 2 m tall, smooth to slightly scabrid; root system well developed, with taproot and many lateral roots, particularly in upper 5 cm; stem terete, hollow, up to 2 cm in diameter, branched, pale green, often purplish stained or dotted, becoming yellow with age, hairy with multicellular white hairs. Leaves opposite, uppermost ones sometimes alternate, simple, sessile and clasping half the stem; stipules absent; blade lanceolate to narrowly ovate or obovate, 3–23 cm × 1–6 cm, base truncate to cordate, apex tapering, margin entire to toothed, ciliate, softly hairy on both surfaces, usually dark green but lower leaves with distinct yellow tinge. Inflorescence an axillary or terminal, cup-shaped head 1–3 cm in diameter, arranged in cymes, surrounded by leafy involucral bracts up to 3 cm long, arranged in various rows, inner ones merging into paleas between the florets; peduncle up to 14 cm long, densely hairy near the head. Ray florets 6–15, female, ligule obovate to rectangular, 14–21 mm × 5–6 mm, with 3 teeth, bright yellow, becoming more golden yellow with age, ovary inferior, 4–4.5 mm long, with 4 longitudinal ribs, style up to 7 mm long, stigma with 2 branches c. 2 mm long; disk florets 40–60, bisexual, tube up to 5 mm long, 5-lobed, yellow to orange; stamens 5, anthers orange, cohering, with apical appendage. Fruit an obovoid to obconical achene 3–6 mm × 1.5 mm, 4-angled, without pappus, glossy black but sometimes mottled. Seedling with epigeal germination.



Guizotia abyssinica – 1, flowering branch; 2, flower head; 3, ray floret; 4, disk floret; 5, fruiting head; 6, fruit.
Source: PROSEA

Other botanical information *Guizotia* comprises 6 or 7 species, all native to tropical Africa. *Guizotia abyssinica* is the only species of economic importance. *Guizotia abyssinica* is closely related to *Guizotia schimperi*, which is considered by some as the progenitor of *Guizotia abyssinica*, but by others as a subspecies of *Guizotia scabra* (Vis.) Chiov.

The Ethiopian and Indian gene pools of *Guizotia 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. Types grown in Ethiopia mature later, are taller and higher yielding. In Ethiopia niger seed is classified into three types according to the length of the maturity period: 'abat noug', which is a late-maturing type grown in the highlands during the main rainy season (June to December); 'mesno noug', which is a short-season type planted late in the season (September) on waterlogged soils and harvested in January; and 'bunegne noug', which is a lowland type planted in July and harvested in October.

Growth and development Seeds germinate 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 types of niger seed are short-day plants with only few day-length-insensitive individual plants. The critical day length is about 12 hours. Under short days, flowering starts about 60 days after germination. Photoperiod sensitivity is stronger in Ethiopian than in Indian cultivars, while in Indian plants induction of flowering 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 has not been found in Indian cultivars. Flowers are pollinated by insects, mostly by bees. Although the style of the disk florets 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.

Ecology Niger seed is a short-day plant adapted to the cool tropical environment of the mid-altitude and highland regions of eastern Africa, but it has adapted to the tropical and subtropical lowlands in India and to temperate conditions in Europe. It is grown at altitudes from 500 m to well above 2500 m. In Ethiopia the major areas where niger seed is produced are situated at 1600–2300 m altitude, where average daily maxima and minima are 23°C and 13°C, respectively, during the rainy season. The optimum mean daily temperature for niger seed production is 16–20°C. Above 30°C, the rates of growing and flowering are adversely affected and maturity is hastened. Night temperatures should not fall below 2°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 500 mm may be sufficient depending on distribution and cultivar. Niger seed is not grown in high-rainfall areas where a too vigorous plant growth would negatively affect seed and oil production; 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. In Ethiopia it is grown on the dark brown clays of Gonder, the reddish brown clay loams of Gojam and Welega and the more loamy clays in Shoa. 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 increased soil salinity.

Propagation and planting Niger seed is propagated by seed. Well-dried seed can be stored dry without special requirements for at least 4 years without losing its viability. The weight of 1000 seeds (achenes) is 2–5 g. In Ethiopia the main planting season is May–July, whereas in India niger seed is planted in June–August as a rainy season crop or in September–mid-November as a winter crop. A level seedbed, obtained after 2 to 3 cultivations, is essential to ensure an even depth of planting of the small seeds and subsequently a good and uniform emergence. Land preparation in Ethiopia is generally not adequately done and is similar to that applied when planting other small-seeded crops. Seed rates vary from 5–15 kg/ha in Ethiopia and from 5–8 kg/ha in India. In Ethiopia seed is traditionally broadcast at a rate of 10–15 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 intercropped with pulses, millet, sorghum, castor, sunflower and sesame. It is also planted around fields, as cattle do not eat it.

For micropropagation hypocotyls, cotyledons and leaves are cultured in vitro and survival rates of regenerated plantlets range from 70–98%.

Husbandry Niger seed is mostly indifferent to the crop that it follows in a rotation, except for another niger seed crop and maize, which have an unfavourable influence. It is grown both as an intercrop (commonly with sorghum, maize, millet, cowpea, soya bean and sweet potato) and in pure stand. Niger seed grows very rapidly once seedlings are established. Hand weeding is generally required twice, the first one when the crop is 10 cm tall and the second not later than the beginning of budding, or when planted in rows, before the foliage covers the space between the rows. Its dense growth and specific root exudates allow niger seed to compete well with weeds.

Traditionally, niger seed is not directly fertilized, but is grown on residual soil fertility. In Ethiopia the response of niger seed to fertilization is low; the application of N and P fertilizers (23 kg/ha N and 10 kg/ha P) appears profitable in delayed plantings only. In India application of 10–20 kg N and 10–20 kg P per ha 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, respectively, both at a rate of 40 kg/ha.

Potassium has not shown significant effects. 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.

Diseases and pests Niger seed is in general not seriously affected by diseases or pests. Leaf spots are caused by *Cercospora guizoticola* and *Alternaria* spp.; the latter is also associated with stem infection. Root rot due to *Macrophomina phaseolina* has been recorded. Minor infections of bacterial blight (*Pseudomonas* sp.) occur sporadically. In India *Phytophthora* root rot sometimes affects seedlings.

Leaf-eating caterpillars such as *Spodoptera* spp. attack niger seed occasionally in Ethiopia and East Africa. Bollworm (*Helicoverpa armigera*) can damage heads and developing seeds. Aphids (*Macrosiphum* sp.) are common, and thrips (*Frankliniella schultzei*) infest niger seed flowers. Other pests of niger seed are niger flies (*Eutretosoma* sp. and *Dioxyna sorercula*), black pollen beetle (*Meligethes* sp.), an apionid weevil (*Piezotrachelus* sp.) and a leaf miner (*Sphaeroderma guizotiae*). Niger fly lays eggs in the disk florets and later the larvae destroy the flowers. Black pollen beetle eats pollen grains and adversely affects pollination. In India control measures of caterpillars and other insect pests have been developed. Birds may also damage niger seed during the ripening stage.

The parasitic weed dodder (*Cuscuta campestris* Yunck.) causes serious losses in Ethiopia and India. Hand-weeding and the application of herbicides (e.g. chloropropham, propyzamide) provide effective control.

Harvesting Because the heads of niger seed mature over a period of time and shattering can reduce the yield by as much as 25%, time of harvesting has to be established carefully. The best time for harvesting is just before the crop matures, about 3 weeks after 50% floret drop. At this stage, when the top leaves start turning from green to yellow, the fruits are yellow-brown and their moisture content is about 45%. In India the practice is to harvest when leaves are dry and heads turn black. Plants are cut by sickle close to the ground, bundled and stacked in the field to dry for a few days. Threshing is done in the field or on a traditional threshing ground. 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. Small pedal-operated threshers for rice may be adjusted to suit niger seed. Before storage the threshed seed is winnowed.

Yield In Ethiopia seed yields vary from 200–500 kg/ha but yields of 1000 kg/ha have also been obtained. Improved cultivars in combination with improved agronomic practices can attain yields of 1000 kg/ha. In India seed yields of 250–400 kg/ha are common, but they increase to 500–600 kg/ha when niger seed is grown in moderately fertile soils.

Handling after harvest Seed is stored in sacks and other containers. It should be protected from storage pests and transported to bulk storage facilities as soon as possible. The moisture content of stored seed must be less than 8% to prevent damage by storage pests, especially moulds. 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 traditionally extracted by bullock-drawn '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 held at the Institute of Biodiversity Conservation (formerly the Plant Genetic Resources Center), Addis Ababa, Ethiopia (about 1000 accessions), the All India Coordinated Research Project on Oilseeds, Jabalpur (560 accessions) and the India National Bureau of Plant Genetic Resources, Akola (200 accessions). In Ethiopia several hundreds of landraces have been characterized and registered. The adoption of improved cultivars at the expense of landraces is not widespread in Ethiopia. In India the niger seed base collection is held at –20°C for long-term storage and at 4°C for medium-term storage. In-vitro and in-situ conservation of the working collections is not done in India; instead, the collections are maintained and regenerated by sibbing (during multiplication, plants of an accession are bagged as a group to avoid crossing with other accessions) to produce viable seed stocks.

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. Large variation and

high heritability were found for plant height and days to flowering; both variation and heritability were lower for number of branches, number of flower heads, 1000-seed weight and yield per plant. Breeding objectives for niger seed are to increase seed yield and oil content and reduce shattering. Following developments in sunflower and safflower, it has been postulated that single-headed dwarf types with uniform maturity must be developed to achieve the first objective. An increase in oil content appears feasible because of existing genetic variability, which can be used in breeding research. As niger seed is self-incompatible, breeders in India and Ethiopia have adopted population improvement programmes such as mass selection and sibbing. Recently a protocol for *Agrobacterium tumefaciens* mediated genetic modification was developed.
Niger seed production in Ethiopia is mainly based on local landrace populations. Five improved cultivars have been released by the Ethiopian Research Organization (formerly Institute of Agricultural Research): 'Sendafa' (now obsolete); 'Esete-1' (1988): medium to late maturing, high seed yield and high oil content; 'Fogera-1' (1988): similar to 'Esete-1' in many aspects, but slightly lower in seed yield; 'Kuyu' (1994): early to medium maturing, high seed yield and a good degree of resistance to many common diseases and pests; and 'Shambu-1' (2002): early maturing, second best in seed yield (after 'Kuyu'), higher oil content than 'Kuyu', and with a good degree of resistance to many common diseases and pests.
Well-known improved cultivars in India are: 'Ootacamund', 'Deomali', 'Paiyur-1', 'IPG-76' and 'JNC-6'; in the United States 'EarlyBird' was developed for the northern prairie states.

Prospects Although niger seed is mainly produced in South Asia, Ethiopia and other African countries, it can potentially be grown in all cooler places in the tropics and in temperate regions. Niger seed is a good precursor for many crops because crops following niger seed have less weed infestation and profit from the large amount of organic matter left in the ground. It can be mechanically planted and harvested using typical agronomic equipment. Both Ethiopia and India are excellent sources of germplasm for development. Niger seed provides an exciting opportunity due to its well-established market, which is of significant size and offers an attractive price.

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Other references Central Statistical Authority, 2001–2003; Geleta et al., 2002; Getinet Alemaw & Adefris Teklewold, 1992; Kandel & Porter (Editors), 2002; Kandel et al., 2004; Leung, Busson & Jardin, 1968; Marini et al., 2003; Murthy et al., 2003; Riley & Belayne, 1989; Tsige Genet & Ketema Belete, 2000.

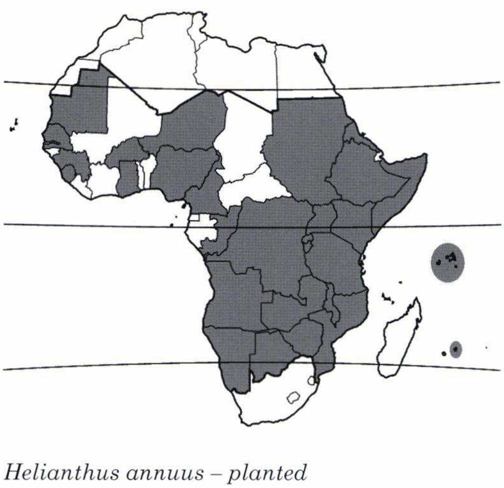
Sources of illustration Umali & Yantasath, 2001.

Authors W. Bulcha
Based on PROSEA 14: Vegetable oils and fats.

HELIANTHUS ANNUUS L.

Protologue Sp. pl. 2: 904 (1753).
Family Asteraceae (Compositae)
Chromosome number $2n = 34$
Vernacular names Sunflower (En). Tournesol (Fr). Girassol (Po). Alizeti (Sw).

Origin and geographic distribution Wild *Helianthus annuus* spread from its origin in the south-western United States to most other regions of North America in association with human migration in prehistoric times. According to archaeological evidence, modern single-headed sunflowers are derived from 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 as a source of oil. Sunflower became popular in Europe as a novel ornamental soon after its first arrival



Helianthus annuus – planted

from Mexico in the botanic garden of Madrid around 1510. Its potential as an oilseed crop for higher latitudes became apparent in the 18th century in 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 the Soviet Union developed high-yielding and oil-rich sunflower cultivars, which played a crucial role in the expansion of sunflower production in Europe and elsewhere between 1920 and 1970. Modern sunflower production in North and South America (mainly the 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 host resistance to diseases and pests have been major factors leading to the spectacular increase of sunflower production since 1980 in Argentina, India, China, Turkey, the European Union (e.g. France, Spain) and South Africa. Sunflower production in tropical Africa is expanding mainly in the highlands of eastern and southern countries. Occasionally sunflower escapes and becomes naturalized, also in tropical Africa.

Uses Sunflower seed yields an edible oil of excellent quality due to a high proportion of unsaturated fatty acids, near absence of toxic substances, light colour, and good taste and flavour. The oil 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 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 oil extraction is a protein-rich meal used as livestock feed. For this purpose, the meal is commonly blended with soybean 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. When oil is extracted industrially, the stalk and flower head of sunflower are processed into cellulose and fibre mats. The indigenous peoples of North America have had a long tradition of preparing bread-like products from ground sunflower seeds.

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

Sunflower is sometimes cultivated as a forage crop. In comparison with maize, it requires a shorter growing season, is more drought tolerant and produces lower yields but a silage of often slightly superior quality. Sunflower is also grown as an ornamental garden and pot plant and is an important bee plant.

Production and international trade Average annual world production of sunflower seed over the period 2002–2004 was about 26.2 million t, equivalent to 9.8 million t oil, from 21.4 million ha in 66 countries. The Russian Federation (4.3 million t) is the largest producer, followed by Ukraine (3.7 million t), Argentina (3.6 million t), China (1.9 million t), France (1.5 million t), Romania (1.4 million t), USA (1.2 million t), India (1.1 million t), Hungary (1.0 million t), South Africa (800,000 t), Spain (780,000 t) and Turkey (750,000 t). Countries in tropical Africa with sizable sunflower production are Tanzania (28,000 t), Sudan (18,000 t), Kenya (12,000 t), Angola, Mozambique and Zambia (each about 11,000 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, the 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 sunflower oilseed production. Most of the sunflower meal is traded on domestic markets, except for the 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 seed is approximately: water 5 g, protein 23 g, oil 50 g, carbohydrate 19 g, dietary fibre 11 g, Ca 116 mg, Mg 354 mg, P 705 mg, Fe 6.8 mg, Zn 5.1 mg, thiamin 2.3 mg, riboflavin 0.25 mg, niacin 4.5 mg, folate 22.7 µg, ascorbic acid 1.4 mg (USDA, 2005). Oilseed sunflower cultivars have a high oil content

(>50%) and low hull fraction (20–25%), against a low oil content (25–30%) and high hull fraction (43–52%) of non-oilseed cultivars. About 98% of all 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% and 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 630–700 mg/kg tocopherols (fat-soluble vitamin E). Sunflower meal has a protein content of 29–45% depending on cultivar and method of oil extraction and is a good source of Ca, P and vitamin B complex. Sunflower proteins are highly digestible and have a good biological value, but are somewhat deficient in the essential amino acid lysine. Chlorogenic acid is the main antinutritional factor in sunflower meal, but at a concentration lower than 6 g/kg it does not affect the nutritional quality. Stem and husk are rich in K and the forage contains: protein 9%, fibre 20% and ash 15%.

Description Erect annual herb up to 4(–5) m tall, long-hairy; taproot strong, up to 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 flower head in mature plants, 3–6 cm in diameter, terete but with ridges, branched in many wild types, unbranched in most cultivated types, woody and angular at maturity and often becoming hollow. Leaves opposite in lower part of plant, higher ones arranged spirally, simple; stipules absent; petiole long; blade of lower leaves cordate, of higher ones ovate, 10–30 cm × 5–20 cm, apex acute or acuminate, margin toothed, hairy on both sides with glandular and non-glandular hairs, veins prominent and forming a reticulate pattern. Inflorescence a terminal head 10–50 cm in diameter, sometimes drooping when mature; receptacle flat to concave, 1–4 cm thick; involucral bracts arranged in 3 rows, ovate to ovate-lanceolate, ciliate. Ray florets sterile, showy, deciduous, corolla ligulate, elliptical, c. 6 cm × 2 cm, usually yellow; disk florets bisexual, numerous, arranged in spiral whorls from the centre of the head, c. 2 cm long, subtended by a pointed palea, 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, style long with nectaries at its base, stigma with 2 curved lobes. Fruit an obovoid achene 7–25 mm × 4–15 mm × 3–8 mm, flattened, slightly 4-angled with rounded base and truncate tip, white, cream, brown, purple, black or white-grey with black stripes. Seed with thin seed coat adnate to the fruit wall. Seedling with epigeal germination; hypocotyl 6–8 cm long, epicotyl c. 0.5 cm long, hairy; cotyledons stalked, leafy, 2.5–3 cm long, glabrous.

Helianthus annuus – 1, flowering stem; 2, fruiting head; 3, fruits.
Redrawn and adapted by Iskak Syamsudin

Other botanical information *Helianthus* comprises about 50 species, all from North America. These are grouped in 4 sections, one being the section *Helianthus* with 11 annual, diploid species including the domesticated sunflower. Cultivars are usually grouped according to plant height:

- Tall (Giant) cultivars: 2–4 m tall, flowerheads 30–50 cm in diameter and large seeds, late maturing, oil content rather low; representative: 'Mammoth Russian';
- Standard cultivars: 1.5–2.1 m; representatives: 'Peredovic', 'VNIIMK 8931' and 'Pro-

gress', 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; representatives: 'Pole Star', 'Jupiter', most modern hybrid cultivars;
- Dwarf cultivars: 0.8–1.2 m tall, with fewer nodes and leaves than standard cultivars but normal internode length; flower heads 13–17 cm in diameter and small seeds, highest oil content; representatives: 'Advance, 'Sunrise'.

Growth and development Sunflower seeds show dormancy until 30–50 days after harvesting, but this is easily overcome by rinsing 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. Young 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 bumblebees. 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 (30–40 days after last anthesis) the head becomes yellow, the bracts brown and about 75% of the leaves are desiccated. During the following 10 days the seed will dry to 10–12% moisture content and start shattering, while the receptacle may still contain more than 30% water.

Ecology Sunflower is cultivated mainly between 20–55°N and 20–40°S, in relatively cool temperate to warm subtropical climates. In the tropics it can be grown in the 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 the composition of the oil changes with less linoleic 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. Long photoperiods increase plant height. Water requirement is 300–700 mm during the 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 not acid; suitable pH ranges from 5.7 to 8.1. The tolerance of sunflower of saline soils is only slightly better than that of soya bean and comparable to that of wheat.

Propagation and planting Sunflower is sown directly in the field at a depth of 3–8 cm. It requires a medium fine seedbed that is free from weeds. The 1000-seed weight is 40–60 g for oilseed and 80–110 g for non-oilseed cultivars. With mechanical planting seed rates are 3–8 kg/ha depending on seed size and spacing (60–75 cm between rows and 20–30 cm within rows). Optimum final plant densities vary with environment and cultivar: 15,000–30,000 plants/ha for 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 groundnut, pulses and millets, plant it on banks around irrigated fields, or use it as living supports for beans and gourds.

Management Sunflower seedlings compete poorly with weeds. Control is effected by inter-row 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 one 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 in particular, are also immobilized in the plant stover (stalk and receptacle), resulting in a rather low fertilizer use efficiency. Recommended applications of fertilizer to sunflower crops with expected seed yields of 1.5–2.5 t/ha vary: 50–120 kg N, 20–30 kg P and 40–80 kg K. Seed oil content tends to decline and the protein content to increase with higher N fertilizer applications. 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. To avoid a build-up of diseases and pests, sunflower should not be grown in 2 consecutive crops. Crop rotation with cereals and pulses is common.

Diseases and pests Sunflower is host to more than 30 pathogens, about half of them of worldwide importance and regularly causing considerable economic losses. Probably the most serious crop limiting 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. Equally common fungal diseases are: red 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*). Downy mildew (*Plasmopara halstedii*), causing damping-off in seedlings and yellowing of the leaves that spreads from the midribs and a characteristic upright orientation of the head, is of less importance in eastern and southern Africa than in Europe; it occurs especially in traditional open-pollinated cultivars. Occasionally serious fungal diseases occur, including powdery mildew (e.g. *Erysiphe cichoracearum*), wilt caused by *Verticillium dahliae*, charcoal rot (*Macrophomina phaseolina*), southern blight or collar rot (*Sclerotium rolfsii*) in warm climates, head rot (*Botrytis cinerea*) in cool and wet conditions, and white rust (*Albugo tragopogonis*). Some of these diseases can be controlled by fungicides or by host resistance. A bacterial foliar disease is caused by *Pseudomonas syringae* and sunflower may also become infected by virus diseases (sunflower mosaic virus (SuMV) and tobacco leaf curl virus (TLCV)) and attacked by nematodes (e.g. *Meloidogyne* spp., *Rotylenchus* spp.).

There are numerous insect pests, many of them specific to a continent, the most damaging being those attacking buds, flower heads and developing seeds. A major cause of poor emergence and plant stands are the larvae of various cutworms (*Agrotis* spp.), wireworms (*Gonocephalum* spp.) and mole crickets (*Gryllotalpa* spp.). Other important sunflower pests in Africa are scarabs (*Schizonycha* spp.), grasshoppers (*Zonocerus* spp.), leafworm (*Spodoptera* spp.), leaf miners (*Liriomyza* spp.) and sucking insects such as *Aphis gossypii* and *Bemisia tabaci*, stem borer (*Heteronychus* spp.), head and developing seed-damaging bollworm (*Helicoverpa armigera*), sunflower moth (*Homoeosoma* spp.), blue bug (*Calidea* spp.) and shield bug (*Nezara viridula*). Insecticides used to control pests in sunflower should not be toxic to pollinating bees during the flowering period. Crop rotation, trap crops, biological control and host resistance in cultivars are some means of control. Cultivars with seed having a phytomelanin layer in the pericarp are less attacked by seed damaging insect pests. Drooping broomrape (*Orobanche cernua* Loefl.) is a parasitic plant that feeds on sunflower roots and may cause considerable damage. Broomrape is difficult to control, but integration of a biocontrol agent with a resistance-inducing chemical offers new perspectives. Birds and rodents can cause major losses to the maturing sunflower crop and need control measures (e.g. chemical repellent, scare guns and early harvesting).

Harvesting Sunflower is ready for harvesting when the heads have turned yellow-brown and seed moisture content is 10–12%, about 120–160 days after planting for tall and 80–110 days for short cultivars. Manual harvesting, as applied by smallholders, involves cutting of 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 seed shattering during harvesting operations. Before storage, harvested seeds are cleaned and dried to 8% in open sacks under shelter in warm and dry weather, or otherwise by artificial dryers.

Yield World average seed yield is 1.2 t/ha. National averages in Africa range from 0.4 t to 1.3 t/ha, e.g. Tanzania 0.4 t, Zambia, 0.6 t, Sudan 0.8 t, Kenya 1.0 t and South Africa 1.3 t per ha. High yields of 2–4 t/ha (1–2 t/ha of oil) are obtained in Europe and the United States from modern hybrid cultivars and with high inputs. Maximum seed yields of 5–6 t/ha have been obtained in field experiments.

Handling after harvest Small quantities of dried seed can be stored in moisture- and insect-proof containers placed in a cool place. Large-scale storage of sunflower seeds requires well-aerated bins or silos to maintain seed moisture content at about 8%. Regular inspection prior to and during storage is necessary to avoid storage insect 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 being hulled (decortication), which involves cracking and separation of the fruit wall. Three methods of industrial oil extraction are available: mechanical expulsion by 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 0.5–1.5% oil. The crude oil is subsequently cleaned by filtration, refined (chemically or by steam) to reduce its free fatty acid content, bleached (with bleaching earth) to remove carotenoids and other pigments, and finally deodorized (stripping by steam) 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 culturing are quite successful methods of achieving difficult interspecific hybridization in sunflower. Wild *Helianthus annuus* and several other species have contributed important characters for the improvement of the cultivated sunflower, such as (nuclear and cytoplasmic) male sterility, fertility restoration, resistance to several diseases and some pests, improved drought and salt tolerance as well as changed fatty acid composition.

Large collections of germplasm of sunflower and wild *Helianthus* spp. are maintained by the Institute of Crop Science (CAAS), Beijing, China (2250 accessions), INRA, Montpellier, France (2500 accessions), the National Institute of Information and Documentation, Bucharest, Romania (1125 accessions), the N.I. Vavilov Scientific Research Institute of Plant Industry (VIR) in St.Petersburg, Russian Federation (3055 accessions), the Research Institute for Field and Vegetable Crops at Novi Sad, Serbia and Montenegro (5150 accessions), and the USDA North Central Regional Plant Introduction Station, Ames IA, United States (3814 accessions, of which more than 1000 wild *Helianthus*).

Breeding Uniform F_1 hybrids have almost completely replaced the open-pollinated cultivars developed by mass and family selection such as 'Peredovik' in Russia (released in 1930). The early hybrid cultivars based on self-incompatibility like 'Advance' in Canada (1946) or on nuclear male sterility like 'INRA 651' in France (1969) still had 30–50% selfed plants. The discovery of cytoplasmic male sterility (CMS) in offspring of an interspecific cross of *Helianthus petiolaris* Nutt. × *Helianthus annuus* together with maintainer and restorer genes in France in 1968–1970 quickly led to a new generation of sunflower F_1 hybrids with the potential of maximally exploiting hybrid vigour: no selfed plants and 100–150% higher yields than open-pollinated cultivars. In the meantime more than 70 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 good seed production even when pollinating insects are less abundant. Multi-branched male lines are commonly 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. There is generally a positive correlation between seed yield, 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 (*Plasmopara halstedii*) and rust (*Puccinia helianthi*), 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 or white rot (*Sclerotinia sclerotiorum*) is difficult to achieve due to its complexity and polygenic inheritance. Broomrape resistance exists, but here also virulent races may overcome this. Bird damage appears to be less in sunflowers with concave-shaped heads which hang parallel to the soil at plant 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 considerable genetic resources present in the wild *Helianthus* gene pool should contribute to higher crop security by improved resistance to diseases and pests, which at present still account for the destruction of 40–50% of the world sunflower crop. Recent advances in sunflower biotechnology, like marker assisted selection and genetic transformation, are expected to contribute considerably to more efficient sunflower improvement, in particular where conventional breeding has failed to produce results. For example, significant progress has been made already in developing transgenic sunflower with partial resistance to *Sclerotinia sclerotiorum*, based on the expression of a gene that detoxifies the oxalic acid secreted by the invading pathogen.

Sunflower produces an excellent vegetable oil, but expansion beyond the highlands of eastern and southern tropical Africa will be difficult because it is unsuitable for hot and humid climates. Numerous diseases and pests, as well as serious risks of damage by birds and rodents are also limiting factors to small-scale and low-input cultivation of this crop.

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Sources of illustration Hess, Landolt & Hirzel, 1972; Mansfeld, 1986; Vaughan & Geissler, 1997.

Authors H.A.M. van der Vossen & J.A. Fagbayide

IRVINGIA GABONENSIS (Aubry-Lecomte ex O'Rorke) Baill.

Protologue Traité Bot. Méd. Phan. 2: 881 (1884).

Family Irvingiaceae

Chromosome number $2n = 28$

Vernacular names Sweet bush mango, rainy season bush mango, dika nut tree, dika bread tree (En). Dika, odika, manguier sau-

Irvingia gabonensis – wild

vage, chocolatier, ogbono (Fr).

Origin and geographic distribution *Irvingia gabonensis* is indigenous to the humid forest zone of the Gulf of Guinea from western Nigeria east to the Central African Republic, and south to Cabinda (Angola) and the westernmost part of DR Congo; it also occurs in São Tomé et Príncipe. It is planted in parts of this area, e.g. in south-western Nigeria and southern Cameroon, and also in Côte d'Ivoire, Ghana, Togo and Benin.

Uses Kernels of the fruits of *Irvingia gabonensis*, called 'ugiri' in Igbo or 'apon' in Yoruba, yield an important food additive popular in West and Central Africa. They are processed by grinding and crushing, and then used to thicken soups and stews. The kernels are also made into a cake called 'dika bread' or 'odika bread' for year-round preservation and easy use. An edible oil is extracted from the seed that is used in cooking. As it is solid at ambient temperatures it has been used as a substitute for cocoa butter, and for soap-making. The presscake is suitable for thickening soup and is a good cattle feed. Unlike the fruit pulp of most other *Irvingia* spp. which is bitter, the pulp of the fruit of *Irvingia gabonensis* is juicy and sweet and eaten fresh. It can be used for the preparation of juice, jelly, jam and wine. The pulp has also been used to prepare a black dye for cloth.

Irvingia gabonensis is commonly preserved on farms to provide shade for crops, especially cocoa and coffee. The medicinal uses of *Irvingia* spp. are many, but it is difficult to assign them to individual species. Preparations from the bark are rubbed on to the body to relieve pains and are applied to sores and wounds and against toothache. They are also taken to treat diarrhoea. Igbo people use a leaf extract as a febrifuge. In Cameroon preparations mainly from the bark are used to treat hernia and yellow fever and as an antidote for poisoning. Kernels are used to treat diabetes. The wood, called 'andok' in Cameroon, is used locally for heavy construction work and for making ships' decks, paving blocks and planking. Young trees are used for making poles and stakes, while branches are made into walking sticks or thatched roof supports. Dead branches are used as firewood.

Production and international trade *Irvingia gabonensis* is cultivated for commercial production in southern Nigeria and southern Cameroon. Fruit is only traded locally, but kernels are widely and extensively traded domestically, from the forest zone to the savanna zone and between countries in West and Central Africa. They are exported to Europe. Cameroon is probably the main exporter. The combined export trade of the kernels of *Irvingia gabonensis* and *Irvingia wombolu* Vermoesen from Cameroon has been valued at US$ 260,000 per year for 107 t. The fruit kernels are very common throughout the year in the markets of Libreville (Gabon). They originate from the local forest, but are also commonly imported from Cameroon and Equatorial Guinea. The wood of *Irvingia* is mainly used locally and is rarely exported.

Properties The nutritive value of the kernels per 100 g edible portion is: water 4 g, energy 2918 kJ (697 kcal), protein 8.5 g, fat 67 g, carbohydrate 15 g, Ca 120 mg, Fe 3.4 mg, thiamin 0.22 mg, riboflavin 0.08 mg, niacin 0.5 mg (Platt, 1962). Drawability (sliminess) and viscosity of soups imparted by the kernels varies between kernels from different trees. They are generally less than those caused by kernels of *Irvingia wombolu*. Fat content of kernels also varies between trees and is 37.5–75 g/100 g; the approximate fatty acid composition is: lauric acid 20–59%, myristic acid 33–70%, palmitic acid 2%, stearic acid 1% and oleic acid 1–11%. The residue obtained after separation from the fat has good properties for processing in the food industry.

The nutritive value of the fruit pulp per 100 g edible portion is: water 81 g, energy 255 kJ (61 kcal), protein 0.9 g, fat 0.2 g, carbohydrate 15.7 g, Ca 20 mg, P 40 mg, Fe 1.8 mg, ascorbic acid 7.4 mg (Leung, Busson & Jardin, 1968). The main flavour components of the fruit pulp are zingiberene and α-curcumene, ethyl and methyl esters of cinnamic acid, dodecanal and decanol imparting spicy-earthy, fruity and wine-yeast flavour notes. The pulp yields about 75% juice. Wine produced from it was found to be of good colour, mouthfeel, flavour and general acceptability.

Heartwood of *Irvingia gabonensis* and *Irvingia wombolu* is pale greenish brown or orange-yellow fading to greyish brown; sapwood is lighter, but not always clearly differentiated. The grain is straight or interlocked, texture fine to medium.

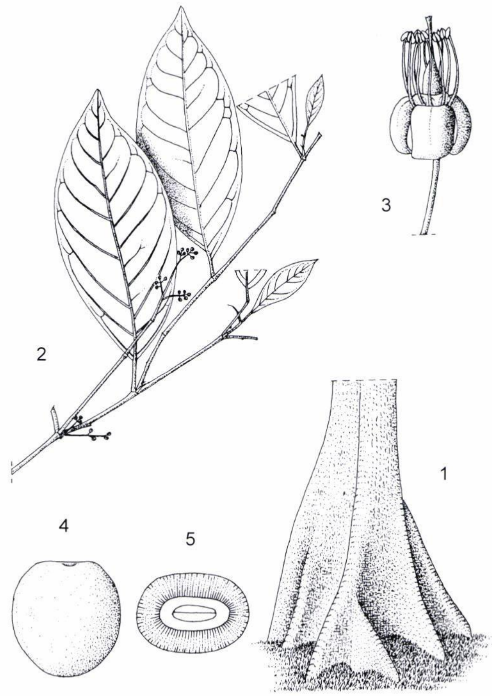
The wood is fairly heavy. The density is 930–1002 kg/m^3 at 12% moisture content. The shrinkage rates are high, from green to oven dry 6.5–7.1% radial and 10.2–12.6% tangential. To avoid end surface checking, logs should be converted soon after felling, preferably by

quarter-sawing.
At 12% moisture content, the modulus of rupture is 163–217 N/mm², modulus of elasticity 18,700–21,700 N/mm², compression parallel to grain 69–79 N/mm², Chalais-Meudon side hardness 5.7–12.7, shear 15 N/mm², cleavage 19–34 N/mm. The timber is moderately difficult to saw or plane and tools should be kept sharp. It dresses to a smooth finish and glues well. Nailing is difficult. The timber is durable and fairly resistant to termites, but susceptible to powder-post beetles and marine borers. The heartwood is untreatable, the sapwood resistant to preservatives.
The stem bark was found to have analgesic effects in tests with mice. Aqueous extracts of the leaves have caused a reduction in intestinal motility in test animals. Addition of a supplement of 4 g/day of 'dika bread' to the diet of type-2 diabetes patients reduced plasma glucose and lipid levels.

Adulterations and substitutes The kernels of all *Irvingia* species are used as a thickener for soups and stews. Groundnuts and okra are used similarly in West and Central Africa.

Description Small to large tree up to 40 m tall; bole generally straight, up to 100 cm in diameter, with buttresses up to 3 m high; outer bark smooth to scaly, grey to yellow-grey, inner bark yellow, fibrous; crown spherical or taller than wide, dense. Leaves alternate, simple and entire; stipules up to 4 cm long, unequal, forming a cone protecting the bud, caducous, leaving an annular scar on the branches; petiole up to 5 mm long; blade elliptical, 4.5–8 cm × 2–4 cm, base cuneate, apex acute or indistinctly acuminate, thinly leathery, pinnately veined. Inflorescence an axillary panicle up to 9 cm long. Flowers bisexual, regular, 5-merous, small; pedicel up to 5 mm long; sepals free, 1–1.5 mm long; petals free, 3–4 mm long, yellowish white; stamens 10, inserted below disk, free, equal, filaments 4–5 mm long; disk 1.5 mm in diameter, bright yellow, nectariferous; ovary superior, 2-celled, style 1–2 mm long. Fruit an ellipsoid to cylindrical drupe, occasionally nearly spherical, slightly laterally compressed, 4–6.5 cm × 4–6.5 cm × 3.5–6 cm, smooth, green when ripe; pulp bright orange, soft, juicy, sweet to slightly bitter, with a few weak fibres, stone woody, 1-seeded. Seed 2.5–4 cm × 1.5–2.5 cm × c. 1 cm. Seedling with epigeal germination.

Other botanical information *Irvingia* comprises 7 species, 6 in tropical Africa and 1 in South-East Asia. *Irvingia gabonensis* is closely related to and difficult to distinguish from *Irvingia wombolu*. *Irvingia gabonensis* has edible fruit pulp while that of *Irvingia wombolu* is bitter and inedible. Both species are called bush mango: rainy season bush mango for *Irvingia gabonensis* and dry season bush mango for *Irvingia wombolu*, in accordance with their respective fruiting periods. Some authorities consider *Irvingia wombolu* merely a variety of *Irvingia gabonensis*. Because of the long history of protection and cultivation, others consider them cultivars of a single species. However, DNA analyses indicate that the 2 taxa are clearly genetically distinct and do not (or hardly) hybridize, even where sympatric.



Irvingia gabonensis – 1, base of bole; 2, flowering twig; 3, flower; 4, fruit; 5, fruit in cross section. Redrawn and adapted by Achmad Satiri Nurhaman

Irvingia excelsa Mildbr. is a large rainforest tree occurring from Cameroon to Gabon and DR Congo. The pulp of its fruit is hard, stiff-fibrous and inedible. The seeds are eaten like those of other *Irvingia* spp.
Irvingia robur Mildbr., a large tree with a disjunct distribution, occurs from Sierra Leone to Côte d'Ivoire and from Nigeria to DR Congo. It fruits and flowers year-round, but with a flow-

ering peak in the dry season and fruiting peak in the rainy season. It occurs in forest on dry land.

Irvingia smithii Hook.f. occurs in forest and savanna from Nigeria to Sudan and throughout DR Congo to Angola. Its fresh fruits are sucked for their sweet pulp. The oil-rich seeds are eaten raw in the Central African Republic and DR Congo. The wood is locally used as timber. A decoction of the bark is taken against dysentery. *Irvingia smithii* always grows near water. The fresh fruits contain characteristic air bubbles and float.

Growth and development Growth in young plants is very slow; later it becomes moderately fast. In Onne (Nigeria), on an acid Ultisol and with an annual rainfall of 2400 mm, 12-year-old trees had reached a height of 12 m and a stem diameter (1.3 m above the ground) of 17 cm. In Ibadan (Nigeria), on an Alfisol and with an annual rainfall of 1280 mm, they reached a height of 8 m and a stem diameter of 12 cm. The flowering season is not clearly defined, but flowering occurs mainly in the late dry season or early rainy season, in April in south-western Cameroon and in September–October in Gabon. Fruits are mature about 4 months later. In cultivation in Côte d'Ivoire some trees flower year-round. The flowers are pollinated by a variety of insects and self-pollination is rare. In the wild trees start fruiting when 10–15 years old, but planted trees may first fruit after 4 years. After the fruits fall the pulp rots away quickly. Successful germination in elephant dung is common. The thickness of the kernel wall varies from strong and thick to thin and brittle. Trees have been identified in which kernels split open spontaneously. Seed is recalcitrant.

Ecology The preferred habitat of *Irvingia gabonensis* is moist lowland tropical forest below 1000 m altitude and with annual rainfall of 1500–3000 mm and mean annual temperatures of 25–32°C. *Irvingia gabonensis* is better adapted to acid Ultisols in high-rainfall areas than to less acidic Alfisols; it prefers well-drained sites. Often 2–3 trees grow together and in some areas it is reported to be gregarious. The presence of *Irvingia gabonensis* is often associated with former human habitation. Trees are fire tender.

Propagation and planting *Irvingia gabonensis* is mainly propagated by seed. When farmers plant it, they choose seed from selected trees on their own farm, from neighbours, or from the market. Criteria for selection are large fruit size, good taste, high yield, regular production (every year), early maturity, good sliminess and drawability of kernels and easy kernel extraction. Transplanting of wildlings and retainment and protection of wildlings when clearing land for agriculture are common. Germination of *Irvingia gabonensis* seeds takes more than 14 days and they should first be extracted from the fruit and dried for at least 2 days. A germination rate of 80% can be reached in this way. Methods of vegetative propagation through rooting of leafy stem cuttings under mist have been developed, and micropropagation, grafting and marcotting experiments are in progress. Preliminary results show that plants from bush mango marcotts can fruit 2–2.5 years after transplanting.

Management Although in most areas *Irvingia gabonensis* occurs in wild stands or is retained in plantations of cocoa, coffee or annual food crops or in home gardens, it is commonly planted in some regions. Management tasks mostly include pruning, harvesting (gathering and picking) and fertilization.

Diseases and pests No diseases or pest of *Irvingia gabonensis* trees have been recorded. Seeds are infested by larvae of the merchant grain beetle (*Oryzaephilus mercator*). Eggs are laid between the testa and cotyledons of the seed or in cracks in the cotyledons. Preventing cracks helps to prevent infestation.

Harvesting *Irvingia gabonensis* fruits are mostly gathered from the ground around each tree, or harvested by climbing when the tree is not too tall. The next step consists of extracting kernels from seed, which is split in halves with a cutlass, and the kernel is removed with the help of a knife. The kernels are then dried in the sun or on bamboo drying racks over the fireplace in the kitchen.

Yield In Onne (Nigeria) 12-year-old trees have yielded 1060 fruits (180 kg) per tree, but in drier areas yields are much lower. Good kernel yields are about 100 kg/tree.

Handling after harvest The preparation of 'dika bread' consists of drying, roasting and grinding or pounding the kernels. The paste obtained is put in a container or 'cake tin' and left to cool for a few hours. Once solid, the cake is removed from the container and is ready for use. If well dried, it can be stored for more than a year. Sometimes women place a tin below the grid on which the dika cake is stored, to collect the oil that drips from it. In Gabon 'dika bread' is marketed in cakes of 100–5000 g. Oil is extracted by boiling the ground kernels and scooping off the oil.

Genetic resources Three centres of genetic diversity in *Irvingia gabonensis* have been identified: southern Cameroon, south-eastern Nigeria and central Gabon. Germplasm collections made in the distribution range of *Irvingia gabonensis* have led to the creation of gene banks in Cameroon and Nigeria by ICRAF and its collaborative partners in the region.
Irvingia gabonensis is fairly widespread. It does not seem to be in danger of genetic erosion. It is classified in the IUCN Red List as a lower risk species, but being close to the qualification 'vulnerable'

Breeding Assessment of the variation in tree characters among planted trees in southwestern Cameroon indicates that farmers have traditionally selected for large fruit and kernel size and easy extractability. ICRAF has started a systematic programme of domestication of *Irvingia gabonensis*. This programme utilizes the variability by selecting trees with desirable traits and propagating them, while keeping a broad genetic base. A clonal approach aimed at cultivar development has been adopted. An assessment of the variability in fruits and kernel traits was made and trees were selected on the basis of desired fruit characteristics. Studies are in progress for the development of methods of marcotting and grafting *Irvingia gabonensis* to capture desired traits in domesticating this species.

Prospects Kernels of *Irvingia gabonensis* are widely traded domestically and between countries in West and Central Africa, indicating that demand is likely to increase. Domestication of this species offers great opportunity for the sustainability of production. The development of methods of transformation and preservation of the product will further add value and expand its market.

Major references Atangana et al., 2001; Ayuk et al., 1999; Harris, 1993; Harris, 1996; Leakey et al., 2000; Leakey et al., 2005; Lowe et al., 2000; Ndoye, Ruiz-Pérez & Eyebe, 1998; Richter & Dallwitz, 2000; Shiembo, Newton & Leakey, 1996.

Other references Adamson, Okafor & Abu-Bakare, 1986; Akubor, 1996; Atangana et al., 2002; Burkill, 1994; Chudnoff, 1980; Dudu, Okiwelu & Lale, 1998; Ejiofor, Onwubuke & Okafor, 1987; Giami, Okonkwo & Akusu, 1994; Harris, 1999; Kang, Akinnifesi & Ladipo, 1994; Okafor, 1975; Okafor & Ujor, 1994; Okolo et al., 1995; Omokolo, Fotso & Mbouna, 2004; Platt, 1962; Sallenave, 1971; Tabuna, 1999; Van Dijk, 1997.

Sources of illustration Harris, 1996; Wilks & Issembé, 2000.

Authors Z. Tchoundjeu & A.R. Atangana

IRVINGIA GRANDIFOLIA (Engl.) Engl.

Protologue Bot. Jahrb. Syst. 46: 288 (1911).

Family Irvingiaceae

Synonyms *Klainedoxa grandifolia* Engl. (1907).

Vernacular names Olène, andok ngoué (Fr).

Origin and geographic distribution *Irvingia grandifolia* occurs in the forest zone from western Nigeria east to eastern DR Congo and south to Cabinda (Angola).

Uses The oil-rich seeds are occasionally cooked and eaten in the Central African Republic. The pulp of the fruit is edible, but is not sought after. The bark macerated in palm wine is taken as an aphrodisiac. A bark decoction is taken against pain in various parts of the body. Rubbing with bark powder also relieves pain. A bark decoction is also used for bathing to treat fever in children. A decoction of the leaves taken together with raw cassava tubers or with a decoction of the leaves of *Staudtia kamerunensis* Warb. is taken to treat hypermenorrhoea. The wood is used locally in heavy construction and is called 'andok ngoué' in Cameroon.

Properties The kernels are rich in oil. The wood is hard, heavy and difficult to work.

Botany Large tree up to 40 m tall; bole straight and unbranched for up to 20 m, up to 150 cm in diameter, often with buttresses up to 4 m high; outer bark greyish, smooth to scaly, inner bark yellow, fibrous; crown hemispherical, with spreading branches. Leaves alternate, simple and entire, pendulous; stipules up to 1 cm long; petiole c. 1 cm long; blade ovate to elliptical, 10–25(–35) cm × 8–15 cm, base mostly cordate, apex acute or minutely acuminate, papery, pinnately veined. Inflorescence a terminal, branched panicle up to 8 cm long, with flowers crowded on the axes. Flowers bisexual, regular, 5-merous, small, sessile; sepals free, 1–1.5 mm long; petals free, 2–2.5 mm long; stamens 10, inserted below disk, free, equal, filaments 3–4 mm long; disk 1.5 mm in diameter, bright yellow, nectariferous; ovary superior, 2-celled, style very short. Fruit an ovoid to ellipsoid drupe, slightly laterally compressed, 4.5–6 cm × 2.5–4 cm × 2–3.5 cm, green turning yellow after falling, pulp soft, juicy, sweet, pyrene 1-seeded. Seed 3–3.5 cm × 1.5–2 cm × c. 0.5 cm. Seedling with epigeal germination.

Irvingia comprises 7 species, 6 in tropical Africa and 1 in South-East Asia. *Irvingia grandifolia* is often deciduous and flushing of new leaves usually affects the whole tree. Its flowering tends to peak at the end of the dry season, its fruiting at the end of the rainy season; leaves turn beautifully red before falling.

Ecology *Irvingia grandifolia* occurs in forest on dry land, occasionally in damp localities or in gallery forest. It is often left standing when forest is cleared for agriculture.

Management Seed of *Irvingia grandifolia* is only collected from the wild and occasionally from trees retained in plantations.

Genetic resources and breeding *Irvingia grandifolia* does not seem to be in danger of genetic erosion.

Prospects *Irvingia grandifolia* is likely to remain of minor economic importance, both as food plant and as a timber tree.

Major references Aubréville, 1962; Burkill, 1994; Harris, 1996; Neuwinger, 2000; Vivien & Fauré, 1988b.

Other references Gilbert, 1958.

Authors L.P.A. Oyen

IRVINGIA WOMBOLU Vermoesen

Protologue Man. ess. forest. Congo: 136 (1923).

Family Irvingiaceae

Vernacular names Bitter bush mango, dry season bush mango (En). Dika, odika, manguier sauvage, chocolatier, ogbono (Fr).

Irvingia wombolu – wild

Origin and geographic distribution *Irvingia wombolu* occurs in the forest zone from the Cassamance in Senegal east to southern Sudan and Uganda, and south to south-western DR Congo and northern Angola.

Uses The kernels from the fruit are an important ingredient in cooking and are preferred over those of other *Irvingia* spp. They are processed by grinding and crushing, and then used to thicken soups and stews. The kernels are also made into a cake called 'dika bread' or 'odika bread' for year-round preservation and easy use. An edible oil is extracted from the seed and used in cooking. As it is solid at ambient temperatures it has been used as a substitute for cocoa butter and for soap-making. The presscake is a good cattle feed and is suitable in the food industry. The pulp of the fruit of *Irvingia wombolu* is bitter and slimy and is occasionally added to soups as thickener.

Irvingia wombolu is commonly preserved when clearing land for agriculture to provide shade for crops, especially cocoa and coffee but also annual crops. The medicinal uses of *Irvingia* spp. are many, but can hardly be assigned to an individual species. Preparations from the bark are rubbed on to the body to relieve pains and are applied to sores and wounds and against toothache. They are also taken to treat diarrhoea. The Igbo people use a leaf extract as a febrifuge. In Cameroon preparations mainly from the bark are used to treat hernia and yellow fever, and as an antidote for poisoning. Kernels are used to treat diabetes. The wood, called 'andok' in Cameroon, is used locally for heavy construction work and for making ships' decks, paving blocks and planking. Young trees are used for making poles and stakes, while branches are made into walking sticks or thatched roof supports. Dead branches are used as firewood.

Production and international trade Kernels of *Irvingia wombolu* and related species are widely traded domestically and between countries in West and Central Africa and are exported to Europe. Cameroon is probably the main exporter. The combined export trade of the kernels of *Irvingia wombolu* and *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill. from Cameroon has been valued at US$ 260,000 per year for 107 t. Côte d'Ivoire also exports large amounts of nuts to Nigeria, Sierra Leone and Liberia. Nigeria is the main importing country. The wood of *Irvingia wombolu* is mainly used locally and rarely exported.

Properties The nutritive value of the kernels of *Irvingia wombolu* per 100 g edible portion is: water 4 g, energy 2918 kJ (697 kcal), protein 8.5 g, fat 67 g, carbohydrate 15 g, Ca 120 mg, Fe 3.4 mg, thiamin 0.22 mg, riboflavin 0.08 mg, niacin 0.5 mg (Platt, 1962). Drawability (sliminess) and viscosity of soups imparted by the kernels varies between kernels from different trees. The kernels of *Irvingia wombolu* are considered better than those of other *Irvingia* spp. Fat content of kernels also varies between trees and is about 37.5–75 g/100 g; the approximate fatty acid composition is: lauric acid 20–59%, myristic acid 33–70%, palmitic acid 2%, stearic acid 1% and oleic acid 1–11%. The residue obtained after separation from the fat is suitable for processing in the food industry.

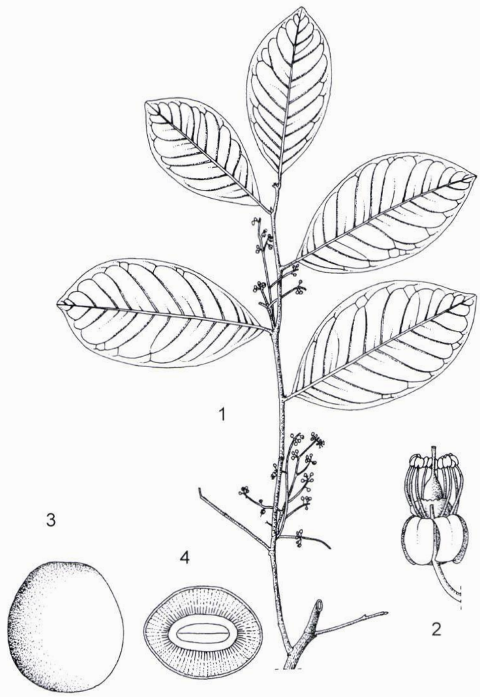
Heartwood of *Irvingia gabonensis* and *Irvingia wombolu* is pale greenish brown or orange-yellow fading to greyish brown; sapwood is lighter, but not always clearly differentiated. The grain is straight or interlocked, texture fine to medium.

The wood is fairly heavy. The density is 930–1002 kg/kg^3 at 12% moisture content. The shrinkage rates are high, from green to oven dry 6.5–7.1% radial and 10.2–12.6% tangential. To avoid end surface checking, logs should be converted soon after felling, preferably by quarter-sawing.

At 12% moisture content, the modulus of rupture is 163–217 N/mm^2, modulus of elasticity 18,700–21,700 N/mm^2, compression parallel to grain 69–79 N/mm^2, Chalais-Meudon side hardness 5.7–12.7, shear 15 N/mm^2, cleavage 19–34 N/mm. The timber is moderately difficult to saw or plane and tools should be kept sharp. It dresses to a smooth finish and glues well. Nailing is difficult. The timber is durable and fairly resistant to termites, but susceptible to powder-post beetles and marine borers. The heartwood is untreatable, the sapwood resistant to preservatives.

Adulterations and substitutes The kernels of all *Irvingia* species are used as thickener for soups and stews. Groundnuts and okra are used similarly in West and Central Africa.

Description Small to medium-sized tree up to 25 m tall; bole often slightly leaning, up to 80 cm in diameter, with buttresses to 2 m high; bark greyish brown; crown spherical, fairly dense. Leaves alternate, simple and entire; stipules large, unequal, forming a cone protecting the bud, caducous, leaving an annular scar on the branches; petiole up to 10 mm long; blade elliptical to obovate, (6.5–)10.5–14(–18) cm × 4–6(–8.5) cm, base obtuse to slightly



Irvingia wombolu – 1, flowering twig; 2, flower; 3, fruit; 4, fruit in cross section.
Redrawn and adapted by Achmad Satiri Nurhaman

cuneate, apex rounded or minutely acuminate, leathery, pinnately veined. Inflorescence an axillary panicle up to 9 cm long. Flowers bisexual, regular, 5-merous, small; pedicel up to 6 mm long; sepals free, c. 1 mm long; petals free, 3–4 mm long, whitish; stamens 10, inserted below disk, free, equal, filaments c. 5 mm long; disk 2–3 mm in diameter, bright yellow, nectariferous; ovary superior, 2-celled, style c. 1.5 mm long. Fruit an ellipsoid drupe, slightly laterally compressed, 4.5–8 cm × 4.5–5 cm × 4.5–5 cm, green, often turning bright yellow then black, pulp yellow, soft, juicy, very bitter, with fairly numerous fibres, stone woody, 1-seeded. Seed 3.5–5 cm × 1.5–2.5 mm × c. 1 cm.

Other botanical information *Irvingia* counts 7 species, 6 in tropical Africa and 1 in South-East Asia. *Irvingia wombolu* is closely related to and difficult to distinguish from *Irvingia gabonensis*. *Irvingia gabonensis* has edible fruit pulp while that of *Irvingia wombolu* is bitter and inedible. Some authorities consider *Irvingia wombolu* merely a variety of *Irvingia gabonensis*. Because of the long history of protection and cultivation, others consider them cultivars of a single species. However, DNA analyses indicate that the 2 taxa are genetically distinct and do not (or hardly) hybridize, even where sympatric. The analyses also showed marked differences between populations of *Irvingia wombolu* from south-eastern Nigeria and Cameroon.

Growth and development *Irvingia wombolu* starts flowering when 6–10 years old. It does not have a clearly demarcated flowering season, but flowering peaks at the end of the rainy season or beginning of the dry season, while fruiting peaks at the end of the dry season. Flowers are pollinated by insects.

Ecology *Irvingia wombolu* occurs in dryland forest with more than 1500 mm annual rainfall. In some locations it grows in seasonally flooded forest and on river banks. It is adapted to a wider rainfall range than other *Irvingia* spp. Trees are fire tender.

Propagation and planting *Irvingia wombolu* is mostly propagated by seed, but methods of vegetative propagation have been developed. Seed loses its viability within one month and has to be planted soon after collection.

Management *Irvingia wombolu* is mostly retained and protected in cocoa and coffee farms, plantations of annual food crops, and home gardens. However, in some regions, including the Mamfe region of south-western Cameroon, most trees are planted especially in cocoa and coffee farms. They are planted at an approximate density of 100 trees/ha. Management includes pruning, fertilization and harvesting (gathering and picking).

Diseases and pests No diseases or pest of *Irvingia wombolu* trees have been recorded. Seeds are infested by larvae of the merchant grain beetle (*Oryzaephilus mercator*). Eggs are laid between the testa and cotyledons of the seed or in cracks in the cotyledons. Preventing cracks helps to prevent infestation.

Harvesting *Irvingia wombolu* fruits are mostly gathered from the ground around the tree. The next step consists of extracting the kernel from the seed, which is split in halves with a cutlass, after which the kernel is removed with the help of a knife. The kernels are then dried in the sun or on bamboo drying racks over the fireplace in the kitchen.

Yield Good yields of kernels have been estimated at 100 kg/tree.

Handling after harvest The preparation of 'dika bread' consists of drying, roasting and grinding the kernels. The paste obtained is put in a container or 'cake tin' and left to cool for a few hours. Once solid, the cake is removed from the container and is ready for use. If well dried, it can be stored for more than a year. Sometimes women place a tin below the grid on which the dika cake is stored, to collect the oil that drips from it. In Gabon 'dika bread' is marketed in cakes of 100–5000 g. Oil is extracted by boiling the ground kernels and scooping off the oil.

Genetic resources Centres of genetic diversity in *Irvingia wombolu* have been identified: southern Cameroon and south-eastern Nigeria. ICRAF and its collaborative partners in the region have established in-situ germplasm collections in the natural distribution range of *Irvingia wombolu* in Cameroon and Nigeria. *Irvingia wombolu* is widespread and does not seem to be in danger of genetic erosion.

Breeding ICRAF has started a programme of domestication of *Irvingia wombolu*. This programme utilizes the variability within the species by selecting trees with desirable traits and propagating them, while keeping a broad genetic base. A clonal approach aimed at cultivar development has been adopted. An assessment of the variability in fruits and kernel traits was made and trees were selected on the basis of desired fruit characteristics.

Prospects Kernels of *Irvingia wombolu* are widely traded domestically and between countries in West and Central Africa and exported to Europe, indicating that demand is likely to increase. Domestication of this species offers great opportunity for the sustainability of production. The development of methods of transformation and preservation of the product will further expand its market.

Major references Asaah, Tchoundjeu & Atangana, 2003; World Agroforestry Centre, undated; Harris, 1993; Harris, 1996; Ladipo, 2000; Leakey et al., 2000; Leakey et al., 2005; Lowe et al., 2000; Richter & Dallwitz, 2000.

Other references Harris, 1999; Ladipo, 1999; Lowe et al., 1998; Tchoundjeu, Atangana & Degrande, 2005.

Sources of illustration Harris, 1996.

Authors L.P.A. Oyen

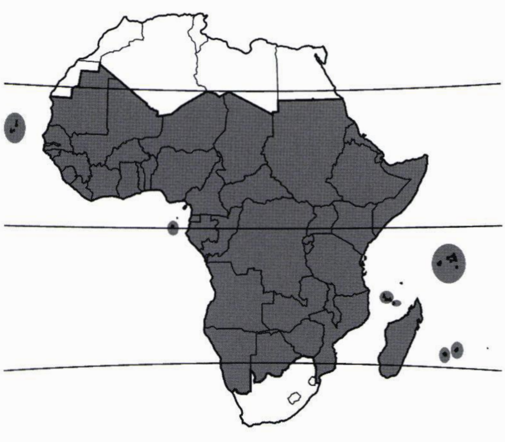
JATROPHA CURCAS L.

Protologue Sp. pl. 2: 1006 (1753).
Family Euphorbiaceae
Chromosome number $2n = 22, 33, 44$
Synonyms *Jatropha afrocurcas* Pax (1909).

Vernacular names Jatropha, physic nut, purging nut, Barbados nut (En). Pourghère, purghère, grand pignon d'Inde, fève d'enfer, gros ricin, médicinier purgatif (Fr). Purgueira, pinhao, rícino major, grão de maluco, galamaluco (Po). Mbono (Sw).

Origin and geographic distribution *Jatropha curcas* probably originated in Mexico or neighbouring parts of Central America, which are the only areas where it has often been collected from undisturbed vegetations. Portuguese seafarers took it to Cape Verde, where it became an export crop, at one time representing 60% of the total value of agricultural exports. It was distributed all over the world long ago and is now naturalized throughout the tropics and subtropics.

Uses Throughout tropical Africa, different parts of *Jatropha curcas* are used for a range of medicinal purposes. It is a source of oil that is traditionally used for soap production and as a source of energy; it is also an important hedge plant. The oil-rich seeds and seed oil (called 'oleum ricini majoris' or for good reason 'oleum infernale' or 'hell oil') are used as purgative and to expel internal parasites, although their application often leads to strong irritation of the gastro-intestinal tract or even poisoning. The leaves and bark have the same purgative effect. The oil is also applied internally and externally as an abortifacient, and externally as a rubefacient to treat rheumatic conditions and a variety of skin infections, although its use on the skin may also cause an irritative rash. The oil is used as an ingredient of hair conditioners. The latex has a widespread reputation for healing wounds, as a haemostatic and for curing skin problems; it is applied externally to treat infected wounds, ulcers, ringworm, eczema, dermatomycosis, scabies and sarcoptic mange in sheep and goats. Upon drying, the initially viscous latex forms an airtight film, resembling that produced by collodion. The latex has a styptic effect and is used against pains and stings of bees and wasps. Dried and pulverized root bark is made into poultices and is taken internally to expel worms and to treat jaundice. Leaves are also applied on wounds and in decoction they are used against malaria in Mali and Madagascar, while in Benin and Réunion a decoction is taken against hypertension. The leaf sap is used externally to treat haemorrhoids in Benin and Madagascar. In Guinea Bissau a hot water extract of the leaves is taken orally to accelerate secretion of milk in women after childbirth. Fresh stems are used as chew sticks to strengthen the gums, and to cure bleeding, spongy gums or gum boils. A decoction of the roots is a cure for diarrhoea and gonorrhoea. In Madagascar a decoction of the leaves and roots is taken to treat malaria. *Jatropha curcas* is also used in the preparation of arrow poison and in the Philippines the bark is used to prepare a fish poison. The seeds are often a source of accidental poisoning, both in animals and humans.



Jatropha curcas – planted and naturalized

The seed oil is not edible as it contains toxic compounds. Traditionally, it is used for the manufacture of candles and soap, as lamp oil and as fuel for cooking. It is a poor lubricant as it dries quickly. Throughout the tropics and warm subtropics *Jatropha curcas* is increasingly planted for bio-fuel purposes. The oil is either used directly in adapted engines powering local grain mills, oil presses, water pumps and small generators, or first refined by transesterification with methanol or ethanol to produce regular fuel suitable for high-performance diesel engines.

The seed cake left after oil extraction is too toxic to be used as animal feed, but constitutes a valuable organic fertilizer rich in nitrogen. Some accessions of *Jatropha curcas* found e.g. in Mexico are almost free of toxins and the seed cake from such selections would provide a nutritious feedstock on account of the high protein content. Their seeds are sometimes boiled or roasted and eaten as a snack, and young leaves as a vegetable.

Leaf sap yields a black dye or ink that is said to be indelible; the bark yields a dark blue dye, which, however, is not fast. Ash from the roots and branches is used as cooking salt, and as lye in dyeing. *Jatropha curcas* is widely cultivated in the tropics as a living fence, for erosion control, demarcation of boundaries and for protection of homesteads, gardens and fields against browsing animals. In Madagascar and elsewhere in Africa it serves as a support for vanilla, black pepper and yams. The wood is very poor as fuelwood. Hybrids of *Jatropha curcas* and other *Jatropha* species are grown as ornamentals.

Production and international trade Official statistics on areas planted and production are still lacking. In recent years, *Jatropha curcas* has become the focus of large planting programmes in several tropical countries on account of its potential as a bio-fuel crop with low agro-ecological demands. Most of these are still in the pilot stage of development, together probably not exceeding 100,000 ha. India alone may have more than 10 million ha of small-scale and large plantations by 2030, mostly on reclaimed wastelands. Countries in tropical Africa with major development projects for jatropha bio-fuel production include Mali, Burkina Faso, Ghana, Tanzania, Malawi, Zambia and Madagascar. The total length of jatropha hedges in tropical Africa is estimated at 75,000 km, yielding potentially 60,000 t of seeds per year.

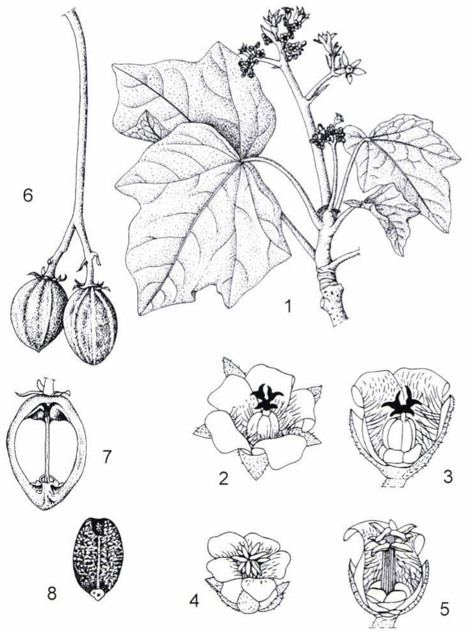
Prices of jatropha seeds vary between countries. Where seeds were used for manufacturing soap (Mali, Tanzania) the price per kg was close to US$ 0.10. Once the demand for seeds for bio-fuel increases, the prices of seeds will rise. In India a price of US$ 0.40 per l of jatropha-based fuel is expected to be realistic (cost price plus modest profit margin). To this price tax has to be added and the value of carbon-credit-certificates deducted. Prices for gasoil in landlocked countries of West Africa were US$ 0.80–0.97 in 2007. It is estimated that large-scale plantations and oil extraction mills could produce jatropha bio-fuel in West Africa at a price 5–12% cheaper than current gasoil prices. In remote areas, small-scale production and use of bio-fuel from *Jatropha curcas* is obviously more promising than the modest margins predict.

Properties Decorticated seeds (kernels) contain per 100 g: water 3–6 g, energy 3100–3300 kJ (740–790 kcal), protein 23–29 g, fat 53–70 g, neutral detergent fibre 4 g, acid detergent fibre 0.1–0.2 g, ash 3.8 g. Fat content of whole seeds is 32–45%, since the seed coat constitutes 35–40% of total seed weight. The fatty acid composition of the oil is: palmitic acid 3.5–15.6%, palmitoleic acid 0.7–0.9%, stearic acid 6.7–7.5%, oleic acid 34.3–46.3%, linoleic acid 30.8–43.1%, linolenic acid 0.2% and traces of myristic, pentadecanoic, margaric, margaroleic, arachidic, gadoleic, behenic, lignoceric and nurvonic acids. Depending on the origin, either the oleic or linoleic acid content is higher. The bio-fuel produced after trans-esterification of the oil has characteristics similar to petro-diesel. The energy balance (the total energy inputs into the crop : the energy output) of jatropha bio-fuel is estimated at 1 : 4–5, which is considerably better than for rapeseed (Canola) oil. Protein content of the seed cake after oil extraction is about 60% with a composition in essential amino acids similar to soya bean protein, but higher in sulphur-containing amino acids.

The toxic compounds in the seed and seed-oil are esters of the diterpenoid 12-deoxy-16-hydroxy-phorbol; in toxic cultivars up to 2.7 mg/g has been found, in non-toxic ones 0.1 mg/g. As they are thermo-stable, the oil and seed cake cannot be detoxified by heating. Quantitative toxicity assessment studies have been effected in many animal models. The irritant properties of the seed oil have been evaluated in the mouse irritation test. Another study showed that the oil does not have mutagenic properties, so that there is no danger for workers handling the cake; however, after initiation with 7,12-dimethylbenz(a)anthracene, the oil induced skin tumours. The seeds also contain a toxic protein fraction: 'curcin'. Purified proteins from this fraction have been shown to inhibit protein synthesis in vitro in a way similar to that of ricin from castor (*Ricinus communis* L.). However, curcin lacks the protein-moiety that allows ricin to pass cell membranes, making curcin a much less dangerous toxin. Curcin has a significant antitumour effect in several tumour cell lines and its mechanisms are related to the N-glycosidase activity. The anti-metastatic potential of curcusone B, a diterpene isolated from the aerial parts, was investigated against 4 human cancer cell lines. Treatment with non-cytotoxic doses of curcusone B effectively suppresses the metastatic processes. Extracts from the seeds showed pregnancy-terminating effects in rodents, but it

is unclear whether this is due to a specific action or a result of general toxicity.
The latex from *Jatropha curcas* has shown proteolytic activity that may be responsible for some of its therapeutic effects, e.g. healing wounds and haemostatic (coagulating effect). The diluted latex however shows anticoagulant activities. Analysis of the latex resulted in the isolation of the protease 'curcain'. The wound-healing properties of curcain were investigated in a mouse model. Application of curcain in a hydrophilic ointment (0.5–1%) showed better wound-healing properties than observed for nitrofurazone, a common drug for wound healing. The latex also contains the cyclic octapeptide 'curcacycline A' and the cyclic nonapeptide 'curcacycline B'. Curcacycline A showed a moderate dose-dependent inhibition of human T cell proliferation, while no direct cytotoxic effects were observed. In a clinical trial common warts treated with the latex disappeared completely after 16–20 days. Curcacycline B enhances the rotamase activity of human cyclophilin B. The leaves of *Jatropha curcas* have a potent cardiovascular action, somewhat similar to that of β-blockers. A methanol extract of the leaves showed moderate protection of human cell-lines in vitro against HIV, while a water extract from the branches strongly inhibited the HIV-induced cytopathic effects with low cytotoxicity. The methanol extract of the roots showed significant activity against castor oil- and magnesium sulfate-induced diarrhoea in mice through inhibition of prostaglandin biosynthesis and reduction of osmotic pressure. The latex shows significant antibacterial action against a variety of gram-positive bacteria. Ground seeds showed molluscicidal activity against different species that are host for human diseases. The seed oil has pesticidal properties comparable to that of neem (*Azadirachta indica* A.Juss.) against insects such as the cotton bollworm (*Helicoverpa armigera*) and the cowpea weevil (*Callosobruchus maculatus*). It is also effective against termites. The latex is strongly inhibitory to several fungal diseases of crops, e.g. *Phytophthora palmivora* and *Fusarium solani* and also to watermelon mosaic virus. Steroids (stigmasterol, β-sitosterol, β-sitosterol-β-D-glucoside) and flavonoids have been found to be present too.

Description Deciduous, somewhat succulent, monoecious shrub or small tree up to 5(–8) m tall; stem arising from a thick, perennial rootstock, with watery to whitish latex; bark smooth, grey or reddish, shiny, peeling off in papery scales. Leaves alternate, simple; stipules minute, soon falling; petiole (3–)10–15(–20) cm long, glabrous; blade broadly ovate in outline, usually shallowly 5-lobed, 7–14(–18) cm × 5.5–14(–18) cm, base shallowly to deeply cordate, apex acute, margins usually entire, glabrous, 5–7-veined from the base. Inflorescence a terminal or axillary umbel-like cyme, often paired, with a solitary female flower terminating each major axis and many male flowers on lateral branches; peduncle up to 5(–7) cm long, hairy; bracts elliptical-lanceolate, c. 1 cm long, acuminate. Flowers unisexual, regular, 5-merous, greenish yellow; male flower with ovate calyx lobes c. 2 mm long, petals fused in lower half, lobes oblong to ovate, c. 3 mm long, disk composed of 5 free glands, stamens 8, in 2 distinct whorls, the 5 outer fused at base, the 3 inner with filaments completely fused; female flower with ovate-lanceolate calyx lobes 4–5 mm long, hairy, petals c. 6 mm long, free, disk composed of 5 free glands, ovary superior, ovoid-ellipsoid, 3-celled, styles 3, fused at base, stigmas 2-lobed, staminodes 10. Fruit a broadly ellipsoid capsule 2.5–3 cm × c.



Jatropha curcas – 1, flowering branch; 2, female flower; 3, opened female flower; 4, male flower; 5, opened male flower; 6, fruits; 7, fruit in longitudinal section; 8, seed.
Source: PROSEA

2 cm, smooth-skinned, initially fleshy and green, turning yellow and eventually dry and black, late dehiscent, 3-seeded. Seeds ellipsoid, 1–2 cm long, mottled black and coarsely pitted. Seedling with epigeal germination, forming a taproot and 4 peripheral roots; hypocotyl elongated; cotyledons broadly oblong and emergent; first 2 leaves alternate.

Other botanical information *Jatropha* belongs to the tribe *Jatropheae* of the subfamily *Crotonoideae*. The genus comprises about 170 species, most of them in warm temperate and subtropical regions and seasonally dry tropics. Africa counts about 70 native species, Madagascar 1 endemic. *Jatropha curcas* belongs to subgenus *Curcas*. Several *Jatropha* species are widely grown in the tropics as medicinal or ornamental plants; they sometimes escape from cultivation.

The seeds of *Jatropha mahafalensis* Jum. & H.Perrier, endemic to Madagascar, contain an oil called 'huile de Betrata' with similar properties as *Jatropha curcas* and with similar traditional uses. The oil is also used for lighting and applied as hair oil against lice. A root decoction is taken as an invigorating drink. The latex contains a cyclic heptapeptide, named mahafacyclin A.

Growth and development Growth in *Jatropha curcas* is intermittent and sympodial; it follows the architectural model of Leeuwenberg. Dormancy is induced by fluctuations in rainfall, temperature and light. Not all plants respond simultaneously; in a hedge plants without leaves may be found besides ones full of green leaves. Flowers of *Jatropha curcas* produce nectar and are scented. The nectaries are hidden in the corolla and only accessible to insects with a long proboscis or tongue. The sweet, heavy perfume at night and greenish yellow colour of the flowers suggest that they are pollinated by moths. In inflorescences, the female flowers open one or two days before the male ones or at the same time as the earliest male flowers. Male flowers last only one day. Seed never sets in indoor cultivation unless the flowers are pollinated by hand. Plants raised from seed are more resistant to drought than those raised from cuttings, because they develop a taproot. Fruit development from flowering to seed maturity takes 80–100 days. Plants from cuttings produce seeds earlier than plants grown from seed. Full production is achieved in the 4th or 5th year. Mycorrhizae have been observed on the roots; they promote growth, especially where phosphate is limiting. The potential lifespan of *Jatropha curcas* is 30–50 years.

Ecology *Jatropha curcas* occurs in semi-arid tropical and warm subtropical climates with mean daily temperatures of 20–30°C and annual rainfall of 300–600 mm. It does not withstand frost, but is resistant to periods of drought of up to 7 months. It will grow on degraded, sandy or gravelly and even saline soils with low nutrient content, but cannot survive in waterlogged terrain. However, economically sustainable oil production requires well-drained soils of reasonable physical and chemical quality, and at least 750 mm annual rainfall, or supplementary irrigation.

Propagation and planting Propagation is done by seeds or cuttings. The 1000-seed weight is 400–730 g. Seed storage behaviour is orthodox. The average germinating capacity after 7 years storage at 16°C is about 50%. Seeds are sown at the beginning of the rainy season. Soaking overnight improves germination. Under good conditions seeds germinate in about 10 days. Seeds can also be sown in seedbeds or containers and 4–6 months later transplanted into the field. Nursery-grown seedlings have a higher survival rate than direct-seeded ones. Hedges around homesteads or fields are mostly grown from cuttings. Branch cuttings of 30 cm length planted directly in the field a few weeks before the beginning of the rainy season will root and regrow easily, as a wax coat protects the cuttings from drying out. However, raising plants in a nursery from rooted cuttings with only 2–3 nodes, prior to field planting, has the advantage of a much larger multiplication rate for valuable selections intended for high-yielding plantations. Clonal propagation by tissue culture, starting from hypocotyl-, petiole- or leaf-explants, is technically possible but rather expensive for mass-propagation.

In plantations established for oil production, spacings applied are 2–3 m between and 2–2.5 m within rows, giving plant densities of 1350–2500 plants/ha.

Management Cultural practices in new plantations include regular weeding, pruning and fertilization. Recently planted seedlings have to be protected against ruminants, because they have not yet developed the repellent toxins in leaves and shoots. Pruning starts 3–4 months after field planting to induce a frame with up to 25 branches for increased flowering and fruit set; maintenance pruning of mature shrubs aims at inducing growth of new laterals and restricting height to facilitate harvesting. When grown as a protective hedge, regular pruning is needed to reduce shade on neighbouring crops. Nutrient requirements for maximum oil production are not yet well-defined for *Jatropha curcas*, but it appears to respond particularly well to organic fertilizers, including the composted fruit walls and seed cake. Leaf litter and prunings from the plantation will also contribute to improving the organic matter content of the soil. Addition of N, P and K fertilizers to the planting hole will boost early establishment and rapid growth of new plantations. Where climatic and soil conditions are favourable and the plants are spaced more widely, intercropping with vegetables or pulses is possible. Fertilization of the intercrop will then also benefit the jatropha crop.

Diseases and pests *Jatropha curcas* is rarely attacked by diseases or pests. Powdery mildew may damage leaves and flowers, while *Alternaria* may cause leaf fall. Caterpillars of *Spodoptera litura* feed on the leaves, while several species of beetles feed on the leaves of young plants. These pests may also affect intercrops grown together with *Jatropha curcas*. It is an alternative host for cassava viruses, so it should not be planted as a fence around cassava fields.

Harvesting Harvesting and separation of seeds from the fruits is done manually. The best pickers can harvest about 30 kg fruit per hour, which is approximately 18 kg of seeds. Since the fruits stay on the branches for quite some time, they have to be picked or knocked down with a stick.

Yield Annual seed production of mature plants, raised from seedlings, may vary from 300 g to 3(–6) kg, depending on the growing conditions and inherent production capacity. Available data from pilot plantations show the following seed yields per ha: 0.5 t within 1 year after field planting, 1.2–1.5 t in year 2 and further increasing to 2.5–3.0 t from year 5 onwards when the plantation is in full production. Yields of 5 t of seeds/ha, which is equivalent to 1.6–2.0 t of oil plus 3.0–3.4 t of seed cake, have been claimed for jatropha plantations under optimum agro-ecological conditions (e.g. India and Nicaragua).

Old and dense hedges in and around villages or towns may produce 2 kg of seeds per m and per year (height 5–6 m, good soil, 800 mm annual rainfall), pruned hedges around gardens and fields usually not more than 0.8 kg.

Handling after harvest Seeds for planting should be carefully dried in the shade until 6–9% moisture content and stored cool in airtight containers. Traditional oil extraction involves boiling of roasted and ground seeds until the floating oil can be skimmed off the surface. More efficient methods are based on oil extrusion by hand-operated or mechanized screw presses. The extraction efficiency of this cold method of oil extraction is increased considerably by prior crushing of the seeds in a hammer mill. The remaining seed cake requires composting before use as organic fertilizer. The oil may be refined in a continuous trans-esterification reactor to produce bio-fuel of diesel-oil quality and glycerol as a valuable by-product. The bio-fuel represents about 92% in weight of the initial oil.

Genetic resources Several types of *Jatropha curcas* are known. A non-toxic type is grown in Mexico (no phorbol esters in the seeds). In Nicaragua a type exists with larger leaves with rounded lobes, and larger but fewer fruits and seeds. Male sterile types exist, which produce more fruits than normal types. A provenance trial in the late 1980s showed that different selections from Africa showed significant differences in vegetative development, but not in morphological characters. Wageningen University (Netherlands) has started a programme to collect and evaluate germplasm of *Jatropha curcas*, maintain it in field gene banks and initiate breeding work.

The Banco Nacional de Germoplasma Vegetal, Departamento de Fitotecnia, Universidad Autónoma de Chapingo, Chapingo, Mexico and the Departamento de Biología, Universidad Nacional Autónoma de Nicaragua, León, Nicaragua both hold about 100 accessions of *Jatropha curcas*, but collection, characterization and maintenance of germplasm covering the full variation of the species is still very much needed.

Breeding Most plant material used so far is derived from simple selection within semi-wild populations or landraces. Between-plant variation for vigour and seed yield is tremendous and great genetic improvement in seed yields and other important characteristics may, therefore, be expected from systematic breeding. Breeding programmes have been initiated recently in several countries, e.g. at Wageningen University (Netherlands), but information on progress is not yet available. Obviously, oil yield per ha will dominate breeding objectives for *Jatropha curcas* cultivars for bio-fuel production. Cultivars with compact growth would facilitate harvesting.

Prospects The multiple traditional uses of

Jatropha curcas, as medicinal, nonfood-vegetable oil and auxiliary plant, have been well exploited in the tropics and subtropics for hundreds of years. Its considerable potential as an oil crop for bio-fuel purposes at relatively low costs and modest demands on the local agro-ecosystem has received much attention in recent years. Prospects are that within the next decade or so, *Jatropha curcas* will become a major source of renewable energy in the drier rural areas of (sub)tropical Asia, Africa and America. Much agronomic and breeding work needs still to be done to maximize the oil production potential per ha and thus improve the economic sustainability of jatropha oil production. Rapid multiplication techniques and facilities have to be developed to make improved planting material available in adequate amounts. This is especially urgent as planting of unimproved material not only leads to low returns on investments, but may also lead to a loss of interest in this crop. More research should also be initiated on medicinal properties of different plant parts, e.g. wound healing, antimalarial and anti-HIV effects. Investigation of the agronomic and medicinal potential of other *Jatropha* species would be valuable as well.

Major references Burkill, 1994; Francis, Edinger & Becker, 2005; Gübitz, Mittelbach & Trabi, 1999; Heller, 1996; Henning, 2001b; Makkar, Aderibigbe & Becker, 1998; Mujumdar & Misar, 2004; Openshaw, 2000; Osoniyi & Onajobi, 2003; Susiarti, Munawaroh & Horsten, 1999.

Other references Anonymous, 1997–1998; Baraguey et al., 2000; Fangrui & Milford, 1999; Grimm, 1999; Haas & Mittelbach, 2000; Heim, Garrigue & Husson, 1919; Henning, 2001a; Lin et al., 2003; Maheu & Husson, 1920; Makkar & Becker, 1999; Makkar, Becker & Schmook, 1998; Muangman, Thippornwong & Tohtong, 2005; Mujumdar et al., 2001; Neuwinger, 2000; Rajore, Sardana & Batra, 2002; Rouillard & Guého, 1983; Satish Lele, 2007; SEPASAL, 1999; Shah, Sharma & Gupta, 2004; Songjang & Wimolwattanasarn, 2004; Sujatha & Prabakaran, 2003; Venturini del Greco & Rademakers, 2006; World Agroforestry Centre, undated.

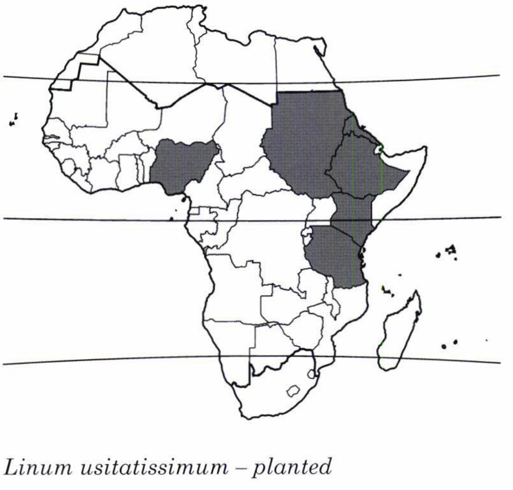
Sources of illustration Susiarti, Munawaroh & Horsten, 1999.

Authors R.K. Henning

LINUM USITATISSIMUM L.

Protologue Sp. pl. 1: 277 (1753).
Family Linaceae
Chromosome number $2n = 30$
Vernacular names Linseed, flaxseed, flax (En). Lin (Fr). Linhaça, linho (Po). Kitani (Sw).

Origin and geographic distribution *Linum usitatissimum* most likely evolved by domestication from wild *Linum bienne* Mill. ('pale flax'), a short-lived perennial which occurs in western and southern Europe and western Asia. India is an important centre of genetic diversity for *Linum usitatissimum*, but cannot be considered the centre of origin because of the absence of its progenitor *Linum bienne*. *Linum usitatissimum* was among the first crops to be taken into cultivation in the Fertile Crescent more than 8000 years ago. It developed into a fibre crop, called 'fibre flax' and an oilseed crop, called 'linseed'. Archaeological evidence indicates that the domestication and early distribution of cultivated flax occurred principally as a fibre crop, but this may be due to the fact that textiles are more easily preserved than oil. Flax provided the fibres for cloth and cordage of the Sumerians, Egyptians, Greeks and Romans. It was traded by the Egyptians by 4000 BC and remnant seed has been found in prehistoric settlements in the Swiss Alps. The high oil content of the seed was also appreciated and Egyptian mummies provide evidence of the use of the oil by 1400 BC. Specialization occurred early: Mediterranean and European types developed into fibre flax; short-season types adapted to the warmer climates of western Asia, the Indian subcontinent and Ethiopia developed into linseed types.



Linum usitatissimum – planted

Linum usitatissimum is now grown widely in many parts of the world, including the tropics. Fibre flax is cultivated in cool and humid temperate climates, whereas linseed is grown in warmer climates. Socio-economics also affect the distribution; Eastern Europe and the Russian Federation produce mainly fibre flax, Canada and the northern United States mainly linseed. In tropical Africa linseed production is concentrated in the Ethiopian highlands, where linseed has been grown since time immemorial. At higher altitudes it is the second most important oil crop after niger seed (*Guizotia abyssinica* (L.f.) Cass.). Linseed is also grown on a small scale in the other highlands of East Africa.

Uses *Linum usitatissimum* is grown for its oil-rich seeds and bast fibre, as distinct or dual purpose crops. There is a long tradition of consuming linseed, usually in a mix with cereals, in western Asia and the Indian subcontinent. In Europe and North America linseed is nowadays a standard ingredient in health foods such as multi-grain breakfast cereals and breads. In Ethiopia the seed is commonly roasted, ground and mixed with spices and some water to be served along with local breads. It is also consumed in soups, soft drinks and with porridges or cooked potatoes.

The oil develops a very unpleasant rancid flavour soon after seed crushing and oil extraction, making it less suitable for human consumption. This is associated with the high content of linolenic acid and rapid oxidation at the double bonds. Eventually, the oil polymerizes into a flexible film. Traditionally it has found wide application as drying oil in paints, varnish and industrial coatings, lamp oil and in the manufacture of window putty, soaps, printing ink, erasers and linoleum, as well as waterproofing for raincoats and tarpaulins. Edible linseed oil with only a few percent linolenic acid and much higher linoleic acid content is produced from 'Solin' or 'Linola' cultivar types recently developed in Canada and Australia. Seed mucilage is used as a substitute for gum arabic as a stabilizer, binder, gelling and suspension agent in foods. It has been patented as an egg-white substitute. Linseed cake and meal after oil extraction are used as a supplement of protein and omega-3 fatty acid in livestock feeds after prior removal of toxic substances.

The traditionally highly valued medicinal properties of linseed have regained considerable interest in recent times. The seeds or their biologically active constituents (soluble and insoluble dietary fibre, α-linolenic acid and lignans) are used in nutraceuticals to alleviate various ailments, such as digestive complaints, high blood cholesterol, coronary and kidney diseases, hormonal problems and certain types of malignant tumours.

Linen woven from the bast fibre is used for household textiles (towels, table cloths etc.), furnishings (curtains, wall coverings and upholstery fabrics) and clothing. Its high moisture absorption, strength, launderability, excellent colour fastness and resistance to shrinkage make it well suited for these purposes. A disadvantage is that it creases easily. The fibre is also used in the manufacture of fine papers such as cigarette, art, currency, archival and security papers, often in blends with other pulps. The flax fibre used for paper is derived from waste material from spinning and weaving mills, linen rags, the short bast fibre fraction or waste product left over from the processing of high quality textile fibre ('flax tow'), or mechanically decorticated straw of flax that has been grown primarily for seed ('seed flax tow').

Straw from the linseed crop is also utilized in the manufacture of twine, bagging and insulating wallboards. The woody core left after fibre extraction is used in the manufacture of chipboard or, in combination with bast fibre, for paper making.

Production and international trade Average annual world production of linseed in 2000–2004 was about 2 million t from 2.6 million ha. The main producers were Canada (650,000 t), China (440,000 t), United States (285,000 t), India (215,000 t), European Union (135,000 t), the Russian Federation (55,000 t) and Ethiopia (55,000 t). Canada is the largest exporter of linseed (over 600,000 t annually), Belgium the largest importer (over 400,000 t) and the second largest exporter (85,000 t).

Annual world production of flax fibre and tow in 2002–2004 was 670,000 t from 475,000 ha, major producers being China (420,000 t), the European Union (160,000 t) and the Russian Federation (51,000 t). Belgium is the largest importer (144,000 t), and also second largest exporter (122,000 t) after France (153,000 t). China is the second largest importer, its annual imports increasing rapidly from 60,000 t to 120,000 t between 2000 and 2003.

Properties The seed contains per 100 g edible portion: water 8 g, energy 2059 kJ (492 kcal), protein 19.5 g, fat 34 g, carbohydrate

34.3 g, total dietary fibre 27.9 g, Ca 199 mg, Mg 362 mg, P 498 mg, Fe 6.2 mg, Zn 4.2 mg, thiamin 0.17 mg, riboflavin 0.16 mg, niacin 1.40 mg, folate 260 μg, ascorbic acid 1.5 mg (USDA, 2004). The fatty acid composition of the oil in traditional linseed is: palmitic acid 5–6%, stearic acid 4–5%, oleic acid 18–20%, linoleic acid 14–16%, α-linolenic acid 40–60%. In the oil of 'Solin' and 'Linola' cultivar types, the linolenic acid levels can be as low as 2%, with a concomitant increase of linoleic acid, while the level of other fatty acids remains unaltered.

The mucilage of linseed consists mainly of soluble dietary fibre, which is composed of polysaccharides, polypeptides and glycoproteins. The ratio of soluble to insoluble dietary fibre in linseed varies from 1:4 to 2:3. The significant reduction in total and LDL cholesterol and in blood glucose associated with regular linseed consumption is attributed to the mucilage. Linseed also improves bowel movement: the mucilage absorbs water from the gastro-intestinal tract, while the insoluble fibre increases stool transit time. The α-linolenic acid is an essential, omega-3 fatty acid in the human diet. It is involved in increasing the activity of membrane-bound phospholipids, enhancing the elasticity of arterial membranes and reducing eicosenoids-mediated inflammatory reactions leading to arteriosclerosis and rheumatoid arthritis. Linseed is rich in plant lignans (diphenolic compounds), which are converted to mammalian lignans in the colon. Lignans inhibit cell proliferation and growth. They have been shown to be effective against hormone-sensitive cancers in particular.

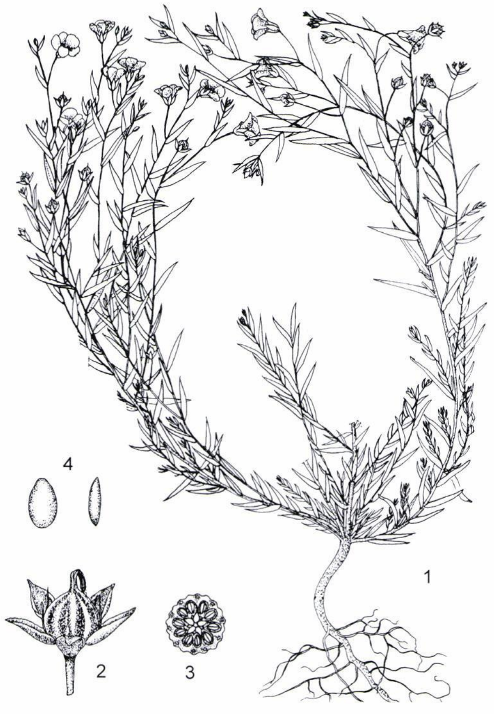
The seed contains the cyanogenic glucoside linamarin, which in the presence of the endogenous enzyme linase (released after seed crushing) hydrolyses to form the poisonous hydrogen cyanide. Prior heating of the presscake avoids cyanide intoxication. The protein in the seedcake is low in lysine. Linseed cake and meal are said to have a regulatory effect on the digestive system of livestock, to increase the butterfat yield in dairy cows and to promote a shiny sheen in the coats of show animals.

Embedded within the cortex of the stem is a ring of 20–50 groups of flexible fibre bundles. Each of these bundles represents a single strand of commercial fibre. The proportion of fibre in the whole dry stem is influenced by both genotype and growing conditions and ranges from 28–36%. Each fibre bundle is made up of 10–40 fibre cells that are longitudinally interlocked. The fibre cells are 10–40 mm long with a diameter of 10–30 μm and a narrow lumen. They are tapered at either end, round to polygonal in cross-section. The fibre cells of linseed genotypes tend to be shorter and coarser with a smaller lumen. The chemical properties of retted raw fibre are: cellulose 64%, hemicellulose 17% and pectin 2%. Flax fibre has a high moisture absorbency and is stronger than the fibre of cotton, rayon and wool, but weaker than ramie fibre. It is soft, lustrous and flexible, but not as flexible or elastic as cotton and wool fibres.

Adulterations and substitutes Vegetable oils for human consumption can often be interchanged, blended or transesterified. In Ethiopia some linseed oil is blended with other high quality oils such as oil of niger seed, sunflower or safflower. Blending is done to minimize the formation of rancidity and so maintain an acceptable flavour. Safflower is also used instead of linseed to prepare a local dish called 'fit-fit' (a mixture of linseed flour, water and spices with local bread), which is often served during fasting seasons.

Description Erect annual herb up to 120 cm tall; root system consisting of a taproot with subsequent branching to a depth of up to 60 cm; stem slender, erect, glabrous, greyish green, often slenderly branched in the upper part. Leaves alternate to almost opposite in lower part of stem, alternate in upper part, simple and entire, sessile, without stipules; blade narrowly elliptical to linear or lanceolate, up to 50 mm × 5(–8) mm, glabrous, dull medium green, 3-veined from base to apex. Inflorescence a loose, terminal, leafy corymb. Flowers bisexual, regular, 5-merous; pedicel erect, 1–3.5 cm long; sepals free, broadly elliptical-ovate, 5–10 mm × 2–5 mm, acuminate; petals free, obovate, 8–15 mm × 4–11 mm, shortly clawed at base, margin slightly toothed, white to pale blue or purple-blue with hues of pink; stamens 5, united at base in a glandular ring, free part 2–6 mm long; styles 5, often shortly connate at base, 2–3 mm long, stigmas linear club-shaped, 1–2 mm long. Fruit a globose capsule 7–10 mm in diameter, 5-celled but often each cell divided by a secondary septum, up to 10-seeded. Seeds compressed, 6–10 mm × 2–3 mm, with indistinct, c. 1 mm long beak, glossy yellow to dark brown. Seedling with epigeal germination; hypocotyl 1.5–4 mm long, epicotyl up to 1.5 mm long; cotyledons elliptical-oblong, 6.5–14 mm long, leafy.

Other botanical information *Linum* com-



Linum usitatissimum – 1, plant habit; 2, young fruit; 3, young fruit in cross section; 4, seeds. Redrawn and adapted by Iskak Syamsudin

prises about 200 species. *Linum usitatissimum* is the only important crop, although a few species have ornamental value. *Linum usitatissimum* is highly variable and to classify this variability numerous subspecific groupings have been proposed. Two main groups are obvious: cultivars grown for the seed and those grown for the fibre. There is also a group of cultivars that are grown for both their seed and fibre. In all 3 groups numerous cultivars exist.

Changes in the nuclear DNA of certain flax cultivars can occur within a single generation due to specific environmental conditions. The characteristics altered include plant height, weight, number of branches and total nuclear DNA. These changes are not random events, but have been shown to occur repeatedly and to be inherited in the progeny.

Growth and development Under tropical conditions, seeds germinate and emerge within 7–10 days after sowing. The first true leaves appear within 2–3 days after emergence. Early growth is slow under cool conditions. The taproot reaches 15 cm when the stem is 3–4 cm long. The taproot, and under dry soil conditions also lateral roots, of some cultivars may grow to a depth of 1 m. Branching is a cultivar characteristic; in some cultivars, e.g. from Ethiopia, branches are formed in the axils of the cotyledons or lower leaves; many linseed cultivars branch strongly from higher nodes, while fibre flax forms very few branches.

Fibre flax is a quantitative long-day plant, linseed is less photoperiod sensitive. Flowers open shortly after dawn and are predominantly self-pollinating. Pollination occurs round mid-morning. Some cross-pollination may occur depending on the population of insects, such as bees. The petals drop after pollination, with complete loss around midday. Stem length reaches its peak soon after flowering. Flowering is indeterminate, resulting in uneven formation of the capsules and subsequent maturation. As the capsules mature, they turn brown as the lower leaves and stem turn yellow. Seeds in the capsules become pale brown, plump and pliable, indicating maximum dry matter content. Seed ripeness is reached when the seeds are free and can be heard rattling inside the capsule.

Linseed cultivars produce about 60 leaves per plant, fibre flax cultivars about 80. Number of capsules per plant varies with genotype, management and climatic conditions but will typically range from 5–15 per plant. Total crop duration of linseed is normally 100–180 days, with 40–60 days from first flowering to harvest. For fibre flax the duration from sowing to harvesting is 90–120 days, to seed maturity 140–200 days.

Ecology Good seed yield can be achieved with a temperature range of 10–30°C, a midday relative humidity of 60–70%, and rainfall of 150–200 mm distributed over the 3-month growing period. Temperatures of –6°C may kill the crop in the seedling stage and frost may also cause injuries during the flowering and green capsule stages. Warm and dry conditions from early capsule development to maturity are required for curing the seed and for threshing. Rainfall towards maturity of the crop may cause secondary flowering and hence uneven maturity. Heavy rain and strong winds may cause lodging. In Ethiopia reasonable seed yields are obtained at 1600–2800 m altitude. In fibre flax hot dry days prior to and during flowering tend to cause branching resulting in shorter, more woody stems.

Optimum soils for flax are well drained but moisture retentive and medium to heavy textured, such as clay loams and silty clays. The soil should be of a fine tilth and not prone to crusting. Flax will not perform well on soils with pH less than 5 or above 7 and is sensitive to soil salinity.

Propagation and planting Flax is propagated by seed. The weight of 1000 seeds ranges from 4–13 g. Owing to the small seeds and poor competitiveness of the seedlings with weeds, a finely prepared, weed-free seedbed with adequate moisture is essential for successful crop establishment. Ploughing and harrowing or two or three passes with a traditional plough can do this. The seed may be broadcast by hand and then covered by dragging twigs of trees across the field. It can also be disked or harrowed but this may result in uneven sowing depth, emergence and maturation. Thus, sowing with a seed drill is preferred. The optimum sowing depth depends on soil type and moisture level. In heavy soils, 1.5 cm is usually enough, while on lighter soils, a depth of 2 cm reduces the risk of drought. On soils in which crusting occurs after heavy rain, making emergence difficult, a light harrowing is advisable. The seed rate depends on genotype, planting method, moisture conditions and objective of production. Higher seed rates are recommended for hand-sown crops and under high moisture conditions. Recommendations for linseed range from 17 kg/ha under low-rainfall conditions to 55–90 kg/ha under optimum water supply. Seed rates of 25 kg/ha are optimum for row-planted linseed in Ethiopia, with row spacing of 20 cm and a plant density of about 500 plants/m^2; for broadcasting seed rates of 35–40 kg/ha are recommended. For fibre flax a seed rate of 80–110 kg is recommended for optimum conditions when a seed drill is used; up to 150 kg/ha is recommended for hand-sown crops. Row spacings for fibre flax are 6–15 cm with a plant density of 1800–3300 plants/m^2. Seeds for planting should be free from weed seeds, shrivelled or diseased seeds and preferably treated with a fungicide.

Management Young linseed plants do not compete well with weeds and good weed control is necessary. This can be achieved by hand weeding twice (3 and 5 weeks after sowing) or with a range of pre- or post-emergence herbicides. Usually, early ploughing is practised to stimulate the germination of weed seeds, followed by shallow harrowing prior to sowing to kill the weeds. Water stress during flowering and early seed development negatively affects seed yield and quality, and where possible supplementary irrigation is recommended from budding until late grain filling. Later irrigation may lead to secondary flowering and uneven ripening. Linseed and fibre flax require relatively small amounts of nutrients though their uptake depends on soil type, cultivar and weather conditions. Typical uptake rates for a linseed or fibre flax crop yielding 5–6 t straw and 0.6–0.8 t seed per ha are approximately 50–75 kg N, 10–16 kg P, 40–60 kg K, 18–36 kg Ca and 8–11 kg Mg. In Ethiopia recommended rates of fertilizer for linseed are 23 kg N and 10 kg P per ha; average recommendations in the United States are 50 kg N, 25 kg P and 50 kg K per ha.

In fibre flax high N rates promote lodging, branching, lignification of the fibre and reduction of fibre wall thickness. Therefore, fibre flax never receives high rates of inorganic nitrogen and responds well to split applications. Ideally, the crop should draw most of its nitrogen from soil organic matter. Ample P is required for good seed yields and high-quality fibre, but excessive rates can result in reduced fibre quality. Sufficient K is essential for both fibre yield and seed quality. Organic manures are best applied to the preceding crop, as direct organic manuring may promote lodging and cause uneven growth.

Crop rotation is required for reducing weed infestation, disease development and improving organic matter of the soil. Flax should preferably not be grown in the same field more than once every 5–6 years and is best grown in a rotation that reduces weed infestation. It performs well after pulses, cereals and potatoes.

Diseases and pests The main diseases affecting linseed and fibre flax are caused by soil- or seed-borne fungi and can usually be controlled by seed dressing, rotation or use of disease resistant cultivars. The major seed-borne diseases are anthracnose (*Colletotrichum linicola*), grey mould (*Botrytis cinerea*), pasmo (*Septoria linicola*, anamorph *Mycosphaerella linicola*) and blight (*Alternaria* spp.). The symptoms of these diseases are stem or leaf lesions. Browning and stem break is a complex of symptoms caused by seed-borne *Polyspora lini* (synonym: *Aureobasidium lini*, teleomorph *Discosphaerina fulvida*). Early infection causes stems to break, infection at a later stage causes elongated brown lesions with purplish margins on the upper parts of the stem, giving heavily affected patches a brown appearance. The principal soil-borne diseases include stem rot (*Sclerotinia sclerotiorum*), wilt (*Fusarium oxy-*

sporum) and scorch (*Pythium megalacanthum*). These diseases attack the root system or the lower part of the stem resulting in either lodging or the cessation of growth and gradual death of the plant from the top downwards. Another disease, rust (*Melampsora lini*), is characterized by the occurrence of bright red pustules (uredospores) on above-ground plant parts, later on replaced by black encrustations (teliospores). The spores are carried with the seed and on chaff fragments and can survive in the soil for up to two years. In infected areas, rust resistant cultivars should be used. It can also be controlled through seed dressing and crop rotation of 3–4 years. Powdery mildew (*Odium* spp.) is another fungal disease and its control is similar to rust. A recent survey showed that wilt, pasmo and powdery mildew are most prevalent in Ethiopia.

Linseed and flax attract a wide range of pests, but most are not considered to be of economic importance. Some may cause severe damage, however, if left unchecked: cutworms (*Agrotis* sp.) gnaw through young stems at ground level; red-legged earth mites (*Halotydeus destructor*) suck the sap from young seedlings resulting in low vigour and possible seedling death; various aphids cause damage through direct feeding or disease transmissions; sap-sucking thrips may retard growth and kill the plant; especially in Europe the larvae of flea beetles (*Aphthona euphorbiae* and *Longitarsus parvulus*) damage roots while the adults feed on leaves, stem and seed; in Canada potato aphid (*Macrosiphum euphorbiae*) became a pest of flax in the 1990s, while the caterpillars of *Heliothis* spp. penetrate the young capsules and cause substantial damage in Australian crops. Control is achieved either through the use of insecticides or by sowing the crop at a time of the year that is out of synchronization with the pest's life cycle.

Various birds may feed on young plants and remove the growing point, resulting in tillering and subsequent non-uniformity of maturation and a decline in yield. Bird control measures such as scarecrows, humming lines and gas guns, and a rapid establishment of the crop are recommended.

Harvesting The optimum time for harvesting linseed is when most capsules are fully mature and turn brown. At this stage, the seeds make a rattling sound in their capsule, while the stem and leaves turn yellow. The moisture content of the seeds will decrease to 10–15%. In Ethiopia harvesting is largely done manually by cutting the stems with a sickle. Some farmers harvest linseed by pulling the stems out of the ground to use them for making utensils, such as sweepers, baskets, etc. Threshing is done manually by beating the capsules with sticks or by oxen or horses trampling them on a well-prepared threshing floor. Then the seeds are separated from chaff by winnowing. In North America short-straw linseed is combine harvested when the seed is sufficiently dry (<10% moisture); under more humid conditions it is cut and swathed to dry before threshing.

The optimum time for harvesting fibre flax is when the leafy stems are green-yellow and the capsules are still forming, at which time the fibres are long and supple. Flax harvested too early and still green produces fine and weak fibres. Conversely, over-ripe, brown to dark brown flax yields brittle fibre with a high proportion of tow. Flax is typically pulled out of the ground rather than cut, to preserve the full length of the fibres. This is done by hand or with pulling machines, which pull and lay the crop on the ground in swathes. The capsules can be removed during pulling or left on the plant during retting and baling and removed in the processing factory. Threshing of the seed is usually done concurrently with 'scutching' of the fibre. Industrial flax or dual purpose crops are often combine harvested with conventional combine harvesters to avoid the cost of specialized pulling and turning equipment.

Yield World average seed yields of linseed in the period 2000–2004 were nearly 0.8 t/ha per year, with national averages varying considerably from 0.3 t/ha in India to 1.3 t/ha in Canada. However, in cool-temperate regions up to 2.0 t/ha is attainable with cultivars of 140–160 days duration. The yield potential of modern cultivars of linseed is estimated at about 3.0 t/ha. The average seed yield in Ethiopia is nearly 0.5 t/ha, while improved cultivars with good management yielded up to 2.5 t/ha in favourable areas, such as Bekoji in the south-eastern part of the country. In Kenya yields of up to 2.3 t/ha have been achieved in experimental fields.

Average world flax (fibre and tow) yields have increased to about 1.5 t/ha per year; the highest yields being reported from Czech Republic (3.3 t/ha) and China (2.9 t/ha). In experiments in Australia stem yields of up to 8.8 t/ha, fibre yields of 1.3–2.6 t/ha and seed yields of 1.6–2.2 t/ha have been obtained.

Handling after harvest Threshing of linseed can be done about a fortnight after harvesting if dry and windy weather situations prevail; if not linseed plants are sun dried for up to 30 days. Seeds can be stored for a long period of time in clean containers under dry and well-aerated conditions. Optimum seed moisture for long-term storage is 9% or less. So far, no storage pests have been reported for linseed in Ethiopia. Traditional methods of oil extraction involve boiling of pounded and macerated seed in water and skimming off the floating oil. Small-scale oil extraction in rural areas has been made more efficient with the introduction of inexpensive screw presses, similar in design to the horizontal expellers of large oil mills, operated by hand or powered by a small diesel engine or electricity.

For fibre production retting is most commonly done in the field in a process called 'dew retting'. The duration and uniformity of dew retting depend on weather conditions. Ideally, harvesting needs to be followed by alternating periods of rain and dry weather; there must be sufficient moisture to ret the straw, but continuous rain can lead to over-retting and loss of fibre quality. To improve the uniformity of dew retting, it is necessary to turn the crop 3–4 times to expose the underside of the crop. When retting is complete and the crop is dry, it can be baled and stored. A range of off-field retting methods exist which are faster and provide greater uniformity of separation, but they are generally more expensive. Dried and retted stem material is 'broken', which involves rolling and/or crimping the stem to loosen the core from the bark. The core is then removed via a process known as 'scutching'. The separated bast fibre is 'hackled' by passing it through a series of combs of increasing fineness that scrape and buff the fibre. The end products are 'line flax', ready to be spun into yarn and 'tow' used in the manufacture of paper and other industrial applications.

Genetic resources *Linum usitatissimum* has been cultivated in many parts of the world and is very variable. Three distinct centres of diversity are recognized: the Mediterranean and western Asia, India and Ethiopia. Large germplasm collections are maintained in the main production countries: Biodiversity Conservation and Research Institute, Addis Ababa, Ethiopia (3110 accessions); Institute of Crop Germplasm Research (CAAS), Beijing, China (2556 accessions); Institute of Food and Oil Crops, Shijiazhuang, China (2165 accessions); Suceava Genebank, Suceava, Romania (4910 accessions) and the North Central Plant Introduction Station, Ames (IA), United States (2815 accessions). Important collections are also maintained in other countries in Europe. Preliminary collection and characterization of linseed has been underway in Ethiopia at Holetta Research Center since the early 1980s in collaboration with the Biodiversity Conservation and Research Institute. A recent analysis of the genetic diversity of 60 Ethiopian and exotic accessions, using morphological and molecular methods, revealed the presence of tremendous genetic diversity.

Breeding Breeding methods are those applied to self-pollinating crop species. Most linseed and flax cultivars grown today are pure lines developed by pedigree selection after crossing (and backcrossing) genotypes with contrasting characteristics. Breeding objectives for linseed focus primarily on seed yield and oil content. Breeding for seed quality is aimed largely at the fatty acid composition and has led to the development of low-linolenic acid cultivars in Australia and Canada. In cultivars developed for non-food purposes on the other hand, the linolenic acid content needs to be high. Breeding for disease resistance has resulted in cultivars that are resistant to Fusarium wilt and to rust. Breeding work in Ethiopia has concentrated on the development of disease resistance and all released cultivars are relatively resistant to wilt.

Well-known linseed cultivars include: 'AC-Emerson' and 'McDuff' (Canada), 'Verne 93' (United States) and the 'Solin' (low linolenic acid) cultivars 'CDC gold' and '2047'.

Some of the cultivars grown in Ethiopia are (with year of release): 'CI-1525' and 'CI-1652' (1984): medium to late maturing, good seed yield, high oil content, brown seed, blue flowers, tolerant to wilt, pasmo and powdery mildew; 'Chilalo' (1992): medium to early maturing, high yielding, medium oil content, brown seed, tolerant to wilt, pasmo and powdery mildew; 'Belay-96' (1996): similar to 'Chilalo' but with higher yield and oil content; 'Berene' (2001): similar to 'Chilalo' but adapted from mid to higher altitudes and with higher oil content; 'Tolle' (2004): medium maturing, high yielding, medium oil content, pale-brown seed, tolerant to wilt, pasmo and powdery mildew.

In fibre flax, breeders emphasize fibre content or fibre wealth (the ratio of fibre weight to total stem dry weight) more than fibre yield, as the latter is strongly influenced by management and environmental factors. Fibre quality is

particularly important for flax grown for textile fibre. Important selection criteria for fibre quality are homogeneity, degree of lignification, strength, fineness and water uptake. Selection for industrial fibre flax may emphasize productivity rather than quality traits, given the normally negative correlation between these two traits. Substantial breeding efforts have been made to improve lodging resistance via straw stiffness and fibre content. Important fibre cultivars are: 'Ariane', 'Viking' and 'Viola' (France), 'Svetoch', 'Alexim' and 'Lenok' (Russia) and 'Heiya', a family of cultivars being developed in north-eastern China.
Various plant biotechnological techniques are finding useful application to supplement conventional linseed and flax breeding, such as in-vitro culture (explants, protoplasts, anthers, microspores), molecular marker-assisted selection, genomics and genetic transformation.

Prospects After a long period of stagnation of flax and linseed production, mainly due to the dominance of petroleum-based synthetic fibres and drying agents, the demand for the products of this crop has been growing rapidly in recent years due to a trend towards eco-friendly and natural raw materials. Linseed is also emerging as a major nutraceutical crop with a wide range of biologically active constituents present in the seed that promote health and may help prevent some important chronic diseases. World production of linseed and flax is expected to expand in the near future in response to increasing demands. Suitable conditions for profitable linseed production do exist in the highlands of East Africa.

Major references Adefris, Getinet & Tesfaye, 1992; Adugna & Labuschagne, 2002; Adugna & Labuschagne, 2004; Adugna, Labuschagne & Hugo, 2004; Lay & Dybing, 1989; Lisson, 1989; Luhs & Friedt, 1994; Morris, 2004; Muir & Westcott (Editors), 2003; Seegeler, 1983.

Other references Adugna & Labuschagne, 2003; Adugna & Labuschagne, 2005; Central Statistical Authority, 2001–2003; Chen & Thompson, 2003; Cui, 2001; Cullis, 2005; FAO, 2005; Fedeniuk & Biliaderis, 1994; Leeson & Caston, 2004; Maggioni et al., 2002; Oh & Cullis, 2003; Payne, 2000; Riungu, 1990; USDA, 2004; Warrand et al., 2005a; Warrand et al., 2005b.

Sources of illustration Seegeler, 1983.

Authors W. Adugna
Based on PROSEA 17: Fibre plants.

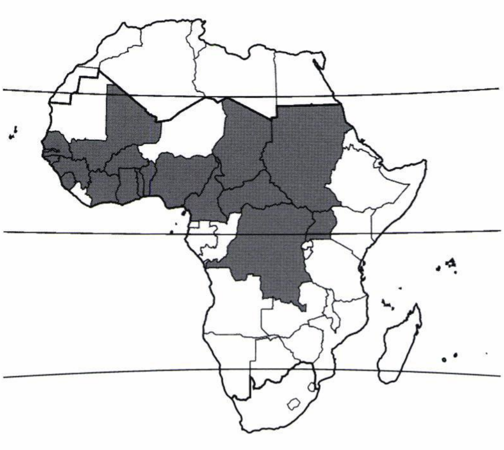
LOPHIRA LANCEOLATA Tiegh. ex Keay

Protologue Kew Bull. 1953: 488 (1954).
Family Ochnaceae
Chromosome number $2n = 24$

Vernacular names Dwarf red ironwood, red oak, false shea, méni oil tree (En). Méné, azobé de savane, faux karité (Fr). Mufo, mené (Po).

Origin and geographic distribution *Lophira lanceolata* is widely distributed in the sudano-guinean savanna zone from Senegal through the Central African Republic and northernmost DR Congo to Uganda.

Uses *Lophira lanceolata* is a multipurpose tree. Its seeds are eaten, but more commonly in the past than at present; now they are mainly used to extract an edible oil, called 'méni oil'. The oil also has cosmetic and medicinal uses and is suitable for making soap. The wood is hard and heavy and is locally used e.g. for mortars, railway sleepers and in bridge construction. It is also used in house construction and to make agricultural and household tools. It is an excellent firewood producing hot flames and little smoke and is also a good source of charcoal. Edible caterpillars are grown on the tree; in northern Cameroon, where they are called 'dessi', 'sankadang' or 'sélénibétéyo' in the Gbaya language, they are collected, traded and consumed by several tribes. The flowers are fragrant and an important source of honey, e.g. in Nigeria. The bark of the plant is used as a colorant in West Africa to prevent cooked yam from becoming dark. During the dry season, the foliage is browsed by cattle.
In traditional medicine méni oil is used to treat dermatosis, toothache and muscular tiredness.



Lophira lanceolata – wild

Rubbing the skin with the oil prevents dryness. The oil is mixed with porridge and given to children as a tonic. The sap of the tree is used to treat tiredness by the Dii, Fulbe and Gbaya peoples in Cameroon.
In Mali pounded roots, mixed with flour are used to treat constipation, while its concoction is used to cure chronic wounds. A concoction prepared from the roots is drunk by women against menstrual pain, intestinal troubles and malaria. The bark of the roots and trunk is used against pulmonary diseases. The bark is also used to treat fevers and gastro-intestinal problems, and in southern Nigeria the root bark is a remedy for yellow fever. The young stems and sometimes the roots are commonly used as chew-sticks, and an infusion of the bark is used as a mouthwash against toothache in Guinea, Mali and Nigeria. An infusion of the young twigs is used to treat fever, respiratory tract infections and dysentery. Concoctions of young fresh or dried leaves taken in the form of a drink are given to treat pain caused by intestinal worms, dysentery and diarrhoea in children, while as a steam bath it is said to cure general tiredness and rheumatism. Pain caused by worms can also be treated by eating young fresh leaves. Concoctions of the young red leaves are also employed in the treatment of headache, hypertension and syphilis. Culturally, the leaves and wood of *Lophira lanceolata* are very important for the Dii people. The leaves are used for traditional dances and masks are made from the wood. The medicinal uses are probably inseparable from the ceremonial uses of the leaves.

Production and international trade The oil and other products of *Lophira lanceolata* are traded on a local scale only. In Cameroon the retail price of the oil is US$ 2–3 per litre.

Properties The approximate composition of the dry seeds per 100 g is: water 8 g, energy 2290 kJ (547 kcal), protein 14 g, fat 44 g, carbohydrate 32 g, fibre 1 g, Ca 101 mg, P 156 mg. On extraction the seeds yield 40–50% of a yellow inodorous semi-solid oil. Its approximate fatty acid composition is: myristic acid 2%, palmitic acid 27%, behenic acid 14%, lignoceric acid 2%, tetradecenoic acid trace, hexadecenoic acid 1%, oleic acid 15%, linoleic acid 33%, docosenoic acid 5%, tetracosenoic acid trace. The α-tocopherol content of the oil is high and in a test its unsaturated fatty acid content remained unchanged for one year. The oil is suitable for cooking and has cosmetic properties. Its viscosity-temperature profile make it useful as base stock for lubricants. The presscake is reported to be unsuitable as cattle feed, but suitable as manure.
Phytochemical analysis of the bark has shown the presence of several flavonoids with some antibacterial and antiviral activity. They include a group of related biflavonoids called lophirones A–J, the biflavonoid isombamichalcone and the tetraflavonoid lanceochalcone. The wood contains the nitrile glycoside esters lanceolin A and B, while the leaves contain lanceolatin A and B and in addition the benzoyl glycoside lanceoloside A and the prenylated isoflavone lanceolone. The presence of benzamide has been reported in the root bark.
The wood is pinkish with a red core, very hard and heavy and very durable.

Description Small to medium-sized tree up to 16(–24) m tall; bole branchless for up to 7.5 m, straight or twisted, up to 70 cm in diameter; bark surface corky, grey, very coarsely flaking, inner bark yellow to brownish red; branches ascending, with prominent leaf-scars. Leaves alternate but clustered at the end of branches, simple and entire; stipules linear-lanceolate, 3–5 mm long, caducous; petiole 2–6 cm long;

Lophira lanceolata – 1, flowering branch; 2, fruit.
Source: Flore analytique du Bénin

blade oblong-lanceolate, 11–45 cm × 2–9 cm, base cuneate, often asymmetrical, apex rounded and sometimes notched, glabrous, red to bright pink when young, pinnately veined with numerous lateral veins, prominent on both sides. Inflorescence a terminal, pyramidal, lax panicle 15–20 cm long, axes angular, grooved, glabrous. Flowers bisexual, regular, 5-merous, white, scented; pedicel 1–1.5 cm long, jointed near the apex, glabrous; calyx lobes unequal, 2 outer ones ovate-acuminate, 7–8 mm × 4–5 mm, 3 inner ones broadly ovate, c. 6 mm × 5 mm, obtuse; petals free, obcordate, c. 17 mm × 13 mm, glabrous; stamens numerous, in 3–5 whorls; ovary superior, sessile, conical, c. 8 mm × 3 mm, 1-celled, style indistinct, stigmas 2. Fruit a conical, somewhat woody, 1-seeded achene surrounded by the calyx, outer sepals accrescent, wing-like, unequal, one 8–10 cm × 2–2.5 cm, the other 2.5–5 cm × 0.5–1 cm. Seed ovoid, c. 16 mm × 8 mm, chestnut-coloured, glabrous. Seedling with hypogeal germination.

Other botanical information *Lophira* comprises 2 species: *Lophira alata* Banks ex P.Gaertn., which yields the well-known timber azobé, and *Lophira lanceolata*. They are very similar in morphology and have often been confused. They are mainly differentiated by their habit and different habitats: *Lophira alata* is a very large tree found in dense forest, while *Lophira lanceolata* is much smaller and grows in savanna woodland. *Lophira lanceolata* is sometimes confused with *Vitellaria paradoxa* C.F.Gaertn., shea butter tree, when not in flower. The leaves of the latter exude latex when damaged.

Growth and development Seeds of *Lophira lanceolata* are recalcitrant. In a test their initial viability was about 50%, which dropped to 5% after storage for 3 months at 9% moisture content. When dried to 3% moisture, seeds did not germinate at all. They are dispersed by wind. Germination takes 3–5 weeks. Reports on growth rates are contradictory. In southern Benin it is reported to grow fast, whereas in Cameroon early growth is reported to be slow. The species is invasive and often found gregariously as a colonizer of cleared forest or in fallow vegetation. It suckers freely. *Lophira lanceolata* is deciduous and is leafless for 3–4 weeks in October–December in Cameroon. Trees flower during the dry season, before new leaves appear. In some years, it flowers twice in Cameroon. When new leaves are expanding, it is easily recognizable from far by its new red leaves grouped at the ends of branches.

Ecology *Lophira lanceolata* is a tree of the wooded savanna where it occurs up to 1500 m altitude. It often grows gregariously on fallow land at the edge of forests. It is found on medium heavy to sandy or gravelly soils. When established it is fire tolerant, but regeneration is affected by regular bushfires.

Propagation and planting Propagation is mainly by seed. When dried, seed loses its viability quickly. Seed is available from CNSF, Ouagadougou, Burkina Faso. To improve growth in the nursery, it is recommended to add soil from under an established tree to the substrate to ensure development of mycorrhizal fungi. Reproduction by air layering is possible. A rooting percentage of marcots of more than 60% has been obtained with cow dung as substrate and IBA (0.8%) as growth hormone. Vegetative propagation by stem cuttings is also possible.

Management In the savanna of Cameroon an annual litter production of 27 t/ha (fresh weight) has been recorded.

Diseases and pests The fruits are attacked by curculinoid beetles (species unknown) both on the tree and when they have fallen.

Harvesting Fruits can be harvested in February–March in Mali and in January–April in Cameroon. As soon as the fruits turn brown, they are collected from the tree to avoid damage by beetles.

Yield The quantity of fruits produced per tree varies with the year and site. In Cameroon the mean quantity of fruits per tree is about 5500. Good seed production is associated with large leaves.

Handling after harvest After collection fruits are sorted and dried in the sun. For oil production, the fruit wall is removed and the seeds are ground or pounded to a paste, mixed with water and boiled. The oil that floats to the surface is scooped off.

Genetic resources As *Lophira lanceolata* has a wide distribution and is common in secondary vegetation, it is not at risk of genetic erosion.

Breeding *Lophira lanceolata* is a potentially important agroforestry tree species of the sudano–guinean savanna. It has been selected by the University of Ngaoundéré, Cameroon for an extensive domestication programme with a view to introducing it in homegardens.

Prospects *Lophira lanceolata* is an important food and medicinal plant species in savanna regions and may well become an important multipurpose agroforestry tree. Research into its domestication should explore opportunities to exploit not only the oil, but also the edible caterpillars, honey, medicinal uses, forage and timber.

Major references Arbonnier, 2000; Bamps & Farron, 1967; Burkill, 1997; Eyog Matig et al. (Editeurs), 2006; Leung, Busson & Jardin, 1968; Malgras, 1992; Mapongmetsem, 2005a; Mapongmetsem, 2005b; Tchiégang-Megueni et al., 2001.

Other references Adamou Baloka, 2000; Bouitang, 1998; Dumaine et al., 2002; Eromosele & Paschal, 2003; Eromosele & Eromosele, 1993; Eromosele et al., 1994; Ghogomu Tih et al., 1994; Irvine, 1961; Keay, 1954b; Mapongmetsem, Motalindja & Nyomo, 1998; Mapongmetsem et al., 1998; Mapongmetsem et al., 1997; Pegnyemb et al., 1998; Persinos & Guimby, 1968; Piot, 1970; Sanon et al., 2005; Satabié, 1982; Yonkeu, Mapongmetsem & Ngassoum, 1998.

Sources of illustration Akoègninou, van der Burg & van der Maesen, 2006.

Authors P.-M. Mapongmetsem

MORINGA DROUHARDII Jum.

Protologue Ann. Inst. Bot.-Géol. Colon. Marseille sér. 4, 8: 15 (1930).

Family Moringaceae

Origin and geographic distribution *Moringa drouhardii* is endemic to Toliara province in south-western Madagascar, where it occurs wild and planted. It is also planted in other places along the west coast.

Uses The seeds yield an oil that is used as a base for cosmetic products and as a medicinal massage oil. The very strongly scented bark and wood are used for treatment of colds and coughs. The tree is often planted on field boundaries.

Properties The oil is odourless, tasteless and does not become rancid in storage, making it an excellent base in perfumery and pharmacology. It was formerly used as a base-oil in enfleurage to extract fragrant volatile compounds from flowers. The seed contains 36–45% oil; the approximate fatty acid composition of the oil is: palmitic acid 8%, stearic acid 9%, oleic acid 74%, linoleic acid 1%, arachidic acid 3%, behenic acid 3%.

Botany Small, deciduous tree up to 10(–18) m tall with a swollen bole and short branches near the top; bark whitish, containing resin. Leaves alternate, 3-pinnate; stipules absent; petiole 10–15 cm long, stalks of pinnae 2–3 cm long, petiolules 3–4 mm long, all glabrous and with glands at base; leaflets opposite, ovate to oblong, 15–30 mm × 5–12 mm, base cuneate, apex acute, glabrous, bright green. Inflorescence an axillary, lax, many-flowered panicle up to 30 cm long. Flowers bisexual, regular, 5-merous, yellowish white; pedicel up to 2 mm long; sepals free, obovate, 5–6 mm × c. 2 mm, narrowing to the base, apex rounded, glabrous; petals free, ovate, 7–10 mm × c. 2 mm, apex incurved, glabrescent outside, slightly short-hairy inside; stamens 5, free, 6–8 mm long, hairy, alternating with 5 staminodes c. 4 mm long; ovary superior, stalked, ovoid, c. 1.5 mm long, 1-celled, style slender, 3–4 mm long. Fruit an elongate capsule 30–50 cm long, somewhat trigonous, narrowed between the seeds, with a beak, glabrous, dehiscent with 3 valves. Seeds trigonous to ovoid, 2–2.5 cm × c. 2 cm, whitish, glabrous.

Growth of young trees is very fast, allowing *Moringa drouhardii* to occupy open spaces in the forest. In cultivation it grows at a rate of more than 1 m per year. Trees start bearing 3 years after planting when they have reached a height of 3–4 m.

Moringa comprises 13 species, of which 8 are endemic to the Horn of Africa and 2 to Madagascar. *Moringa oleifera* Lam. originates from tropical Asia, but has been introduced throughout the tropics; it has become naturalized in many African countries, including Madagascar. Its fruits are used as a vegetable.

Ecology The natural habitat is very dry forest. Rainfall may be as low as 200 mm per year and very unreliable. Completely dry years are not uncommon. *Moringa drouhardii* occurs on calcareous soils.

Management Propagation by seed is straightforward. Seeds are sown in fertile soil in a nursery. During the dry season seedlings can be transplanted into the field without irrigation, even into dry places with poor soil.

Genetic resources and breeding *Moringa drouhardii* is still fairly common in its natural habitat and is commonly planted. It does not seem to be endangered or vulnerable.

Prospects The excellent qualities of the oil in cosmetic and medicinal products and its adaptation to very dry conditions deserve further research into the possibilities of domestication and utilization in small-scale industries.

Major references de Saint Sauveur, 2001; Delaveau & Boiteau, 1980; Keraudren, 1965;

Keraudren-Aymonin, 1982; Olson & Carlquist, 2001.

Other references Jahn, Musnad & Burgstaller, 1986.

Authors E. Munyanziza

MORINGA PEREGRINA (Forssk.) Fiori

Protologue Agric. Colon. 5: 59 (1911).

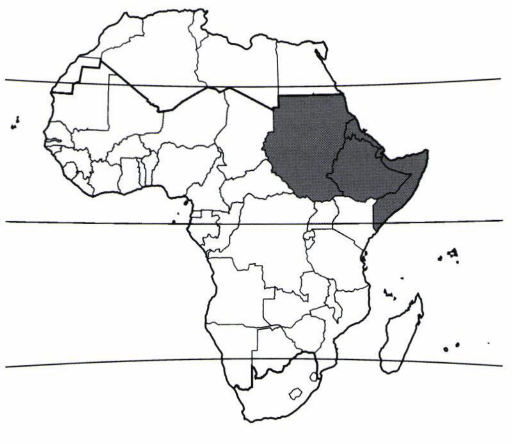
Family Moringaceae

Synonyms *Moringa aptera* Gaertn. (1791).

Vernacular names Ben tree, wispy-needled yasar tree, wild drum-stick tree (En). Ben blanc, moringa aptère, arbre à noix de ben (Fr).

Origin and geographic distribution *Moringa peregrina* occurs naturally in arid or semi-arid countries bordering the Red Sea, from Somalia and Yemen to Israel and on to Syria. In tropical Africa it is reported from Sudan, Ethiopia, Eritrea, Djibouti and Somalia. It is reported from Iran and Pakistan, but its occurrence there needs confirmation.

Uses The main product derived from *Moringa peregrina* is seed oil, called 'ben oil'. The use of the oil goes back to antiquity and is already referred to in old Egyptian texts and the Bible. The oil is used for cooking, in cosmetics and in medicine. In Yemen the oil is used as a lubricant for small machinery. The seeds are also used as coagulant to purify water, e.g. in Sudan. In southern Sudan and Yemen *Moringa peregrina* is a bee plant and its leaves are used as fodder. The seeds are used in medicine in the Middle East and Sudan. The oil is used to treat abdominal pain. The tuber of the young plant is eaten in Yemen and Oman. The plant is grown as ornamental in Saudi Arabia and the Middle East. The wood is collected for fuel in the southern Sinai, but it has now become scarce.



Moringa peregrina – wild

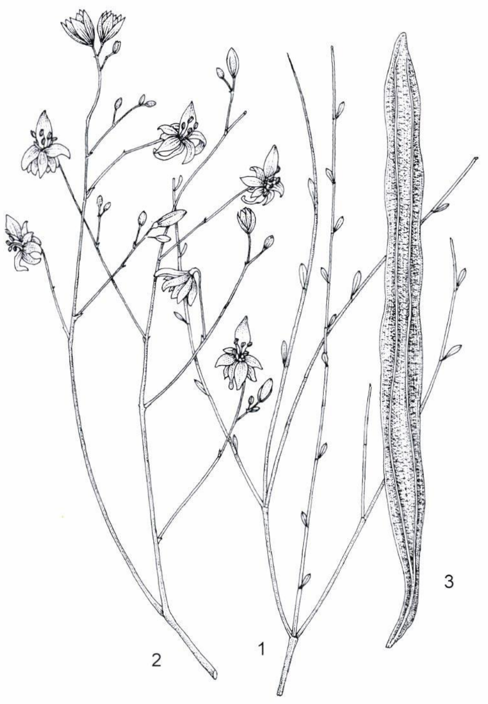
Production and international trade The amounts of ben oil produced from *Moringa peregrina* are not known, but seem to be declining. The oil is mainly produced for home consumption or local markets.

Properties The seed of *Moringa peregrina* contains about 50% oil. It is similar to the oil extracted from the seed of *Moringa oleifera* Lam. The approximate fatty acid composition of the oil is: palmitic acid 9%, stearic acid 4%, arachidic acid 2%, behenic acid 2%, oleic acid 71%, linoleic acid 1%, and gadoleic acid 2%. The oil contains the sterols campesterol, stigmasterol and β-sitosterol and the tocopherols α-, γ-, and δ-tocopherol. The water purifying properties of the seed are caused by a protein which coagulates dispersed particles.

Adulterations and substitutes The oils of *Moringa peregrina*, *Moringa stenopetala* (Baker f.) Cufod. and *Moringa oleifera* are all referred to as 'ben oil' and can be used as substitutes. The oil of *Moringa oleifera* is used most widely.

Description Shrub or small tree up to 10 m tall, with tuberous rootstock; bole up to 40 cm in diameter; bark grey, purple-grey or bright brown; crown ovoid; branches terete, slender, young stems grey-white or waxy blue-green; twigs brittle. Leaves alternate, in bunches at the ends of branches, 15–40 cm long, 2-pinnate, with 2–5 pairs of pinnae; leaflets opposite or alternate, obovate, oblanceolate or spatulate, 3–20(–35) mm × 2–10(–13) mm, base cuneate to rounded, apex rounded or notched, grey or waxy green. Inflorescence an axillary, lax, much-branched panicle 18–30 cm long. Flowers bisexual, slightly zygomorphic, 5-merous, white with purple heart or pink-flushed, sometimes scented; pedicel 2–9 mm long, jointed; sepals free, oblong to lanceolate, 7–9 mm × 1.5–3 mm, acuminate, hairy on both surfaces; petals free, narrowly oblong, obovate or spatulate, 8–15 mm × 2–5 mm, hairy inside; stamens 5, free, 4.5–7 mm long, alternating with 5 staminodes, 4–5 mm long; ovary superior, shortly stalked, cylindrical, hairy, 1-celled, style slender. Fruit an elongate capsule (10–)32–39 cm × (1–)1.5–1.7 cm, somewhat trigonous, slightly narrowed between the seeds, with a beak, glabrous, dehiscent with 3 valves. Seeds globose to ovoid or trigonous, 10–12 mm × 10–12 mm, brown.

Other botanical information *Moringa* is



Moringa peregrina – 1, leaf; 2, inflorescence; 3, fruit.
Redrawn and adapted by Achmad Satiri Nurhaman

the only genus of the *Moringaceae*, a family related to *Brassicaceae*. It comprises 13 species, of which 8 are endemic to the Horn of Africa and 2 to Madagascar.

Growth and development Young seedlings have broad leaflets and form a large tuber. Through many dry seasons, the shoot dies back to the tuber to below ground-level. As the plant gets older the stem becomes permanent and the leaves get progressively longer, while the leaflets get smaller and more widely spaced. Adult trees produce leaves with a full complement of tiny leaflets, only to drop them as the leaf matures. However, the naked leaf axes remain, giving the tree a wispy look similar to *Tamarix* spp.

Ecology *Moringa peregrina* grows on rocky slopes of wadis and gullies, up to 850 m altitude in *Acacia-Commiphora* woodland, sometimes on nearly bare rock with a strongly reduced root system.

Propagation and planting Planting trials of *Moringa peregrina* have been done in Sudan. Both seeds and cuttings can be used for multiplying it in a nursery. Exposure to full sunlight and high temperatures reduced seedling growth. Transplanting 5-month-old seedlings gave good survival rates. Branches of 1–1.5 m in length have been used as cuttings and these have performed well. *Moringa peregrina* grows fast from both seeds and cuttings; 3–4 m annual growth in height is not unusual when adequate moisture is available. First fruits are produced about 3 years after planting.

Management Pollarding or pruning following harvesting is recommended to promote branching. This increases pod production and facilitates harvesting as the tree is kept at a manageable height.

Harvesting Seeds are collected from the wild.

Yield A single tree may produce up to 1000 pods per year.

Handling after harvest Traditional methods to extract the oil used by Bedouin are very simple, but yield little oil. Seeds are crushed, water is added and the seeds are boiled. The mixture is left overnight to allow the oil to float to the surface, from where it is skimmed off. In a more advanced method the seeds are crushed, some water is added and the mixture is gently heated for 10–15 minutes. The oil is then extracted using a screw press or hydraulic press.
For water purification, seeds are ground to a paste. The paste is put in a bottle and water is added. The mixture is shaken for 5 minutes to activate the protein. The mixture is then sieved and the solution is added to turbid water. After slowly stirring for 20 minutes, fine particles including bacteria coagulate, sink and settle on the bottom. After one hour clear water can be drawn off.

Genetic resources Although there is concern about the decline of *Moringa peregrina* stands especially where it is collected for firewood, it is not listed in the IUCN Red List 2006. It is endangered in the Sinai in Egypt. Efforts to restore the local vegetation by restoring the stand of the dominant species, including *Acacia tortilis* (Forssk.) Hayne, have resulted in an increase in the numbers of trees of *Moringa peregrina* as well. *Moringa peregrina* is included in a field genebank of fodder plants in Oman.

Prospects Protection of *Moringa peregrina* and its vulnerable habitat is needed. Continued use of the seed for oil production and water clarification requires its domestication and cultivation. Initial results of experiments to achieve this are promising.

Major references Jahn, 1986a; Jahn, 1986b; Jahn, Musnad & Burgstaller, 1986; Keraudren, 1965; Moustafa et al., 1998; Olson, 2002; Somali, Bajneid & Al-Fhaimani, 1984; Thulin, 1993; Tsakis, 1998; Verdcourt, 2000.

Other references Batanouny, 1999; Fahn, Werker & Baas, 1986; Ibrahim et al., 1974; Olsen, 1999; Olson, 2003; Olson & Carlquist, 2001; Verdcourt, 1965.

Sources of illustration Zohary, 1966.

Authors E. Munyanziza & K.A. Yongabi

OLEA EUROPAEA L.

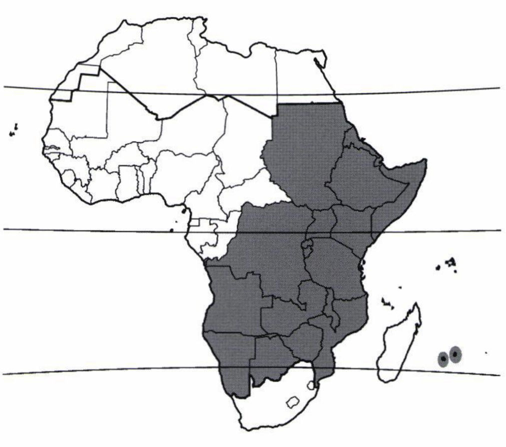
Protologue Sp. pl. 1: 8 (1753).

Family Oleaceae

Chromosome number $2n = 46$

Vernacular names Olive (En). Olivier (Fr). Oliveira (Po). Mzeituni, mzaituni (Sw).

Origin and geographic distribution Olive is a characteristic fruit tree of the Mediterranean Basin. The wild Mediterranean olive or oleaster (*Olea europaea* subsp. *europaea* var. *sylvestris* (Mill.) Lehr) is a typical component of the Mediterranean shrub vegetation and the most likely progenitor of the cultivated olive (*Olea europaea* subsp. *europaea* var. *europaea*). First domestication is associated with early civilizations in the eastern Mediterranean or Middle East. Archaeological evidence of olive cultivation dates back to the 4th millennium BC. The Phoenicians and Greeks in particular contributed to the expansion of olive cultivation around the Mediterranean Sea during the first millennium BC. In the Roman empire of the 2nd century AD, olive oil became one of the most economically important commodities.



Olea europaea – wild

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 850 million olive trees are still grown in the Mediterranean region. In tropical Africa a small olive industry producing table olives is developing in Namibia.

The wild African olive (*Olea europaea* subsp. *cuspidata* (Will. ex G.Don) Cif.) occurs in Central, East and southern Africa and in the Indian Ocean Islands. It is also found in Arabia and from south-western Asia to China.

Uses The main product of the olive tree is the edible oil extracted from the mesocarp (pulp) of the fruit 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 mono-unsaturated fatty acids and polyphenolic anti-oxidants. Lower grade olive oil is used in the manufacture of soap, cosmetics and lubricants. In perfumery the oil is a good, although sticky, carrier oil for essential oils. Traditionally, olive oil also has various pharmaceutical applications and has served as lamp oil, as well as for treating wool.

Fruits are processed into whole green and black table olives, often mixed with various condiments. They are sometimes pitted, and then stuffed with sweet pepper or anchovy. They are sliced, minced or made into paste such as 'tapenade' in the south of France. They are eaten as an appetizer or used in cooking. The presscake is not a very suitable livestock feed, but can be used as fuel or fertilizer. The leaves provide cattle feed and in Tanzania they are used in brewing beer. The wood is valuable, hard and fairly durable, but it is rarely available in large sizes. It is used for turnery and furniture, and is much appreciated for handicrafts; in larger sizes, it is also used for flooring and railway sleepers. The Maasai people of East Africa use it to make clubs and for poles for houses. It makes excellent fuelwood and charcoal.

The leaves have been used for a long time to clean wounds. Olive leaves are applied to lower blood pressure and to help improve the function of the circulatory system. They are also taken as a mild diuretic and may be used to treat conditions such as cystitis. Having some ability to lower blood sugar levels, the leaves have been taken to treat diabetes. The oil is traditionally taken with lemon juice in teaspoonful doses to treat gallstones.

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 2002–2005 was 2.5 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 (2.1–2.9 million t). The total area planted with olive trees is estimated at 8.1 million ha in 25 countries. The principal olive oil producing countries are Spain (32%), Italy (23%), Greece (14%), Turkey (8%), Tunisia (5%), Syria (5%), Morocco (3%), Egypt (2%), Portugal (2%) and Algeria (1%), which together account for 95% of the world supply. About 600,000 t per year reach the international vegetable oil market; the European Union and United States are the main importers of olive oil. Olive oil commands better prices than other table oils.

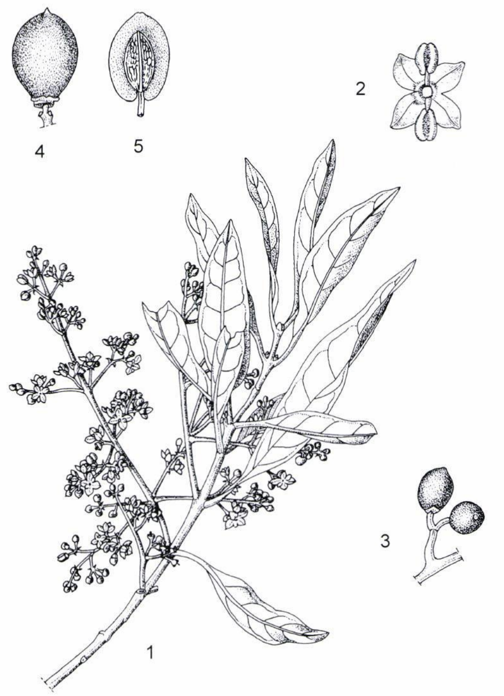
The 1.1 million t of table olives produced annually represent about 8% of total olive fruit yields. Spain is the largest producer of table olives (25%) followed by the United States (14%), Turkey, Morocco, Syria, Greece and Italy (6–9% each). In the Mediterranean Basin, table olives are sold in great variety by specialized sellers.

Properties Mature olive fruits weigh 2–12 g. They consist of mesocarp 70–90%, endocarp (stone) 9–29% and seed 1–3%. Per 100 g fresh edible portion, the mesocarp contains: water 60–70 g, crude protein 1–2 g, fat 15–30 g, carbohydrate 3–6 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 acid, behenic acid 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 micro-organisms during processing. The bitterness in table olives is largely removed in the early stages of processing.

The heartwood is yellowish brown to reddish brown, with dark streaks, demarcated from the pale yellow sapwood. The wood is heavy and hard, and oily to the touch. The grain is straight or slightly wavy, the texture fine and even. The density at 12% moisture is more than 1150 kg/m^3. It dries moderately slowly with high shrinkage and considerable distortion. Shrinkage from green to 12% moisture content is about 4.5% radial and 6.5% tangential. The wood is difficult to work because of its hardness and tends to blunt cutting edges rapidly. With care it may be turned and planed. It produces a nice finish. Its natural durability is high, but it is moderately susceptible to termites and borers, The heartwood and water extracts from it are fluorescent.

Description Evergreen tree up to 20 m tall or densely branched shrub up to 5 m tall; root system extensive with main roots thickened by fasciation; bole often fluted or crooked, up to 100(–200) cm in diameter, at the base with protuberances (spheroblasts) with additional lateral roots; bark rough, longitudinally fissured, grey to dark brown; crown with spreading branches, young branches 4-angular, whitish, thorny, with numerous lenticels. Leaves opposite, simple and entire, without stipules; petiole up to 1.5 cm long; blade elliptical to lanceolate, 3–9 cm × 0.5–3 cm, cuneate at base, acute at apex, leathery, dark grey-green and glabrous above, densely silvery scaly beneath, pinnately veined. Inflorescence an axillary panicle, 3–8 cm long, many-flowered. Flowers bisexual, regular, 4-merous, fragrant; pedicel short; calyx cup-shaped with broadly triangular lobes, persisting in fruit; corolla c. 2.5 mm long, white, with short tube and 4 elliptical lobes; stamens 2, filaments short, anthers large; ovary superior, 2-celled, style short, stigma 2-lobed. Fruit a globose to ellipsoid drupe 0.5–4(–6) 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.

Other botanical information *Olea* com-



Olea europaea – 1, flowering twig; 2, flower; 3, fruits; 4, fruit of cultivated type; 5, fruit of cultivated type in longitudinal section.
Redrawn and adapted by Achmad Satiri Nurhaman

prises 33 species, most of them occurring in eastern and southern Africa and in tropical Asia. In the complex species *Olea europaea*, 6 subspecies, one of which with 2 varieties, are recognized based on morphological characters and geographic distribution:

- subsp. *europaea* var. *europaea*, the cultivated olive.
- subsp. *europaea* var. *sylvestris* (Mill.) Lehr., the wild olive or oleaster of the Mediterranean basin.
- subsp. *cuspidata (*Wall. ex G.Don) Cif. (synonyms: *Olea africana* Mill., *Olea chrysophylla* Lam., *Olea europaea* subsp. *africana* (Mill.) P.S.Green), the most widespread wild olive in tropical Africa.
- subsp. *laperrinei* (Batt. & Trab.) Cif., a wild olive endemic to the Saharan mountains.
- subsp. *maroccana* (Greut. & Burdet) P.Vargas, a wild olive occurring in the Atlas mountains in Morocco.
- subsp. *cerasiformis* G. Kunkel & Sunding, the wild olive of Madeira.
- subsp. *guanchica* P.Vargas, J.Hess, F.Muñoz Garmendia & J.Kadereit, the wild olive of the Canary Islands.

The wild types are generally distinguishable from the cultivated olive by their much smaller fruits (5–12 mm long) with thin layer of oil-bearing mesocarp and often more dense, twiggy and spiny habit. Although recent molecular evidence based on chloroplast and mitochondrial DNA polymorphisms has confirmed considerable genetic diversity between the taxa, all have remained largely interfertile and the wild types should provide a valuable gene-pool for the improvement of the cultivated olive, e.g. for disease and pest resistance and adaptation to new environments.

More than 2000 cultivars are known, which according to their use, can be distinguished into three groups:

- 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.

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.

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, 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 periods 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).

In tropical Africa wild olive occurs in montane woodland, rainforest and wooded grassland at 1000–3150 m altitude. They are often found on rocky hillsides, in forest margins and along dry riverbeds, and may occasionally form almost pure stands.

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. Seed 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, 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.

Management 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). This corresponds 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. This 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 and 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 Olive fruits intended 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 2005 was 2.0 t of olive fruits per ha. Fruit yield per ha varies from 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, giving a world average of 350–400 kg/ha in 2005.

Handling after harvest Oil extraction should start within 1–3 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 uniform paste, from which the oil is cold-extracted by mechanical pressing or centrifuging. 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. The cold-extracted cake or pomace may undergo further solvent extraction to produce an industrial grade 'olive-pomace' oil.

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 in 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).
Wild olive is widespread in tropical Africa and locally common, and not under threat of genetic erosion.

Breeding Olive improvement has a long tradition of clonal selection. Breeding programmes based on inter-cultivar 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 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 and other wild subspecies of *Olea europaea*.

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. Olive also contributes considerably to environmental protection (soils, flora and fauna) in dry and hilly areas. There may be opportunities for olive cultivation in Central, East and southern Africa, in particular where wild olive trees already occur.

Major references Barranco, Fernandez-Escobar & Rallo (Editors), 1998; Besnard et al., 2002; Di Giovacchino, 1997; Garrido Fernandez, Fernandez Diez & Adams, 1997; Green, 2002; Katsoyannos, 1992; Loussert & Brousse, 1978; Tombesi, 1994; Villemur & Dosba, 1997; Zohary, 1995.

Other references Aka Sagliker & Darici, 2005; Bartolini & Petrucelli, 2002; Besnard & Berville, 2000; California Rare Fruit Growers, 1997; Fabri & Benelli, 2000; International Olive Oil Council, 1997; Lavee, 1990; Lavee, 2005; Maundu & Tengnäs, 2005; Metzidakis & Voyiatzis (Editors), 1999; Ministry of Trade and Industry, Namibia, undated; Mkize, 2005.

Sources of illustration Moutier & van der Vossen, 2001; Turrill, 1952.

Authors H.A.M. van der Vossen, G.N. Mashungwa & R.M. Mmolotsi

ONGOKEA GORE (Hua) Pierre

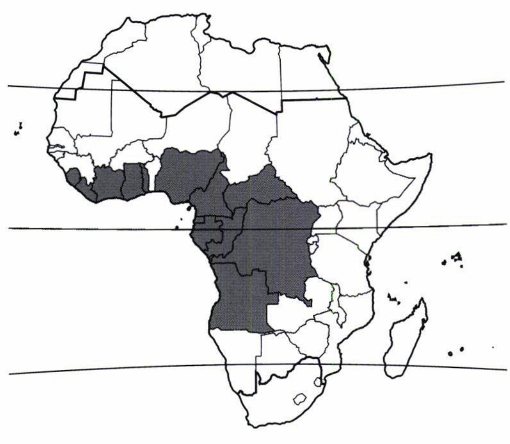
Protologue Bull. Mens. Soc. Linn. Paris 2: 1314 (1897).

Family Olacaceae

Synonyms *Ongokea klaineana* Pierre (1897), *Ongokea kamerunensis* Engl. (1909).

Vernacular names Angueuk, boleko, isano (En). Angueuk, boléko, ongokéa (Fr). Nsanu (Po). Kileku, ntuli, oleko (Sw).

Origin and geographic distribution *Ongokea gore* occurs in dense evergreen and moist



Ongokea gore – wild

semi-deciduous forests from Sierra Leone to eastern DR Congo and south to Angola.

Uses The wood of *Ongokea gore*, called 'angueuk' in trade, is used mostly locally in heavy construction, for railway sleepers and vehicle frames, in interior and exterior carpentry, for flooring, containers and boxes, turnery and veneer. It is well suited for interior joinery provided it is perfectly dry to avoid deformation. The seed oil, called 'boleko oil' or 'isano oil', is inedible but can be used as additive to linseed oil in the manufacture of paints, varnishes and linoleum and to oil for moulding cores in metal foundry. It can also be used to protect metal and wooden surfaces. Polymerization at moderately high temperatures yields a film with remarkable properties: strong, flexible and insoluble in acid and alkaline solvents. This makes it suitable for manufacturing brake pads and linings. In association with linseed oil the oil can be made into a standoil (a heat-polymerized oil, very thick and strongly adhesive, but slowly drying; used as a final coat in oil painting) of superior qualities. Boiling boleko oil with copal gives this resin a very high heat resistance. The oil can be used to make de-emulsifying products for the crude oil extraction industry and for the prevention of icing-up of airplane wings. It can also be vulcanized to yield highly resistant synthetic-rubber products. Ozonolytic cleavage can yield saturated double acids, which are used in the synthesis of polyamides. The use of fatty acids from boleko oil in the manufacturing of silicones and of isolating glue for lithium-based batteries has been patented. The oil is used traditionally to anoint the skin.

The pulp of the fruit is edible. The bark is laxative; in Congo fresh bark is rubbed on the breasts of lactating mothers to purge their babies; similarly, in Gabon a decoction of the bark is used as a wash for babies or they are given a pinch of pounded bark mixed with a little salt. The sap is used as styptic and the bark to treat splenomegaly in DR Congo. The seeds are used as bait for small rodents and the fruits as spinning tops for children.

Production and international trade The wood of *Ongokea gore* is of little importance in international trade and is mostly included in statistics under 'miscellaneous timbers'. Few accurate data are available: Equatorial Guinea exported 400 m^3/year between 1963 and 1968, while Cameroon exported 500 m^3/year in 1997 and 1998. In the Central African Republic the total extractible volume has been estimated at 3.7 million m^3, of which 2.2 million m^3 is quality class 1 and 2.

Boleko oil has been traded in small amounts. At the end of the 1950s less than 100 t/year were exported, although France and Belgium had high hopes to develop the use of the oil in the paint industry. Potential production at that time was estimated at 30,000 t/year for DR Congo alone. No information is available on the current production and trade of boleko oil.

Properties The heartwood of *Ongokea gore* is pale yellow to pale brown and darkens on exposure to light. It is indistinctly demarcated from the 6–10 cm thick sapwood. The grain is straight, sometimes finely interlocked or wavy, texture fine and even. Quarter sawn surfaces are sometimes finely mottled or banded and slightly lustrous. The wood is heavy, with density at of 840–910 kg/m^3 at 12% moisture content. The rates of shrinkage on drying are high, from green to oven dry 4.0% radial and 10.7% tangential. The wood should be dried slowly, and there is a high risk of distortion and a slight risk of checking. Logs should be quarter sawn before drying to avoid warping.

At 12% moisture content the modulus of rupture is 94–143 N/mm^2, modulus of elasticity 10,000–16,135 N/mm^2, compression parallel to grain 53–74 N/mm^2, shear 9.0–10.8 N/mm^2 and cleavage 19.8–33.6 N/mm.

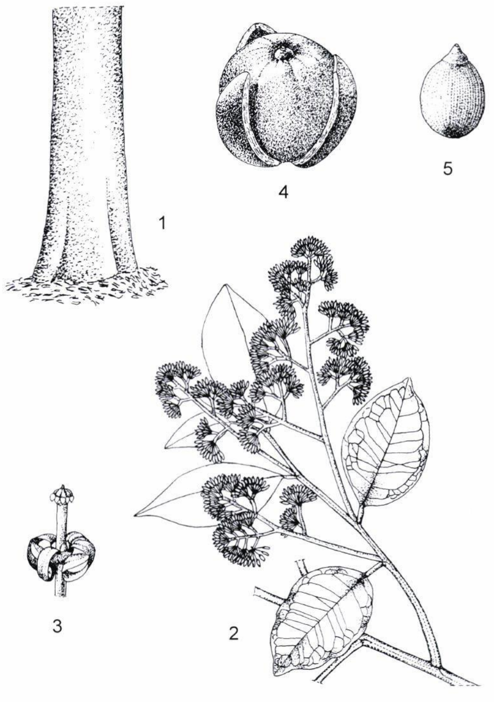
Once dry the wood is easy to work, saw and plane with little blunting of tools. It is easy to finish, sand and polish. It can be painted, varnished, waxed and glued without difficulty. For nailing preboring is often required. It can be sliced into veneer, but requires much force.

The heartwood is durable; in a test in Japan it was little affected by decay fungi or termites and was resistant to marine borers and in a test in Ghana it was little affected in a 3-year wood graveyard test. The sapwood is sensitive to blue-stain and to dry-wood borers. The heartwood is extremely resistant to impregnation, whereas the sapwood moderately resistant.

The dry seed contains about 63% oil. The seed oil differs from other vegetable oils in its fatty acid composition. Boleko oil has a high iodine number, but it does not dry when exposed in a thin film such as linseed oil or tung oil. When heated to 250°C a strongly exothermic spontaneous polymerization reaction starts, which may lead to a further increase in temperature to more than 400°C and to an explosion. Diacetylenic fatty acids and hydroxy-diacetylenic fatty acids characterize the oil; it consists mainly of: isanic acid and bolekic acid (together 30–50%) and of isanolic acid (15–35%). It further contains saturated and unsaturated fatty acids of which linoleic acid is the most important one. Isanic acid is an unbranched C_{18}-fatty acid with a single ethylene bond and 2 conjugated acetylene bonds; its formula is 17-octadecene-9,11-diynoic acid. Bolekic acid is 13-octadecene-9,11-diynoic acid, isanolic acid 17-octadecene-8-hydroxy-9,11-diynoic acid. The unsaponifiable matter of the oil contains a crystalline dialcohol with molecular formula $C_{28}H_{44}O_2$.

The pulp of the fresh fruit contains 67% moisture; its smell is reminiscent of apple, it is sweet but slightly astringent. The root and stem bark of *Ongokea gore* contain cyclohexanoid protaflavanones named ongokeins; they are related to sakuranetin and are characterized by a non-aromatic C_6-ring moiety that is otherwise only known from certain ferns.

Description Medium-sized to large, glabrous tree up to 40 m tall; bole straight and cylindrical, unbranched for up to 20 m, 100(–150) cm in diameter, without buttresses but sometimes with heavy root swellings; bark grey to dark brown or black, 1–2 cm thick, finely fissured and peeling off in fine irregular scales; crown pyramidal, rather open, with few heavy branches; leaf-bearing branches laterally compressed. Leaves alternate, simple and entire, without stipules; petiole thin, 0.5–1 cm long, grooved above, decurrent into 2 fine ridges along the branch; blade elliptical, 4–12 cm × 2–5 cm, base rounded to cuneate, apex shortly acuminate, margins retrorse especially near the base, lateral veins 6–10 at each side of the midrib, joining at some distance from the margin. Inflorescence an axillary panicle, up to 15 cm long, consisting of densely flowered, umbel-shaped cymes. Flowers bisexual or functionally unisexual, regular, 4-merous, greenish; pedicel filiform, c. 6 mm long; calyx shallowly cup-shaped, c. 1 mm in diameter; petals strap-shaped, 3–4 mm long, recurved; disk 4 lobed; stamens united into a tube c. 3 mm long; ovary superior, sessile, 1-celled, style hardly exserted from the staminal tube. Fruit a globose drupe, 2–4 cm in diameter, enclosed by the enlarged calyx except for apical part, slightly acuminate, 1-seeded. Seed globose, c. 1.5 cm in diameter. Seedling with epigeal germination; hypocotyl very short, epicotyl c. 18 cm long; first pair of leaves opposite.



Ongokea gore – 1, base of bole; 2, flowering twig; 3, flower; 4, fruit; 5, fruit stone.
Redrawn and adapted by Iskak Syamsudin

Other botanical information *Ongokea* comprises a single species. It is closely related to *Aptandra* a genus with about 4 species in tropical America and one species in tropical Africa, *Aptandra zenkeri* Engl., which differs from *Ongokea gore* in its raceme-like inflorescences and large, collar-shaped, pinkish calyx surrounding the fruit.

Growth and development In Côte d'Ivoire *Ongokea gore* flowers from January to June and fruits from May to July; in DR Congo fruiting is abundant in September, in Gabon in December and January. The fruits are eaten by many animals and the seeds are dispersed e.g. by monkeys.

Ecology *Ongokea gore* is found scattered in dense evergreen forest and in moist semi-deciduous forest. It occurs on dry ground and in periodically inundated localities. In Gabon it often occurs in forest dominated by *Sacoglottis gabonensis* (Baill.) Urb. and *Aucoumea klaineana* Pierre.

Propagation and planting Germination is slow and may take several months and even more than one year. Because of its slow and irregular germination, *Ongokea gore* is not grown in nurseries.

Management Large trees of *Ongokea gore* occur scattered in the forest. In Liberia 1 tree with a bole diameter over 60 cm has been reported per 43 ha for evergreen forest, and 1 tree per 7.5 ha for moist semi-deciduous forest.

Harvesting Fruits of *Ongokea gore* are collected from the wild and mostly the pulp is allowed to rot away before the fruit stones are collected from the soil.

Handling after harvest Fresh logs sink in water and cannot be transported by river. Depulping of fruits can be done by passing the fruits between rubber rollers and washing them with cold water. Boleko oil is produced by hydraulic pressing, but this is hampered by the high viscosity of the oil. During pressing the temperature can rise to 80°C which can alter the properties of the oil. The press cake contains considerable amounts of polymerized oil. The cake is unsuitable as cattle feed, but can be used as manure. The oil can also be extracted by solvents after the kernels have been ground and subjected to treatment with cold methanol.

Genetic resources *Ongokea gore* is widespread and does not seem to be in danger of genetic erosion. No germplasm collections are known to exist.

Prospects *Ongokea gore* is likely to remain important in its region of origin. There are no indications that it will become a commodity in international trade, but its volume in miscellaneous timber lots is likely to increase. Demand for the oil is likely to remain low except if local paint industries develop or if new applications for its unique fatty acids are found.

Major references Anonymous, 1957; Aubréville, 1959a; Chudnoff, 1980; CIRAD Forestry Department, 2003; C.T.F.T., undated; Miller et al., 1977; Normand, 1950; Pouliquen, 1959; Vieux & Taratibu, 1968; Voorhoeve, 1979.

Other references Burkill, 1997; De Borger, 1960; De Vries, 1956; De Vries, 1957; Heckel, 1902; Jerz, Waibel & Achenbach, 2005; Keay, 1989; Libouga, Womeni & Bitjoka, 2002; Magliocca, 1998; Mangala, 1999; Normand & Paquis, 1976; Pauwels, 1993; Raponda-Walker & Sillans, 1961; Sallenave, 1955; Saunders & Hall, 1968; Tsunoda, 1990; Villiers, 1973a; von Mikusch, 1963; von Mikusch, 1964; Wilks & Issembé, 2000.

Sources of illustration Pauwels, 1993; Voorhoeve, 1979; Wilks & Issembé, 2000.

Authors D. Louppe

PANDA OLEOSA Pierre

Protologue Bull. Mens. Soc. Linn. Paris 2: 1255 (1896).

Family Pandaceae

Origin and geographic distribution *Panda oleosa* occurs from Liberia east to the Central African Republic and DR Congo.

Uses An oil is extracted from the seeds for domestic use in the kitchen. The seeds are eaten after cooking. In Gabon pounded seeds are added to sauces, soups and stews in the same way as fruit kernels of *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill. The wood is used for carpentry and canoes. Several plant parts are used in traditional medicine. The bark is used internally to treat abdominal troubles, threatened abortion, intestinal parasites and blennorrhoea, and as an anti-inflammatory, analgesic and aphrodisiac. It is applied externally to treat rheumatism, wounds, yaws, sores, whitlow, swellings and haemorrhoids. A root decoction is taken against bronchial affections. The seed oil is applied to ulcers, pounded roasted seeds to burns. A leaf infusion is used as an enema to treat dysmenorrhoea, and pounded leaves are rubbed on the body as a tonic. The nectar from the flowers is collected by honey bees.

Production and international trade In Gabon seeds are sold on local markets.

Properties Semi-dried seeds of *Panda oleosa* contain per 100 g: water 26.8 g, energy 2085 kJ (498 kcal), protein 15.3 g, fat 51.5 g, carbohydrate 3.3 g, Ca 85 mg, P 174 mg. Dried seeds contain per 100 g: water 4.8 g, energy 2315 kJ (553 kcal), protein 23.4 g, fat 45.2 g, carbohydrate 22.9 g, fibre 6.0 g, Ca 371 mg, P 523 mg (Leung, Busson & Jardin, 1968).

Seeds contain about 50% of oil on a dry matter basis. The fatty acid composition of the seed oil is: myristic acid 1%, palmitic acid 26%, stearic acid 6%, arachidic acid 0.5%, oleic acid 33.5% and linoleic acid 32.5%.

The wood is brownish yellow to pinkish red, with irregular grain and fine texture. It is moderately heavy, with a density of 645–670 kg/m^3 at 12% moisture content. At 12% moisture content, the modulus of elasticity is 11,760–14,210 N/mm^2, compression parallel to grain 51–54 N/mm^2, compression perpendicular to grain 3 N/mm^2 and Chalais-Meudon side hardness 2.4–2.5.

In screening tests bark of *Panda oleosa* exhibited HIV-inhibitory activity. The flavonol constituent ent-4'-O-methylgallocatechin was isolated from the bark, but the anti-HIV activity was probably mainly produced by tannins.

Botany Small to medium-sized, dioecious, evergreen tree up to 20(–35) m tall; bole cylindrical or sinuous, up to 80(–100) cm in diameter, often with short buttresses at base; bark surface greenish brown to dark brown specked greyish, inner bark rose-violet with dark purplish brown spots; crown dense, strongly branched; young twigs angular, glabrous. Leaves alternate, simple; stipules narrowly lanceolate, small, caducous; petiole 0.5–1.5 cm long, channelled above; blade elliptical to oblong-elliptical, 10–30 cm × 4–13 cm, cuneate to rounded at base, acuminate at apex, margins wavy to toothed, leathery, glabrous, pinnately veined with 4–7 pairs of lateral veins. Inflorescence a raceme 15–35 cm long, solitary or in fascicles on older branches, shortly hairy. Flowers unisexual, regular, 5-merous; pedicel 1.5–4 mm long, jointed; calyx cupule-shaped, c. 1 mm long, obscurely toothed; petals free, oblong-elliptical to lanceolate, c. 5 mm × 2 mm, red; male flowers with 10 stamens in 2 whorls unequal in length and rudimentary ovary; female flowers with superior, 3(–4)-celled ovary and a short style ending in 3(–4) long stigmas. Fruit a globose drupe 5–7 cm in diameter, yellowish green; pyrene with thick, woody, pitted wall, 3(–4)-seeded. Seeds triangular-ovoid, concave, c. 2 cm long, compressed, glossy brown. Seedling with epigeal germination; hypocotyl 12–20 cm long, epicotyl c. 3 cm, cotyledons broadly obtriangular, 6–8 cm broad, broadly notched at apex.

Panda oleosa grows slowly. In Gabon seedlings were 35–40 cm tall 15 months after germination. The base of the bole is often swollen and pitted, caused by elephant damage. Young leaves are vivid red-pink. Many trees produce fruits each year, and fruits may persist on the tree for several months. The fruits are commonly eaten by elephants, which disperse the seeds in their dung. However, germinating seeds are sometimes also found in areas without elephants. The fruit stone (pyrene) is hard to crack, but in West Africa chimpanzees use stones for cracking. It is sometimes also opened by squirrels.

Panda comprises a single species. Together with the African genera *Centroplacus* and *Microdesmis* and the Asian *Galearia* it is classified in the family *Pandaceae*.

Ecology *Panda oleosa* is usually un understorey tree in evergreen to semi-deciduous forest, usually in primary forest, in swampy as well as dry sites. It can also be found in riverine and periodically flooded forest.

Management Seeds germinate slowly, starting after 10 months to 4 years. Seedlings survive in the shade of the forest, but they are most common in openings in the forest canopy. In general, seedlings are not common in the forest, although older trees are gregarious in many areas. Sometimes large numbers of young seedlings have been observed around a mother tree, but survival rates are low. In Gabon the fruit stones are collected on the forest floor and the seeds are extracted after cutting open the hard wall with a chopping-knife, which is a dangerous task.

Genetic resources and breeding *Panda oleosa* is fairly widespread and locally common, and there are no indications that it is threatened by genetic erosion.

Prospects The edible seeds of *Panda oleosa* and their oil are an interesting forest product in several countries. Domestication programmes are hindered by the slow germination and growth and therefore sustainable harvesting from the natural forest seems to offer the greatest opportunities. The difficulties in opening the hard fruit stone wall are a drawback in marketing the seeds.

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Other references Busson, 1965; Garcia et al., 1993; Hawthorne, 1995; Hawthorne & Parren, 2000; Leung, Busson & Jardin, 1968; Neuwinger, 2000; Raponda-Walker & Sillans, 1961; Robyns, 1958; Takahashi, 1978; White & Abernathy, 1997.

Authors R.H.M.J. Lemmens

PENTACLETHRA EETVELDEANA De Wild. & T.Durand

Protologue Bull. Herb. Boissier, sér. 2, 1: 20 (1900).

Family Mimosaceae (Leguminosae - Mimosoideae)

Origin and geographic distribution *Pentaclethra eetveldeana* occurs in Cameroon, Equatorial Guinea, Gabon, Congo, DR Congo and Cabinda (Angola).

Uses An edible oil can be extracted from the seeds of *Pentaclethra eetveldeana*; this oil has similar qualities to that of *Pentaclethra macrophylla* Benth. The seeds are eaten in DR Congo. The wood is used for construction and implements (e.g. pestles and mortars). It is also suitable for flooring, interior trim, joinery, furniture, cabinet work, toys and novelties, mine props, vehicle bodies, railway sleepers, turnery, veneer, plywood, hardboard and particle board. The wood is commonly used as firewood and for charcoal production. In DR Congo a leaf decoction is taken to treat stomach-ache and colds, and the root bark is used to treat malaria, epilepsy and haemorrhoids. In Congo a bark decoction is administered to treat respiratory troubles, tuberculosis, genito-urinary complaints and as an anthelmintic; it is applied externally against rheumatism and as an anodyne. Bark sap is administered as eye drops to treat filariasis. The foliage serves as food for edible caterpillars, and honey bees collect nectar from the flowers.

Production and international trade *Pentaclethra eetveldeana* timber is exported in small amounts from Congo and DR Congo, but statistics are not available.

Properties The composition of the seed oil has not been documented, but is probably similar to that of *Pentaclethra macrophylla*. The heartwood is pinkish white or yellowish white to dark brown, and distinctly demarcated from the up to 2.5 cm thick white to pale yellow sapwood. The grain is straight, texture medium to coarse. Dark-coloured veins may be visible on the radial surface of the wood, whereas the tangential surface is slightly striped. The wood is moderately heavy, with a density of about 750 kg/m^3 at 12% moisture content. It air dries fairly well, but shrinkage is considerable and it is liable to checking. Although the wood is fairly hard, sawing does not cause great difficulties as long as speeds are slow. The wood finishes satisfactorily. It does not split in nailing and holds nails well. The wood is moderately durable, being susceptible to pinhole borer and marine borer attacks and moderately resistant to termites. The heartwood is resistant to impregnation by preservatives, the sapwood permeable.

Bark extracts of *Pentaclethra eetveldeana* showed antifungal activity. Some monoglycerides and fatty acid conjugates of triterpenes were isolated from the root bark.

In Gabon the honey produced by bees from *Pentaclethra eetveldeana* nectar is reportedly toxic, causing nausea and colic, but this is not the case in DR Congo.

Botany Medium-sized tree up to 30 m tall; bole often sinuous, up to 50 cm in diameter, with small buttresses at base or without buttresses; outer bark grey, fissured, inner bark brown; crown dome-shaped; young twigs brown pubescent. Leaves alternate, bipinnately compound, up to 40 cm long; stipules linear-lanceolate, caducous; petiole 4.5–7 cm long, swollen and jointed at base, channeled; pinnae opposite, in 9–16 pairs, 4–12 cm long, at base markedly jointed, with 15–30 pairs of leaflets; leaflets opposite, sessile, obliquely rhomboid, 8–13 mm × 2–3.5 mm, apex acute, glabrous. Inflorescence a terminal or axillary panicle up to 30 cm long, consisting of spikes, many-flowered; peduncle 1.5–2 cm long, pubescent. Flowers bisexual, regular, 5-merous, small, fragrant, sessile; calyx campanulate, 1.5–2 mm long, with broadly triangular lobes c. 0.5 mm long; petals oblong-lanceolate, c. 4 mm long, basally swollen and fused for 1–2 mm, whitish; stamens 5, c. 5 mm long, anthers with large gland between the thecae, staminodes 5, filiform, c. 9 mm long; ovary superior, shortly stiped, 1-celled, densely hairy, style c. 4 mm long, stigma club-shaped. Fruit an obliquely ellipsoid-oblong pod up to 20 cm × 4 cm, woody, reddish brown, longitudinally striped, tapering to the base, apex obtuse, long-persistent and opening explosively on the tree and then recurving strongly, 3–8-seeded. Seeds orbicular to ovoid, flattened, 2–3 cm × 2–2.5 cm, smooth, reddish brown.

The roots of *Pentaclethra eetveldeana* produce nodules containing nitrogen-fixing bacteria. The base of the bole is often severely deformed by elephant feeding. The flowers produce large amounts of nectar and attract primates (e.g. chimpanzees), birds and insects. The woody pods are held erect above the canopy and open explosively when ripe. However, some monkeys are able to break through the tough wall of the pod and eat the unripe seeds.

Pentaclethra comprises 3 species, 2 in Africa and 1 in South America. The other African species, *Pentaclethra macrophylla* Benth., can be distinguished by its larger leaflets and stellate hairs.

Ecology *Pentaclethra eetveldeana* occurs in rainforest, most commonly in secondary forest, where it may be dominant. It can also be found in pockets of forest in savanna regions and in gallery forest.

Management The germination rate of seeds is generally high, but germination is often unevenly distributed. It is recommended that the seeds be planted directly into the field because the taproot of the seedlings is easily damaged in transplanting. Planted trees can be managed by coppicing.

Genetic resources and breeding As it is most common in secondary and disturbed forest, *Pentaclethra eetveldeana* is not endangered by genetic erosion.

Prospects *Pentaclethra eetveldeana* might be an interesting timber tree for sustainably managed natural forest in Central Africa because of its easy regeneration after disturbance of the forest and its fair wood properties, but its often small-sized and irregular bole is a drawback.

Major references Bolza & Keating, 1972; Latham, 2004; Latham, 2005; Villiers, 1989.

Other references Babady Bila & Herz, 1996; Gilbert & Boutique, 1952; Laine et al., 1985; Neuwinger, 2000; Raponda-Walker & Sillans, 1961; White & Abernathy, 1997.

Authors R.H.M.J. Lemmens

PENTACLETHRA MACROPHYLLA Benth.

Protologue Journ. Bot. (Hook.) 4(30): 330 (1842).

Family Mimosaceae (Leguminosae - Mimosoideae)

Chromosome number $n = 7$, $2n = 26$

Vernacular names African oil bean, Atta bean, Owala oil tree, Congo acacia, nganzi (En). Owala, mubala, arbre à semelles, acacia du Congo (Fr). Sucupira, marroné (Po).

Origin and geographic distribution *Pentaclethra macrophylla* occurs in the forest zone of West and Central Africa, from Senegal to south-eastern Sudan and to Angola and on the islands of São Tomé et Príncipe.

Uses *Pentaclethra macrophylla* is planted or retained along the edges of home gardens and farms mainly for its seed from which an edible oil can be extracted. Throughout the forest zone of West Africa the seeds are eaten boiled or roasted. They are also fermented to yield a snack or condiment with a meaty taste, very popular in south-western Nigeria where it is called 'ugba'. The empty dry pods are used as fuel for cooking. Farmers protect this species on farms because its open crown does not severely affect crop growth and because some trees are leafless during the growing season. The leaves also contribute to soil fertility. *Pentaclethra macrophylla* wood, called 'mubala' or 'ovala', is suitable as fuel wood and for charcoal making. As few trees develop a straight trunk of harvestable size, timber of larger sizes is only occasionally available. The wood is hard and difficult to work, but suitable for poles, railway sleepers and general carpentry. Traditionally, pestles and mortars have been made from it. Ash from wood or pods is used as a mordant in the dyeing industry. In DR Congo the edible caterpillars of the giant silkworm moths *Nudaurelia oyemensis* (called 'minsangula') and *Imbrasia obscura* (called 'minsendi') feed on the leaves. Bees forage the flowers for honey. *Pentaclethra macrophylla* is used in Africa in traditional human and veterinary medicine. The ripe fruits are applied externally to heal wounds. Extracts of the leaf, stembark, seed and fruit pulp have anti-inflammatory and anthelmintic activity, and are used to treat gonorrhoea and convulsions, and also used as analgesic. The root bark is used as a laxative, as an enema against dysentery and as a liniment against itch. In Cameroon an infusion of the bark is used as an abortifacient. *Pentaclethra macrophylla* is occasionally planted along roads. It plays a role in various traditional ceremonies.

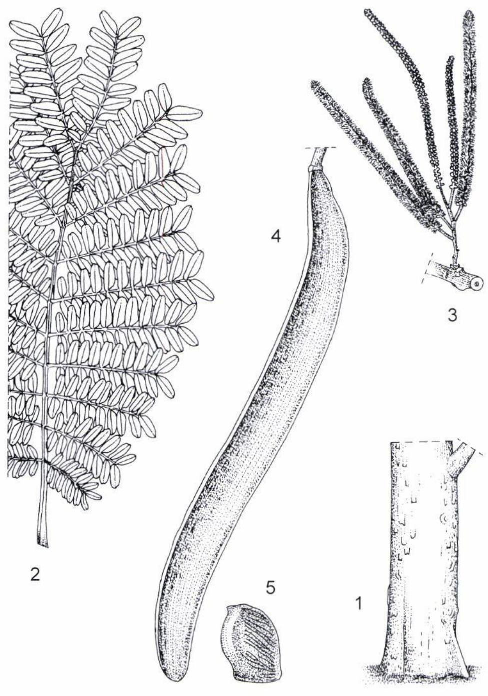
Pentaclethra macrophylla – wild

Production and international trade Most production is for home or local consumption and no information on production and trade of oil, 'ugba' or timber is available.

Properties Unfermented seed contains per 100 g: water 3–10 g, energy 2330–2540 kJ (557–607 kcal), protein 17–22 g, fat 35–52 g, carbohydrate 12–43 g, crude fibre 2.5 g. The fatty acid composition of the oil is: palmitic acid 3–4%, stearic acid 0–2%, arachidic acid 4%, behenic acid 5–6%, lignoceric acid 11–12%, oleic acid 19–29%, linoleic acid 42–54%, linolenic acid 0–3%; in addition 2 unusual long-chain fatty acids are present: hexacosanoic acid 5% and octacosanoic acid 1%. The seed con-

tains the growth-retardant alkaloid paucine (caffeoyl-putrescine). When the seed is fermented to 'ugba' it is detoxified. The fermentation causes a marked reduction in protein content, and a slight increase in carbohydrate, oil and ash contents.
The heartwood is reddish brown and not always distinctly demarcated from the whitish or grey sapwood. The grain is interlocked and texture coarse. At 12% moisture content the density is 910 kg/m³. The rates of shrinkage are high, 11–16.5% volumetric. Logs should be quarter sawn before drying. At 12% moisture content, the modulus of rupture is 130–226 N/mm², modulus of elasticity 16,000–21,150 N/mm², compression parallel to grain 75.2–83.6 N/mm², Janka side hardness 11,020 N, Chalais-Meudon side hardness 8.5–14.1. The wood is hard and strong, but difficult to work. It is susceptible to marine borers and occasionally attacked by termites. The silica content is less than 2%.

Description Medium-sized to fairly large tree up to 35 m tall; bole up to 100 cm in diameter, often crooked and low branching, with irregular, thick buttresses up to 3 m high, or without buttresses; outer bark greyish to reddish brown, thin, flaking irregularly, inner bark fibrous, yellow to orange; twigs brown stellate-hairy. Leaves alternate, bipinnately compound, 20–45 cm long; stipules needle-shaped, 3–5 mm long, caducous, with basal gland; petiole 3–6(–8) cm long, swollen and jointed at base, channeled; pinnae opposite, in 9–13 pairs, (8–)10–14 cm long, at base markedly jointed, with (6–)8–14(–20) pairs of leaflets; leaflets opposite, sessile, obliquely oblong to elliptical, 12–25 mm × 5–10 mm, apex rounded, glabrous except for scattered hairs on margins and midrib below. Inflorescence a terminal or axillary panicle up to 30 cm long, consisting of spikes, many-flowered, densely covered with brownish stellate hairs. Flowers bisexual, regular, 5-merous, small, fragrant, sessile; calyx campanulate, with broadly elliptical lobes, c. 0.5 mm long; petals oblong-lanceolate, c. 3 mm long, basally swollen and fused for c. 1 mm, yellow; stamens 5, c. 5 mm long, yellow, anthers with large gland between the thecae, staminodes 10–15, filiform; ovary superior, sessile, 1-celled, glabrous at first, upper part hairy, style extending during flowering, stigma indistinct. Fruit an obliquely linear-oblong pod up to 50 cm × 10 cm × 2 cm, woody, dark brown, tapering to the base, apex rounded, sides longitudinally ribbed, long-persistent and opening explosively on the tree and then recurving strongly, 5–8-seeded. Seeds elliptical in outline, flattened, 3.5–7 cm × 2.5–3.5 cm × c. 1 cm, smooth, purplish brown. Seedling with hypogeal germination; cotyledons remaining in the testa; hypocotyl not developing, epicotyl 8–10 cm long, with several scales; leaves alternate, first leaf bipinnate.



Pentaclethra macrophylla – 1, base of bole; 2, leaf; 3, inflorescence; 4, fruit; 5, seed.
Redrawn and adapted by Achmad Satiri Nurhaman

Other botanical information *Pentaclethra* comprises 3 species, 2 in Africa and 1 in South America. The other African species, *Pentaclethra eetveldeana* De Wild. & T.Durand, can be distinguished by its smaller leaflets and simple hairs. The American *Pentaclethra macroloba* (Willd.) O.Kuntze yields timber traded as 'gavilán' and is an important medicinal plant.

Growth and development The bole is often gnarled and twisted and forked at a low level and the base is often damaged by elephants, but trees with a longer straight trunk are occasionally found. Watershoots around the base are common and the tree coppices well. The crown has been described as heavily branched and dense, but also as open and allowing crops to grow well below the tree. Some specimens are leafless during the rainy season, though the species is mostly evergreen. *Pentaclethra macrophylla* nodulates and fixes atmospheric nitrogen. The main flowering season in West Africa is March–April, with smaller flushes in June and November; in Liberia trees flower in February–April and fruit in September–December. The flowers are strongly fragrant, very rich in nectar and much visited by honeybees.

Ecology *Pentaclethra macrophylla* is common in primary forest and secondary forest and coastal savanna, often in the vicinity of creeks and rivers. It is most common at altitudes up to 500 m, although growth can be good at higher elevations where rainfall is adequate and temperatures are never cooler than 18°C. It requires a mean annual rainfall of (1000–)1500–2000(–2700) mm and a mean annual temperature of about 25°C. It prefers medium loamy, well-drained soil. The natural distribution suggests that it is adapted to relatively acid soils. It tolerates waterlogging.

Propagation and planting The seed is recalcitrant and should be planted immediately. Storage at 15°C can extend longevity to about 3 months. There are 50–80 seeds per kg. Mechanical scarification and soaking in water for 24 hours enhances germination. *Pentaclethra macrophylla* can also be propagated by cuttings, air-layering or budding. Only juvenile stem cuttings will root and are best treated with a growth hormone. Cuttings may produce seed after 4 years, budded trees after 3 years. Although direct sowing is common, better planting material is obtained from seedlings produced in nurseries and hardened off before planting.

Management Trees of *Pentaclethra macrophylla* are commonly protected and often tended in farm land, e.g. in DR Congo where it is grown on farms and on abandoned farm land to improve bush fallow. An area around the stem may be clean-weeded to facilitate collection of the seeds.

Diseases and pests No serious diseases or pests of *Pentaclethra macrophylla* are known, but many insect species and pathogens attack the pods and seeds. The major insect pests are *Cossus cadambae*, *Sitophilus* spp., *Spodoptera exempta* and several giant silkworms. Some of the insect pests skeletonize the green pods, some bore into the pods and seeds; others lacerate the pods, causing lesions that allow fungal and bacterial pathogens to invade the seeds.

Harvesting Fruits are available at most periods of the year because the large woody pods are persistent. Harvesting pods is an arduous and dangerous task and collectors may charge as much as half of the yield as their fee.

Handling after harvest The seeds of *Pentaclethra macrophylla* are roasted or boiled, or fermented to produce 'ugba'. The seeds are boiled for 3–12 hours; then the seedcoat is removed. When the cotyledons are cooled to room temperature they are sliced into small pieces of 4–5 cm × 1–2 mm and washed with water. The slices are boiled for 1–2 hours, cooled and soaked in water for 10 hours. Then the slices are drained in a basket lined with banana leaves. The drained slices are wrapped in blanched leaves of banana or *Mallotus oppositifolius* (Geiseler) Müll.Arg. and incubated at ambient temperature for 4–6 days when prepared for use as a snack or sidedish, or for 7–10 days when prepared as a condiment for soups. The fermentation is proteolytic and proceeds under alkaline conditions. It is caused mainly by *Bacillus subtilis*, but other *Bacillus* spp. are also involved, while other bacteria may be present as contaminants.

Genetic resources Although not immediately endangered by genetic erosion, numbers of *Pentaclethra macrophylla* have declined strongly in some areas. In Nigeria stands are now largely confined to the south-eastern region and even there regeneration rates seem inadequate. No collections of genetic resources exist. However, the National Centre for Genetic Resources and Biotechnology and the Forestry Research Institute of Nigeria have initiated the study, collection and conservation of edible plant resources, including *Pentaclethra macrophylla*.

Prospects The domestication of *Pentaclethra macrophylla* as a tree crop in agroforestry has been recommended. Selection of trees with non-shattering pods or with pods that shatter simultaneously and the development of pruning methods that make harvesting easier are desirable.

Major references Akindahunsi, 2004; Aubréville, 1959a; Banks & Schoeman, 1963; Isu & Ofuya, 2000; Jones, Robinson & Southwell, 1987; Keay, 1989; Ladipo & Boland, 1995; Latham, 2004; Oboh & Ekperigin, 2004; Voorhoeve, 1965.

Other references Afkah, Aguwa & Agu, 1999; Akubor & Chukwu, 1999; Emebiri & Anyim, 1997; Emebiri, Nwufo & Obiefuna, 1995; Enujiugha, 2003; Enujiugha & Akanbi, 2005; Folefoc et al., 2005; Hilditch, Meara & Patel, 1951; Isu & Njoku, 1997; Ladipo, Kang & Swift, 1993; Okwulehie, 2004; Okafor, 1991; Okwulehie, 2004; Onyeike & Acheru, 2002; Oxford Forestry Institute, 1997–2004; Takahashi, 1978; Udosen & Ifon, 1990.

Sources of illustration Villiers, 1989; Wilks & Issembé, 2000.

Authors G. Oboh

PENTADESMA BUTYRACEA Sabine

Protologue Trans. Hort. Soc. London 5: 457 (1824).

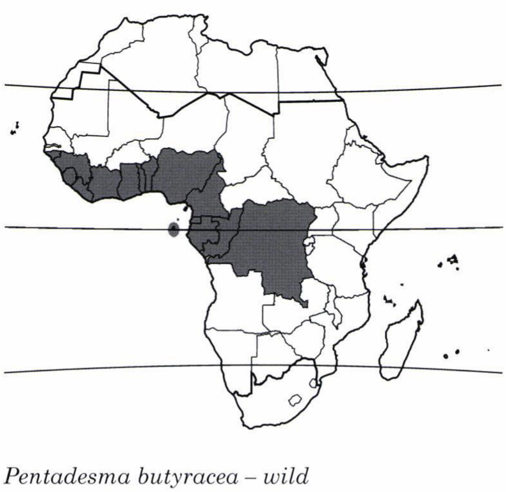
Family Clusiaceae (Guttiferae)

Chromosome number $2n = 56$

Vernacular names Kanya, butter tree, tallow tree (En). Lami, arbre à beurre, arbre à suif, arbre à chandelle (Fr). Pau ová, mata passo, mamão (Po).

Origin and geographic distribution *Pentadesma butyracea* occurs naturally from Guinea Bissau to Cameroon and westernmost DR Congo. It occurs in the Seychelles as an escape from an early introduction.

Uses A vegetable fat named 'kanya butter' or 'vegetable tallow' is extracted from the seed. Kanya butter is used as a cooking fat and has been marketed as margarine. It is used as a substitute for shea butter from *Vitellaria paradoxa* C.F.Gaertn. when the latter is rare or cannot be used traditionally, e.g. during treatment of leprosy or epilepsy. Peul women, who are not permitted to use shea butter when they have given birth, may also use kanya butter as a substitute. Fresh seeds are used as a substitute for kola nuts from *Cola* spp.



Pentadesma butyracea – wild

Kanya butter is a suitable base for topical medicines. Its application relieves chest-pain, cough in children, strain and abscesses. It is used as a cosmetic for hair and skin. Mixed with other oils it is a base material for soap making, and suitable for illumination.

The presscake is unsuitable for livestock because it is rich in antinutritional compounds. In certain regions, the oily presscake is applied externally to animals (e.g. sheep) to treat galls and is also used to plaster walls of houses (e.g. Tata Somba houses in north-western Benin).

The sweet, yellow pulp of ripe fruits is edible, but unripe fruits are bitter. The leaves serve as a galactagogue vegetable. They are believed to make the milk easily digestible and help in teething. An infusion of ground roots is used to wash children during weaning, while infusions of the bark are put in a bath to relieve fever. A decoction from the roots is used as vermifuge in Liberia. The latex from the bark is applied to the skin against skin parasites. The wood is used as general purpose timber and as fuel. In Guinea it is used to make masts and oars for small boats. It is also suitable for heavy construction, heavy flooring, railway sleepers, ship and boat building, vehicle bodies, boxes and crates, veneer and plywood, interior trim, furniture and cabinet work, joinery and turnery, sporting goods, implements and toys. Roots and possibly young twigs are used as a toothbrush. The seeds are used as bait for porcupines and palm rats.

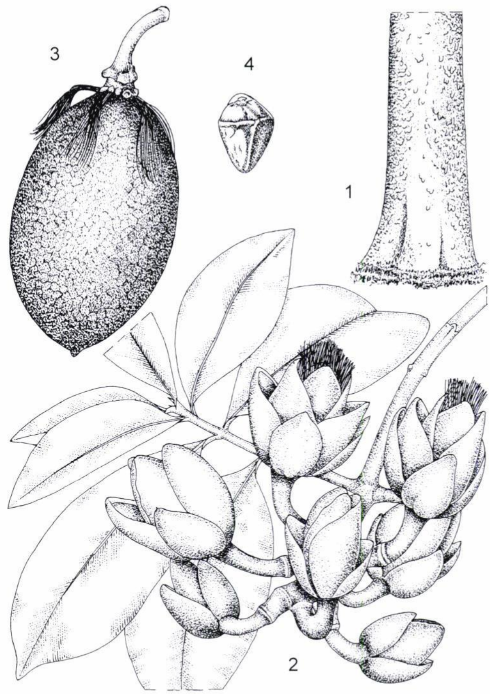
Properties The kernel of the seed contains per 100 g dry matter 50 g fat and 1.5–1.8 g unsaponifiable matter. It also contains an odourless and tasteless resin, that is yellowish in colour and toxic. The fatty acid composition of kanya butter is palmitic acid 3–8%, stearic acid 41–46%, palmitoleic acid 0.2%, oleic acid 48–51%, linoleic acid 0–2%. Kanya butter is similar to shea butter in several characteristics, including slip point, saponification number, solidification point and fatty acid composition.

The heartwood of *Pentadesma butyracea* is yellowish or pinkish brown, distinctly demarcated from the whitish to pale pink sapwood, which is fairly wide. The grain is straight to slightly wavy, texture coarse. The wood is heavy, with a density of 850–1000 kg/m³ at 12% moisture content, hard and strong. It air dries slowly with little splitting, but cupping may occur. The rates of shrinkage are moderately high, from green to oven dry 4.5–4.7% radial and 8.0–8.7% tangential. At 12% mois-

ture content, the modulus of rupture is 140–270 N/mm², modulus of elasticity 6900–19,300 N/mm², compression parallel to grain 56–101 N/mm², cleavage 17–19 N/mm, Janka side hardness 8000 N, Chalais-Meudon side hardness 5.0–12.6.
The wood saws satisfactorily, but may cause gumming of saw blades and overheating. It planes, polishes and moulds well and bores satisfactorily, although heating may occur; the wood holds nails well, but splitting on nailing is rather common. It is not durable, being susceptible to attack by pinhole borers and marine borers, but fairly resistant to termites. The heartwood is very resistant to impregnation with preservatives, the sapwood moderately permeable.

Adulterations and substitutes Shea butter from *Vitellaria paradoxa* is often preferred to kanya butter and has similar properties and uses. However, kanya butter is sometimes preferred to shea butter because of its better odour.

Description Evergreen, medium-sized to fairly large tree up to 35 m tall; bole cylindrical, up to 100–150 cm in diameter, sometimes with small buttresses or stilt roots; bark rough and scaly, inner bark red-brown to brown, finely fissured, exuding bright yellow sap; twigs angular or ribbed, dark brown to black. Leaves opposite, in dense terminal clusters, simple and entire; stipules absent; petiole up to 2.5 cm long, stout; blade obovate to oblong-oblanceolate, 9–25 cm × 3.5–7 cm, base cuneate, apex shortly acuminate, leathery, glabrous, shiny dark green above, pinnately veined with numerous, parallel lateral veins, ending in marginal vein, with glandular canals parallel to veins. Inflorescence a terminal thyrse, 1–7-flowered. Flowers bisexual, regular, 5-merous, yellowish or greenish white; pedicel 1–4 cm long, often curved; sepals free, ovate, up to 5 cm long, very unequal, leathery; petals free, oblong to ovate, up to 6 cm long, keeled; stamens numerous, in 5 bundles opposite the petals, 4–6.5 cm long, fused at base; disk glands 5, alternating with petals, up to 0.5 cm high; ovary superior, ovoid-ellipsoid, 1–2 cm long, 5-celled, style elongate, ending in 5 linear spreading lobes up to 0.5 cm long. Fruit an ellipsoid to ovoid berry, 9–15 cm × 6.5–12.5 cm, base with persistent calyx, stamens and disk glands, apex pointed, wall coarse, brown, leathery, 5–15-seeded. Seeds pyramidal, with flattened sides or irregular, 3–4 cm × 2.5–3 cm, dark brown. Seedling with hypogeal germination; epicotyl reddish, 10–30 cm long; first leaves opposite, 7–16 cm × 2.5–4.5 cm.



Pentadesma butyracea – 1, base of bole; 2, flowering branch; 3, fruit; 4, seed.
Redrawn and adapted by Achmad Satiri Nurhaman

Other botanical information *Pentadesma* comprises about 5 species, all in tropical Africa. Although all *Pentadesma* species yield edible fat, there is only information on the use of *Pentadesma butyracea*.

Growth and development Trees first flower when about 8 m tall. Flowering occurs during a large part of the year, but mainly during the main rainy season. In Gabon trees flower from March to September. The flowers produce large amounts of nectar, which is eaten by monkeys; they are probably important pollinators. In Gabon fruits are produced mainly from October to December, and in Benin from March to June. They are eaten by elephants and monkeys, which disperse the seeds.

Ecology *Pentadesma butyracea* occurs in tropical rainforest on moist or swampy ground, mostly on river banks. It does not occur where mean annual rainfall is less than 1000 mm. It prefers deep soils. In Ghana it is strongly associated with leached soils. In Benin it occurs naturally in riparian forest.

Propagation and planting *Pentadesma butyracea* is propagated by seed. Freshly harvested, mature and healthy seeds germinate well, but seeds are very sensitive to desiccation and fermentation. When stored in a dry place at 25–36°C they lose their viability quickly; at 10–15°C they keep their viability longer, but it is difficult to break dormancy. The best results are obtained when seeds are stored in jute bags and are watered regularly. Under natural conditions trees may also regenerate by root suckers.

Harvesting In Benin fruits are usually gathered in April–June, mostly by women. After collection, they are put together under a tree and covered to accelerate fermentation of the fruit pulp and to facilitate seed extraction. It has been estimated that a woman may collect 15–40 kg of seeds per season.

Yield In Côte d'Ivoire a mature tree is estimated to produce about 500 fruits, weighing about 600 g and containing about 120 g seed, or a total of about 60 kg seed per year.

Handling after harvest In rural areas, fruits are processed by water extraction, usually the job of women. Gathered fruits are put together under a tree and covered. After 10 days the fruit pulp has decayed and the seeds can be extracted easily. Seeds are boiled and then dried in the sun or a kiln to prevent further rotting. Dry seeds are pounded until they are clean and are turned over daily to prevent mouldiness. To extract the oil, seeds are crushed and ground into a paste. The paste is boiled in water and the oil is skimmed off. The oil yield rarely exceeds 35% of the seed dry weight.

Genetic resources *Pentadesma butyracea* is widespread, regenerates well and does not seem to be in danger of genetic erosion.

Prospects *Pentadesma butyracea* is a multipurpose tree that is important for income generation of rural households. Harvesting its fruits and extraction of the butter are profitable activities. The best opportunities for marketing may be for cosmetics and pharmaceuticals as an alternative for shea butter. Its domestication as a reforestation or agroforestry species deserves attention.

Major references Adomako, 1977; Aubréville, 1959b; Houngbédji, 1997; Natta et al., 2003; Ouattara, 1999; Schreckenberg, 1996; Sinadouwirou, 2000; Sinsin & Sinadouwirou, 2003; van Meer, 1965.

Other references Athar & Nasir, 2005; Avocèvou C., 2005; Bamps, 1966; Bolza & Keating, 1972; Falconer & Arnold, 1996; Keay, 1954a; Kershaw, 1982; Kryn & Fobes, 1959; Spirlet, 1959; Takahashi, 1978; Tuani, Cobbinah & Agbodazé, 1994; Voorhoeve, 1979; White & Abernethy, 1997; Wilks & Issembé, 2000.

Sources of illustration Keay, 1954a; van Meer, 1965; Wilks & Issembé, 2000.

Authors B. Sinsin & C. Avocèvou

PYCNANTHUS ANGOLENSIS (Welw.) Warb.

Protologue Notizbl. Königl. Bot. Gart. Berlin 1: 100 (1895).

Family Myristicaceae

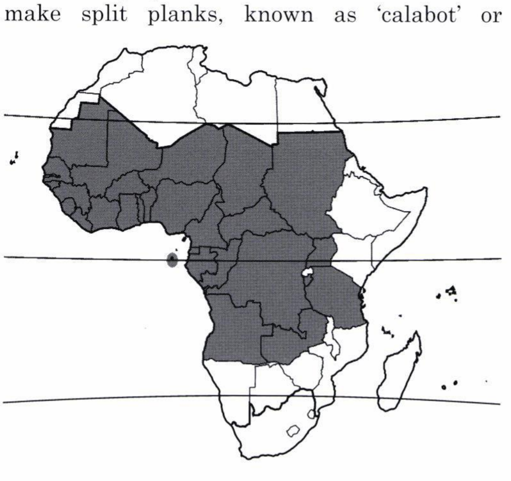
Chromosome number $2n = 38$

Synonyms *Pycnanthus kombo* (Baill.) Warb. (1897).

Vernacular names African nutmeg, boxboard (En). Ilomba, faux muscadier, arbre à suif (Fr). Menebantamo (Po). Mkungu mwitu (Sw).

Origin and geographic distribution *Pycnanthus angolensis* is found in the forest zone of tropical Africa, from Senegal and Guinea to Angola, and through DR Congo to Uganda, Tanzania and Zambia.

Uses A yellow to reddish brown fat, called 'kombo butter' or 'Angola tallow', is extracted from the seed and is important in West and Central Africa for illumination and in soap making. It is not edible. The seeds somewhat resemble those of nutmeg (*Myristica fragrans* Houtt.) and are burnt as candles. In Central Africa they are used as spice. Traditionally the wood is highly valued as fuel and is used to make split planks, known as 'calabot' or



Pycnanthus angolensis – wild

'caraboard' in the coastal zone of Cameroon. Because it is easy to work, it is used to make shingles both for roofing and covering the sides of native houses, and planks for doors and window frames. The long straight bole makes it suitable for making canoes. Since the Second World War the wood has become an important timber for plywood corestock, veneer, mouldings, interior trim, interior joinery, furniture components and paper pulp. In agroforestry *Pycnanthus angolensis* is planted or retained for shade in coffee and cocoa plantations in the humid lowlands of Cameroon, in Uganda often also in banana plantations. Farmers in Cameroon consider it a good indicator of soil fertility. In Uganda it has been planted as an amenity tree.

Throughout its area of distribution, various preparations of the bark, and to a lesser extent other parts of the tree, are used medicinally to treat skin infections, especially of the mouth. Preparations made from the bark are used as a potent purgative, to cleanse the milk of lactating mothers and to treat coughs and chest complaints. In Ghana a decoction of the bark is taken to treat anaemia, in Côte d'Ivoire as a poison antidote and against ascites and leprosy. In Congo the bark is used to treat a number of gynaecological problems, from infertility to gonorrhoea. In Côte d'Ivoire a root macerate mixed with parts of other plants is taken by draught to treat schistosomiasis. In São Tomé the bark is used to treat malaria.

Production and international trade No information is available on the trade in kombo butter. Trade in the timber 'ilomba' began after the Second World War due to an increased demand for plywood and improvements in wood conservation techniques and also as a substitute for okoumé (*Aucoumea klaineana* Pierre). Trade in ilomba increased spectacularly between 1946 and 1959 from 100 to 5600 boles. Gabon and Cameroon became the first major exporters in 1952/1953, followed by Côte d'Ivoire in 1954 and Congo in 1955. For several years, ilomba was among the most valued timbers in Central Africa. Between 1950 and 1960, the quantity of wood exported from Gabon was 3000 m^3, from Cameroon 278,000 m^3. Cameroon has enforced a ban on exports of ilomba logs since 1999. Exports of ilomba have fallen drastically. In 2003 the combined exports of veneer, sawnwood and plywood from Cameroon amounted to 72 m^3, from Gabon to 816 m^3. Exports from the Congo basin dropped to 0.06% of total timber exports or about 3000 m^3 in 2003. In 2001 11,000 m^3 of ilomba veneer were exported from Côte d'Ivoire at an average price of US$ 240/m^3, and 5000 m^3 from Ghana at an average price of US$ 351/m^3. The export of plywood from Côte d'Ivoire in 2001 amounted to 3000 m^3 at an average price of US$ 329/m^3, and from Ghana in 2002 to 1000 m^3 at an average price of US$ 456/m^3.

Properties The seeds of *Pycnanthus angolensis* are aromatic, but information on volatile constituents is not available. The seeds yield 45–70% of a yellow to reddish brown solid fat known as 'kombo butter', which tastes bitter and is suitable for making soap and candles, while the residue is used for manure as it is unsuitable as cattle feed. The melting point of the fat is 51°C. The fatty acid composition of kombo butter is lauric acid 5.5%, myristic acid 61.5%, palmitic acid 3.6%, myristoleic acid 23.6%, oleic acid 5.7%. Crude kombo butter contains about 20% kombic acid (a dihydroxymethylphenyl derivative of hexadecatetraenoic acid) and sargaquinoic acid (a quinone derivative) and several of their derivatives. These terpenoid quinonic acids have promising antioxidant properties for pharmacology, cosmetics and the stabilization of plastics. They have also shown hypoglycaemic activity in diabetes patients.

The bark contains dihydroguaiaretic acid, which has shown non-selective toxicity towards several human tumour cell lines. Extracts of the bark also showed the presence of flavonoids (2'-hydroxy-formononetin), tannins and saponin glycosides, which might be responsible for its biological activities. Terpenoid quinones that have shown hypoglycaemic activity in both insulin-dependent and insulin-independent diabetes have been extracted from the bole and leaves.

The heartwood is whitish to pinkish brown, sometimes with yellowish markings and indistinctly demarcted from the sapwood. The grain is generally straight, the texture medium to coarse. The wood has no lustre and when freshly sawn it has an unpleasant odour which disappears on drying.

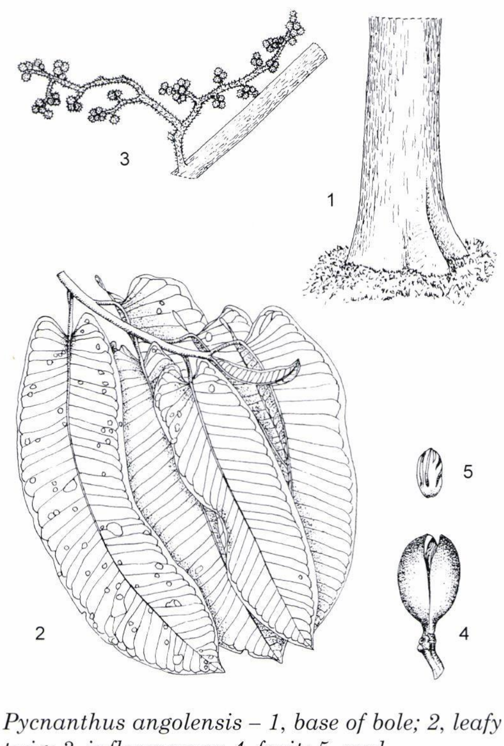
At 12% moisture the density is 440–570 kg/m^3. The wood is rather difficult to dry, it is prone to collapse, end splitting and distortion. Good ventilation is required for air drying. Kiln drying can give good results if done carefully. Shrinkage rates from green to oven dry are 4.6% radial and 8.4% tangential. Drying of beams more than 55 mm thick is very difficult and steaming for 2 days is recommended. At

12% moisture content, the modulus of rupture is 62–72 N/mm², modulus of elasticity 8300–12000 N/mm², compression parallel to grain 38–39.5 N/mm², shear 5.4–8.9 N/mm², cleavage 13–24 N/mm, Janka side hardness 2700–3400 N.

The wood is easy to saw and plane with normal tools; blunting effects are moderate. It is difficult to polish. Nailing and screwing are easy and holding properties are good. The wood may stain in contact with tools. It peels and slices well to produce good-quality veneer and plywood, although steaming is recommended because of the occasional presence of numerous small hard spots. It glues well with all types of glue. It paints well but is rather absorbent.

The wood is not durable and liable to attack by termites, powder-post beetles, pinhole borers and marine borers, but it is permeable to preservatives.

Description Evergreen, monoecious or dioecious, medium-sized to large tree up to 25–35(–40) m tall; bole usually straight and cylindrical, branchless for up to 15(–25) m high, up to 120(–150) cm in diameter, usually without buttresses; outer bark greyish brown, with orange-brown exudate; crown small, with branches at right angles to the bole; twigs slender, pendulous, densely rusty hairy. Leaves distichously alternate, simple and entire, without stipules; petiole 1–2 cm long; blade oblong to oblong-lanceolate, 7.5–30(–40) cm × 4.5–11(–16) cm, base cordate, apex acuminate, dark green above, glaucous below, young leaves velvety reddish brown hairy, but glabrescent, pinnately veined with 20–40 pairs of lateral veins. Inflorescence an axillary panicle, often on leafless branches, 10–30 cm long, rusty hairy, with flowers in numerous head-shaped clusters. Flowers unisexual, regular, very small, sessile, with 3-lobed perianth covered with dark brown hairs; male flowers with 2–4 stamens, filaments merged into a column; female flowers with superior, sessile, 1-celled ovary, stigmas 2, sessile. Fruit an ellipsoid to oblong or globose drupe, 3–4.5 cm × 2–4 cm, in bunches, yellowish orange when ripe, fruit wall rather hard and tough, 2–10 mm thick, splitting longitudinally with 2 valves, 1-seeded. Seed ellipsoid, aromatic, 1.5–3 cm × 1–1.5 cm, dark brown, with pink to red aril, laciniate almost to the base. Seedling with epigeal germination, but cotyledons remaining in the testa.



Pycnanthus angolensis – 1, base of bole; 2, leafy twig; 3, inflorescence; 4, fruit; 5, seed.
Redrawn and adapted by Iskak Syamsudin

Other botanical information *Pycnanthus* comprises 3–4 species, all in Africa. *Pycnanthus angolensis* is variable, especially in the hairiness of the leaves, the size and shape of the fruits, and reportedly also in the quality of the timber. Two subspecies have been distinguished: subsp. *angolensis* and subsp. *schweinfurthii* (Warb.) Verdc., the latter occurring DR Congo and East Africa, but possibly also more to the west, and differing from subsp. *angolensis* in having larger, often more globose fruits with thicker fruit wall. The wood of *Cephalosphaera usambarensis* (Warb.) Warb. and several American *Virola* species closely resembles that of *Pycnanthus angolensis*. *Cephalosphaera usambarensis* is restricted to eastern parts of Kenya and Tanzania, where its timber is occasionally used.

Growth and development Seeds of *Pycnanthus angolensis* are recalcitrant. The duration of germination is 16–36 days. The cotyledons are pulpy and the first two leaves which appear after two months are simple, opposite or alternate, later leaves alternate. A deep secondary root system develops during the first seven months of growth. In natural stands numerous seedlings appear around the mother tree. In the first year the stem height reaches 20–30 cm and it can reach 50 cm in the second year. In Sierra Leone a mean annual increment in diameter of 1.6–2.4 cm has been observed. Because of the long straight trunk, the volume/trunk ratio is higher than in most other African forest tree species. *Pycnanthus angolensis* is evergreen, and at any latitude in its range leaf fall and flushing occur simultaneously. The flowering period is long and depends on the location. In Cameroon it flowers in October–May with male and female flowers at separate parts of the same tree, generally also at different times, while it fruits in September–April. Dehiscence takes place on the tree or the whole infructescence falls before dehiscence.

Ecology *Pycnanthus angolensis* occurs in upland and wet evergreen forest and semi-deciduous forest with more than 1600 mm rainfall. It is especially abundant in old fallows and secondary forest as its rate of natural recruitment after disturbance of the forest is high. In southern Africa it occurs in riverine and swamp forest, but in West Africa it does not occur in swamps. In Uganda it also occurs in gallery forest. It is mostly found in small groups or solitary and it regenerates in small to medium-sized gaps in the forest. Its abundance increases with rainfall, the optimum being about 2000 mm/year; above 2600 mm/year numbers decline strongly. It occasionally occurs where rainfall is only 1300 mm or less with 4–5 dry months. Seedlings are very sensitive to drought. *Pycnanthus angolensis* is a light-demanding tree typical of the dominant forest strata, although it can tolerate slight shade when young. It occurs up to 1200(–1400) m altitude. *Pycnanthus angolensis* tolerates light and heavy soils, but is scarce on sandy soils, while other reports indicate that it is often found on poor soils.

Propagation and planting *Pycnanthus angolensis* is propagated by seed. There are about 500 seeds per kg. Young broken or cut trees resprout easily, but in a trial vegetative propagation by stem cuttings failed to succeed. Seeds should not be dried, but sown as soon as possible because of their short viability. Germination is easy and with proper care the germination rate of fresh seed can reach 100%. Soaking in cold water for 24 hours hastens germination. In the case of unsorted seeds, the germination rate is about 50%. Seeds can be planted directly in the field or in an open field nursery preferably in polythene bags. It is important to protect the seeds from rodents. A mixture of sand and arable soil (50/50) is a suitable germination substrate. The seedling rapidly grows a large taproot, whose development should be checked timely in the nursery. Cutting the taproot when it is large greatly reduces the plant's growth rate. It is advisable to transplant seedlings after 1–2 years when 30–50 cm tall, at the beginning of the rainy season. A slight mulching is recommended. In the humid lowlands of Cameroon farmers used to retain or transplant seedlings from the wild when clearing new fields. To improve growth, compost or chemical fertilizer may be applied. In direct sowing in the field, the recommendation is to plant 3–5 seeds per hole and thin to a single plant after germination. Field spacing has been 4 m × 5 m, but recent recommendations are 9 m × 10 m (110 trees/ha).

Management Protection and retention of natural *Pycnanthus angolensis* trees has long been done by farmers in the humid lowland forest of West and Central Africa. In plantations the initial thinning should be done when trees are about 7 years old to reduce the density to 300–350 trees/ha; when trees approach the age of 12 years a second thinning should reduce the density to 150–200 trees/ha.

Diseases and pests Although its leaves are often marred by small holes, no important diseases or pests have been detected in *Pycnanthus angolensis* in either the natural state or plantations and from a phytosanitary point of view, silviculture of the species is very easy. Nevertheless, some sporadic insect (*Monochamus scabiosus*, *Mallodon downesi*, *Bryochaeta interrupta*) and fungi (*Ophiostoma* sp., *Microthyriella* sp.) attacks have been reported in Côte d'Ivoire, Cameroon and Gabon.

Harvesting In good plantations in the evergreen forest zone the exploitable diameter of 50 cm is reached when trees are 30 years old, and a diameter of 60 cm at 45 years.

Yield Little information on seed yield is available; an average tree may produce 60–100 seeds annually. In well growing plantations the annual increment at 15 years of age is 15 m^3/ha/year, at 30 years it can be 10 m^3/ha/year.

Handling after harvest Logs should be treated with preservatives and be converted soon after felling to avoid discoloration by fungi and damage by insects. Logs can be floated and be transported by river.

Genetic resources Because of its wide distribution and occurrence in secondary forest, there is little risk of genetic erosion. No genetic conservation programme is known to exist.

Breeding *Pycnanthus angolensis* is one of the most important agroforestry tree species of the humid lowland forest of West and Central Africa identified by the World Agroforestry Centre (ICRAF) for a domestication programme.

Prospects *Pycnanthus angolensis* is an important medicinal plant in the humid forest region. It is traditionally protected by farmers during forest clearing. Large amounts of timber have been exported, but recently volumes have dropped markedly. The export of the wood as veneer and plywood has been most important in recent years. New opportunities for exploiting the oil and medicinal properties should be investigated. However, as a fairly fast-growing species that is not very liable to diseases and pests, *Pycnanthus angolensis* seems to have good prospects for timber plantations and for sustainably managed natural production forest.

Major references Borie, 2000; CTFT, 1975; Duguma, Tonye & Depommier, 1990; Katende, Birnie & Tengnäs, 1995; Mapongmetsem et al., 1995; Mapongmetsem et al., 1999; Mapongmetsem, Nkongmeneck & Duguma, 2002; Normand & Paquis, 1976; Richter & Dallwitz, 2000; Verdcourt, 1997.

Other references Adjanohoun et al., 1996; Adjanohoun et al., 1991; ATIBT, 2004; Berhaut, 1979; CTFT, 1961; Dalziel, 1937; Dounias, 1995; Forest Product Laboratory, 1999; Irvine, 1961; Laird, 1999; Letouzey, 1955; Luo et al., 1999; Mapongmetsem et al., 1999a; Miquel, 1985; Pérez et al., 2005; Pope, 1997; Raponda-Walker & Sillans, 1961; Simon et al., 2005; Taylor, 1960; Vabi & Mala'a, 1995; World Agroforestry Centre, undated.

Sources of illustration Verdcourt, 1997; Voorhoeve, 1965; Wilks & Issembé, 2000.

Authors P.-M. Mapongmetsem

RICINODENDRON HEUDELOTII (Baill.) Pierre ex Heckel

Protologue Ann. Inst. Bot.-Géol. Colon. Marseille 5(2): 40 (1898).

Family Euphorbiaceae

Chromosome number $2n = 22$

Synonyms *Ricinodendron africanum* Müll.Arg. (1864).

Vernacular names Groundnut tree, corkwood tree, African oil-nut tree (En). Essang, essessang (Fr). Menguela, munguella (Po). Muawa (Sw).

Origin and geographic distribution *Ricinodendron heudelotii* occurs from southern

Ricinodendron heudelotii – wild

Senegal eastwards to Kenya, and southwards to Angola and Mozambique.

Uses The seeds of *Ricinodendron heudelotii* are widely used in cooking in West and Central Africa. An edible oil is extracted from the seeds and a paste made by crushing dried kernels is sometimes used as a thickening agent for soups and stews. A paste from the dried and pounded kernels is also stored for making porridge in times of food shortage. The protein-rich leaves are eaten as a cooked vegetable with dried fish and are used as forage for goats and sheep.

The wood, called 'erimado' or 'essessang' in trade, is very light, soft and perishable, but is occasionally used in carving and for making household utensils, furniture, boxes and crates. In Uganda the Semliki and Unyoro people use it for making doors for their huts, while in southern Nigeria and DR Congo well-sounding drums are carved from it. It is a potential substitute for balsa wood (*Ochroma pyramydale* (Cav. ex Lam.) Urb.) for making floats and lifebelts. The wood is also suitable for boat building, sporting goods, toys and novelties, hardboard, particle board, plywood, wood-wool and wood-pulp. The ash of the wood is used as vegetable salt in cooking, indigo dyeing and soap making. The seeds are used in rattles and as counters in games. In Bas Congo (DR Congo) the tree is planted to attract edible caterpillars (*Imbrasia epimethea*), and several other edible caterpillars are collected from it. The leaves are used as wrapping material and for mulching. In DR Congo *Ricinodendron heudelotii* is planted as amenity tree, as live fence and for erosion control.

Many parts of the tree are used in medicine.

Bark of the root and stem is used in decoctions or lotions to treat constipation, cough, dysentery, rheumatism, rickets in children, oedema, elephantiasis, fungal infection, blennorrhoea, painful menstruation, and to prevent miscarriage, relieve pain in pregnant women, cure infertility in women, give strength to premature babies, and to mature abscesses, furuncles and buboes. The sap is instilled into the eye against filaria and ophthalmia and leaf decoctions are used as febrifuge. Leaves are also used to treat dysentery, female sterility, oedema and stomach pain. Roots are used as aphrodisiac in Côte d'Ivoire. Fruits and latex are used in West Africa to cure gonorrhoea and diarrhoea.

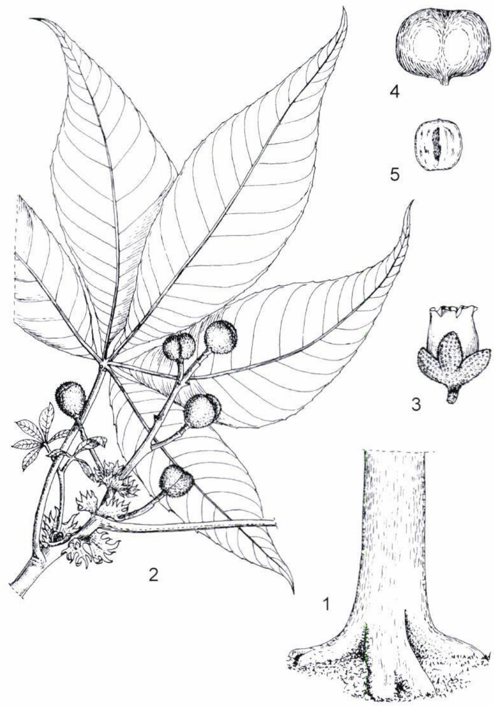
Production and international trade Kernels of *Ricinodendron heudelotii* are traded internationally and are found in many markets in West and Central Africa; they are exported to Europe from Cameroon as 'ndjanssang'. The humid forest zone of Cameroon appears to be the main production area. In 1995, 36,000 kg of seeds were marketed in this zone, for a total value of about US$ 79,000.

Properties The dried seeds of *Ricinodendron heudelotii* contain on average per 100 g: water 6 g, energy 2200 kJ (530 kcal), protein 21 g, fat 43 g, carbohydrate 23 g, Ca 611 mg, P 926 mg, Fe 0.4 mg, thiamin 10 μg, riboflavin and niacin traces (Leung, Busson & Jardin, 1968). Some sources give a fat content of up to 60%. The fat is pale yellow and liquid but somewhat viscous at ambient temperatures. Its fatty acid composition is: palmitic acid 6–10%, stearic acid 6–7%, oleic acid 7–9%, linoleic acid 28–36%, α-eleostearic acid 30–51%. The fat also contains small amounts of β-eleostearic acid, catalpic acid, gadoleic acid and lignoceric acid. When exposed to air in a thin layer it dries to a frosted film; when the oil is heated first to 280°C it dries to a hard clear film.

The heartwood is whitish to pale yellow, and is not differentiated from the sapwood. The wood darkens on exposure to light. The grain is straight, texture coarse and even. The wood is light-weight with a density of 130–300 kg/m^3, soft and brittle. It dries rapidly and with little or no degrade. The shrinkage rates are low: from green to oven dry 1.9–2.4% radial and 4.7–5.4% tangential. At 12% moisture content, the modulus of rupture is 29–46 N/mm^2, modulus of elasticity 3700–4800 N/mm^2, compression parallel to grain 14–21 N/mm^2, shear 2.2–3.2 N/mm^2, cleavage 5.0–7.3 N/mm (tangential) and Chalais-Meudon side hardness 0.2–0.6.

The wood saws and works easily, and nails without splitting, but turning and planing are difficult. The wood is liable to decay and attack by termites, powder-post beetles and marine borers. The wood is permeable to preservatives.

Description Deciduous, dioecious, medium-sized tree up to 30(–45) m tall; bole straight and cylindrical, up to 120(–150) cm in diameter, base with short, thick buttresses often extending into heavy superficial roots; outer bark smooth at first, becoming rough and fissured, grey; inner bark pink to red, densely mottled and granular; crown candelabra-shaped, commonly with many broken branches; twigs with few lenticels, densely brown stellate hairy but soon glabrescent, with thick pith. Leaves alternate, palmately compound with (3–)5–7(–8) leaflets; stipules fan-shaped, 1–5 cm × 1.5–4 cm, with gland-tipped teeth, persistent; petiole up to 5–30(–40) cm long; leaflets obovate to elliptical-lanceolate, median leaflet 10–30 cm × 5–15 cm, lateral ones smaller, base cuneate, apex long-acuminate, margin almost entire to shallowly glandular-toothed, thinly papery, glabrous



Ricinodendron heudelotii – 1, base of bole; 2, part of branch with young fruits; 3, male flower; 4, fruit; 5, seed.
Redrawn and adapted by Iskak Syamsudin

above, glabrous to densely stellate hairy below. Inflorescence a terminal panicle, densely stellate hairy but glabrescent; bracts awl-shaped to linear, 3–7 mm long; male inflorescence up to 40 cm long; female one up to 20 cm long. Flowers unisexual, regular, (4–)5-merous, pedicellate; sepals fused at base, c. 4 mm long, densely stellate hairy; petals laterally coherent, oblong, c. 6 mm long, greenish white to pale yellow; disk lobes yellowish; male flowers with 6–14 stamens c. 6 mm long; female flowers with superior, globose ovary, 2–3-celled, stellate hairy, styles 2–3, bifid. Fruit a 2–3-lobed drupe 2.5–3.5 cm × 4–5 cm, green when young, black when ripe, each lobe containing one 1-seeded stone. Seeds globose, c. 1.5 cm in diameter, reddish brown to black. Seedling with epigeal germination; hypocotyl up to 20 cm long, epicotyl short; cotyledons with petiole 1.5–2.5 cm long, blade leafy, 6–7 cm × 5–6 cm, glandular at margins, palmately veined; first leaf 3-lobed.

Other botanical information *Ricinodendron* comprises a single species. It is closely related to *Schinziophyton*. In *Ricinodendron heudelotii* 2 subspecies are recognized: subsp. *heudelotii* occurring from Senegal to Benin, and subsp. *africanum* (Müll.Arg.) J.Léonard from Nigeria eastwards and southwards. The former has mostly 3-lobed fruits, in the latter 2-lobed fruits are more common.

Growth and development The roots of *Ricinodendron heudelotii* reach deep and cause little competition for nutrients and water in the upper soil layers with adjacent crops. The tree starts bearing fruits at 8–10 years of age. In Sierra Leone flowering takes place in April–May, and fruits are produced in September–October; trees are leafless for a few weeks when the fruits fall. In central Cameroon fruits are collected in July–September. Bats, hornbills and rodents are believed to contribute to the dispersal of the seed. Fruits also break open and scatter their seed when they fall on the ground.

Ecology *Ricinodendron heudelotii* occurs in clearings in rainforest; it is characteristic of humid secondary forest and common in abandoned farmland at 200–500 m altitude. The minimum annual rainfall required is about 1000 mm, but annual rainfall may be as high as 10,000 mm/year as in Dibunscha, Cameroon. It is a fast-growing and light-demanding tree, requiring mean annual temperatures of 18–32°C. *Ricinodendron heudelotii* prefers medium-textured and freely draining acidic soils.

Propagation and planting Seeds start germinating 3–6 weeks after sowing. Scarification before sowing accelerates germination. Vegetative propagation is possible by rooting of leafy stem cuttings, layering and side grafting.

Management There is still little experience with management of planted *Ricinodendron heudelotii*. Trials are in progress at ICRAF, Cameroon. In DR Congo stakes are sometimes planted to create a live fence as they easily strike root. Although the species loses its leaves during the dry season, some farmers in Cameroon use it to shade cash crops such as cocoa. Coppicing is possible, but reports on regrowth are contradictory.

Diseases and pests Some caterpillars have been reported to defoliate *Ricinodendron heudelotii* in DR Congo, such as *Lobobunaea phaedusa*, *Imbrasia* spp. and one identified locally as 'mimpemba'. However, these caterpillars also constitute a considerable protein supply for local people. In Cameroon, a psyllid (*Diclidophlebia xuani*), and aphids have been reported to cause serious damage to young plants.

Harvesting Fallen fruits are collected from the ground.

Handling after harvest After collection, the fruits are left to rot in big piles. Once the fruit pulp is rotten, the stones are extracted by washing and boiling the fruits vigorously. Then the stones are removed from the hot water, put in cold water and left overnight. They are boiled vigorously once more until the shells crack. Shells are then removed using a knife. After extraction, seeds are dried.

Logs felled for timber should be extracted from the forest and converted rapidly because they are prone to staining.

Genetic resources *Ricinodendron heudelotii* is very widespread in tropical Africa and genetic variation is large. Within a sample of 47 accessions, considerable variation was found in fruit size, seed size and oil content of the seed (49–63%). Because of its wide distribution and prevalence in secondary forest and on farmland there is no risk of genetic erosion. No germplasm collections are known to exist.

Breeding Domestication of *Ricinodendron heudelotii* has started recently under the Tree Domestication Program of the World Agroforestry Centre (ICRAF) in Cameroon. Selection work is still in its infancy. Plant characters preferred by farmers have been identified. They include high yield, long fruiting season, stable yield, thin shell, self-cracking stones and good taste. It appears that fruit size is only weakly correlated with seed size. The self-cracking shell character is not related to shell thickness.

Prospects Continuing intensification of agriculture in humid tropical Africa will increasingly rely on domesticated, fast-growing, multipurpose tree species that fit well in agroforestry systems. If selections can be made that meet farmers' requirements and if appropriate packages of management practices can be developed, *Ricinodendron heudelotii* is likely to become a more important component of such systems and contribute to the regional demand for edible and industrial oil.

Major references Anigbogu, 1996; Ayuk et al., 1999a; Fondoun, Tiki Manga & Kengue, 1999; Franzel, Jaenicke & Janssen, 1996; Latham, 2004; Ndoye, Ruiz-Pérez & Eyebe, 1998; Ngo Mpeck et al., 2003; Shiembo, Newton & Leakey, 1997; Tchoundjeu & Atangana, 2006; Tiki Manga et al., 2000.

Other references Beentje, 1994; Berhaut, 1975; Burkill, 1994; Firestone, 1999; Katende, Birnie & Tengnäs, 1995; Léonard, 1962; Leung, Busson & Jardin, 1968; Radcliffe-Smith, 1987; Richter & Dallwitz, 2000; Tabuna, 1999; Tane, 1997; Tchiegang et al., 1997.

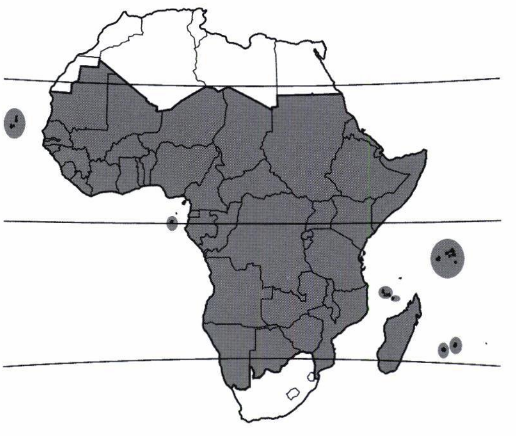
Sources of illustration Govaerts, Frodin & Radcliffe-Smith, 2000; Radcliffe-Smith, 1987; Wilks & Issembé, 2000.

Authors Z. Tchoundjeu & A.R. Atangana

RICINUS COMMUNIS L.

Protologue Sp. pl. 2: 1007 (1753).
Family Euphorbiaceae
Chromosome number $2n = 20$
Vernacular names Castor, castor oil plant (En). Ricin (Fr). Rícino, carrapateiro, mamoneiro, bafureira (Po). Mbarika, mbono mdogo, mnyonyo (Sw).

Origin and geographical distribution *Ricinus communis* is indigenous to north-eastern tropical Africa. 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. It is now widely cultivated 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. *Ricinus communis* occurs across the African continent, from the Atlantic coast to the Red sea and from Tunisia to South Africa and in the Indian Ocean islands.



Ricinus communis – wild and planted

Uses About 95% of castor seed is used for the expression of 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 believed to give a cooler and brighter light than other vegetable and mineral oils, burn more steadily and produce very little soot. It is now only used in rural areas and even there often mixed with or as a substitute for kerosene. Currently, castor oil is primarily used as a high-quality lubricant and a versatile raw material in the chemical industry. It has long been used as a lubricant in carts and Persian wheels. It is characterized by a high lubricity, high viscosity remaining constant over a wide range of temperatures, and 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 filler in cosmetics such as lipsticks, nail varnishes and shampoos. Saponification of castor oil yields a clear, transparent soap. Washing jute fibre with the soap gives it a shiny silky appearance. The soap has poor detergent qualities, but is easily water-soluble. 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' which is soluble in water. It is used as a wetting agent in dyeing cotton and linen fabrics, as a defoaming agent in the sugar industry, 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 that the United States has declared it 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 is commonly referred to in South Africa as 'blue bottle' because of the characteristic blue bottle in which it was traditionally packed and sold. It was much feared by children because of the unpleasant taste. The oil is now sometimes given as a sweetened aromatized emulsion or as capsules. It stimulates peristalsis by irritating the intestinal mucosa but causes little griping. It 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 is given orally, alone or with quinine sulphate, to induce labour in pregnancy at term. Ricinoleic acid prepared from the oil is a component of contraceptive creams and jellies.

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

In China and tropical Asia, the leaves of castor are used to treat skin diseases. They are also fed to the eri silkworm (*Philosamia 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 commonly grown as an ornamental.

Production and international trade Between 1985 and 2005 annual world production of castor seed gradually increased to 1.4 million tonnes, while the harvested area fluctuated around 1.4 million ha. In 2005 the most important producers of castor seed were India (870,000 t), China (268,000 t) and Brazil (177,000 t). In Africa important producers are Ethiopia (15,000 t), South Africa (4900 t), Angola (3500 t), Kenya (1000 t) and Tanzania (1000 t). Most of the castor seed is processed in the countries of production. Major importers are France, the United States, Germany and Japan.

Data on cultivated area and yield 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, fat 43–53 g, carbohydrate 7–10 g, crude fibre 15–25 g, ash 2–3.8 g. The seed and to a minor extent other plant parts, contain extremely toxic proteins, the toxic alkaloid ricinine and allergens. The oil is non-drying, viscous, nearly colourless, transparent and has a characteristic odour and taste. It has the highest viscosity of all vegetable oils; ricinoleic acid, which makes up about 90% of the fatty acids of the oil, renders the special properties to the oil. Other fatty acids include: palmitic acid (2%), stearic acid (1%), oleic acid (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 fluids. In inks, it is used to reduce water pick up and improve drying characteristics.

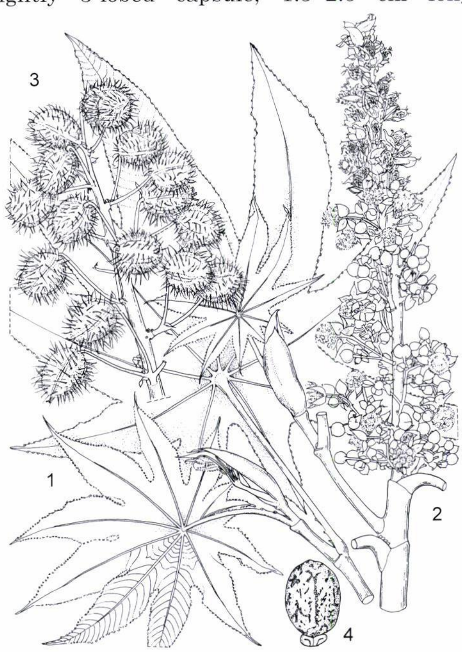
When the oil is pressed or extracted from the seed, the poisonous proteins remain in the castor cake. The main toxic proteins are 'ricin', a potent cytotoxin, and 'RCA' (Ricinus communis agglutinin), a powerful haemagglutinin. Poisoning by ingestion of castor seed is due to ricin, as RCA does not penetrate the walls of the intestines. Ricin is extremely poisonous when injected into the bloodstream; as little as 1 mg can kill an adult. It irreversibly inhibits ribosome activity; a single molecule that has entered a cell can inactivate over 1500 ribosomes per minute. 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 is 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 treatment of cancer and Aids.

The pyridine-carbonitrile alkaloid ricinine is a convulsant agent; it causes respiratory depression. At low doses it improves memory retention. 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, e.g. in the United States.

Castor is used extensively in physiological studies to elucidate mechanisms involved in phloem transport.

Adulterations and substitutes Castor oil is sometimes adulterated with rosin oil (a product from pine trees), blown oils and other unheated oils from groundnut, coconut, sesame, rape and cotton seed. The addition of any of these lowers the acetyl value. Rosin oil is detected by the increase in the unsaponifiable matter content, while addition of fatty oils, that have not been blown, lowers the specific gravity and viscosity and increases the product's solubility in petroleum ether.

Description Evergreen, glabrous, soft-woody shrub or small tree, often grown as an annual, up to 7 m tall; taproot strong and with prominent lateral roots; stem and branches with conspicuous nodes and ring-like scars, shoots usually glaucous, variously green or red; glands often present at nodes, petioles and main axes of inflorescences. Leaves arranged spirally, simple; stipules 1–3 cm long, clasping the stem, deciduous; petiole 3.5–50 cm long, terete; blade palmately 5–12-lobed, up to 50(–70) cm in diameter, membranous, lobes acuminate, median one up to 8(–20) cm long, margins with glandular teeth. Inflorescence an erect terminal panicle, later appearing lateral by overtopping, up to 40 cm long, usually glaucous, consisting of cymes. Flowers unisexual, regular, with short pedicel, 1–1.5 cm in diameter; calyx lobes 3–5, acute; corolla absent; male flowers towards the base of the inflorescence, with many stamens in branched bundles; female flowers towards the top of the inflorescence, with early caducous sepals, ovary superior, 3-celled, usually soft-spiny, styles 3, red or green, 2-cleft. Fruit an ellipsoid to globose, slightly 3-lobed capsule, 1.5–2.5 cm long,



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

brown, spiny or smooth, dehiscing in 3 cocci each opening by a valve and 1-seeded. Seeds ellipsoid, 9–17 mm long, compressed, with a brittle, mottled, shining seedcoat and with distinct 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 margins; first leaves opposite.

Other botanical information *Ricinus* comprises a single species. *Ricinus communis* exhibits considerable variation, especially in plant size and duration, shape and size of the fruit and of the seed and the pattern and colour of the seed coat. The numerous varieties are so thoroughly connected by intermediates and hybridize so freely when brought together, that it is untenable to consider them as separate taxa. Colour differences in leaves, stems and inflorescences have resulted in the selection of many horticultural variants that may be classified into cultivar groups. In many countries red and white types are distinguished based on the colour of young shoots. Within these groups, cultivars are recognized based on seed characteristics.

Growth and development Seedlings of castor emerge 10–20 days after sowing. The development of the plant is in accordance with Leeuwenberg's growth model in which the apical buds systematically die after one growth unit, so that the growth is sympodial. 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 cultivars, common in peasant agriculture, flowering is more diffuse. Flowering starts early in the life of castor. 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.

Under favourable conditions, castor has a high rate of photosynthesis, which has been attributed to the high chlorophyll content in the leaves.

Ecology *Ricinus communis* is often found as a ruderal near villages and in urban regions; under natural conditions in north-eastern Africa it occurs commonly along seasonally dry rivers.

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, while 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 at 300–1500 m, the limiting factor being frost. Suitable soil temperatures for germination are 10–18°C. Castor requires average day temperatures of 20–26°C with a minimum of 15°C and a maximum of 38°C. Temperatures of 40°C or higher are detrimental. It is susceptible to damage by frost. It prefers clear, sunny days with low humidity. Castor can withstand dry arid climates, but also heavy rains and short flooding. In regions with an average annual rainfall of 750 mm or less, sowing should be done 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 For mechanized cropping under rain-fed conditions, field preparation starts by ploughing deep enough to break 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 recommended. Smallholders usually intercrop castor in annual crops or plant it along the edges of fields or as a shade crop e.g. for ginger, turmeric or sugarcane.

Castor is propagated by seed. In spot-sowing 2–3 seeds are planted per hole at a depth of 3–8 cm; alternatively castor is sown in rows. The weight of 1000 seeds is 100–1000 g. Short-cycle cultivars may be grown in sole cropping as a second crop. In intercropping, distances between rows of castor may be as much as 4–5 m, and it 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 during weeding. Recommendations for in-row spacing range from 25–35 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 the cultivar.

Management Castor is generally grown on sandy or clayey deep red loams and on light alluvial loams. It is one of the few crops which can be grown economically on gravelly and poor soils. Deep black-cotton soils are not usually used for castor nor are very fertile soils with high nitrogen content, as they produce excessive vegetative growth. 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 hand weeding 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 done carefully. Effective weed control often results in a relatively bare soil surface. As the root system of castor has a low soil-binding ability, fields are often susceptible to erosion. Conservation measures in the cropping system and care in selecting sites for large plantings of castor are necessary. Peasant farmers do not usually irrigate castor, although it is often beneficial for yield.

As castor takes 5–8 months to come to harvest, it is grown as a main season crop. In general, application of organic manures such as compost or farmyard manure, groundnut or castor cake and inorganic fertilizers is said to be beneficial, the organic manures having beneficial residual effects over a period of 2–3 years. It has been calculated that a crop yielding 3.3 t fruit (2 t seed and 1.3 t hulls) removes 80 kg N, 8 kg P, 26.5 kg K, 8.5 kg Ca and 6 kg Mg. Castor is often grown mixed with groundnut and an application of NPK 1:2:3 to the latter crop increases the yields of both crops.

Diseases and pests Few diseases are of economic importance. Normally, serious attacks only occur in badly-growing crops under humid conditions. The most damaging diseases that attack seedlings are various rots caused by *Fusarium*, *Phytophthora*, *Rhizoctonia* and *Sclerotinia* 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. Widespread leaf spot diseases of castor in Africa are caused by *Xanthomonas axonopodis* and *Cercospora ricinella*. 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.

The African cassava mosaic bigeminivirus (ACMV) transferred by the whitefly *Bemisia tabaci* affects castor throughout Africa.

Probably the most damaging pests are those attacking the inflorescence, such as the cacao bug *Helopeltis schoutedeni* occurring throughout Africa. Peach moth or castor shoot and capsule borer *Dichocrocis punctiferalis* is a most important pest in tropical Asia. Young caterpillars feed on the green capsules and bore their way inside at the apical or basal end. Throughout Africa the scale insects *Pseudaulacaspis pentagona* and *Saissetia coffeae* affect castor, as do *Agrotis* cutworms, the cotton leafworm *Spodoptera littoralis* and the false coddling moth *Thaumatotibia leucotreta*. In East Africa the hairy castor caterpillar *Euproctis producta* may cause damage. Many other pests have been observed, but damage is mostly minor and localized. Tall, perennial cultivars 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 cultivars.

Castor is a host of head-bug (*Eurystylus oldi*), a pest in sorghum. In Mali it is becoming serious in newly introduced compact-panicled cultivars of sorghum, whereas traditional open-panicled cultivars are fairly resistant.

Harvesting The duration of the crop in the annual types of castor varies from 4–9 months, but perennial types may continue to bear for 10–15 years. Improved types with non-shattering capsules are harvested soon after they are fully dry. In types with shattering capsules, the capsules are harvested before they dry up and while they are still green. Harvesting may be repeated every 2 weeks. For manual harvesting simple tools in the form of a tin with a notch have been developed. Where castor seeds are merely collected from wild or volunteer plants, their harvesting sometimes involves no more than collecting scattered seeds.

Under intensive cropping, harvesting and hulling are the most time-consuming operations. Suitable machines and cultivars which are adapted to large-scale cultivation have been developed. Mechanical harvesting consists basically of removing fruits from the standing plants. Important problems still to be solved are the uneven ripening and the varying thickness of the fruit wall, both producing a large proportion of unopened fruits or broken seeds.

Yield Average seed yield of castor is about 1000 kg/ha, with a maximum of about 3000 kg/ha. Statistics on yields 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 inflorescences are stacked in heaps till the capsules blacken; they are then spread out in the sun to dry. 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 hullers 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 seed-coat is easily damaged.

About 10% of the total production is estimated to be retained by producers for propagation and domestic requirements. Hardly any sorting or grading of the seed is done and the bulk of the crop is sold by the producers without cleaning. Castor seeds can be stored for 2–3 years in gunny bags or in other containers without any detriment to the content or the quality of the oil. They are, however, seldom stored for more than 6 months and are utilized for oil extraction soon after threshing. Storage trials have shown that cracked or damaged seeds deteriorate rapidly and that wetting further accelerates this deterioration. Damaged seeds yield oil with a higher acidity and a dark colour that is difficult to bleach.

Genetic resources As castor is distributed widely throughout the tropics, there seems to be no risk of genetic erosion, also because a great deal of genetic diversity is being maintained on farmers' fields. Studies on the genetic variability are necessary to elucidate and categorize the wide morphological variability. A germplasm collection of more than 1000 accessions, partly from tropical Africa, is maintained at the N.I.Vavilov Institute of Plant Industry, St.Petersburg, Russian Federation. The Institute of Oil Crops Research (CAAS), Wuhan, China holds nearly 1700 accessions and the National Plant Germplasm System of the United States holds over 1000 accessions. In the Biodiversity Conservation and Research Institute, Addis Ababa, Ethiopia a collection of local castor is available.

Breeding All natural types 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 focussed on problems associated with mechanisation such as annual life cycle, dwarf plant architecture and indehiscent thin hulled and sparsely spiny fruits, maturing synchronously. The main aim of modern castor breeding are high seed yield, high oil and ricinoleic acid contents, easy harvesting and resistance to diseases and pests.

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', 'CS-9' and 'SKI-7' and the GCH series of hybrids in India.

Prospects Castor is of great economic importance in the tropics and great steps have been made in the development of castor as an industrial oil crop for the temperate regions. It grows over a wide area, regenerates well, and is traditionally managed and protected by farmers. 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.
Castor is important because of its multipurpose functions and its adaptability to a wide range of ecological conditions, including degraded sites. Special consideration should be given to using castor for soil rehabilitation in local land-use systems.

Major references Bojean, 1991; Kolte, 1995; Radcliffe-Smith, 1987; Radcliffe-Smith, 1996; Seegeler, 1983; Weiss, 2000; Wiley & Oeltmann, 1991.

Other references Coates Palgrave, 1983; CSIR, 1959; Ellis & Holliday, 1970; Ogunniyi, 2006; Palmer & Pitman, 1972–1974; Ratnadass et al., 2001; Saharan, Naresh Mehta & Sangwan, 2005; Seegeler & Oyen, 2001; Tongoona, 1993; Wild, Biegel & Mavi, 1972.

Sources of illustration Seegeler & Oyen, 2001.

Authors A. Maroyi

Based on PROSEA 14: Vegetable oils and fats.

SCHINZIOPHYTON RAUTANENII (Schinz) Radcl.-Sm.

Protologue Kew Bull. 45: 157 (1990).

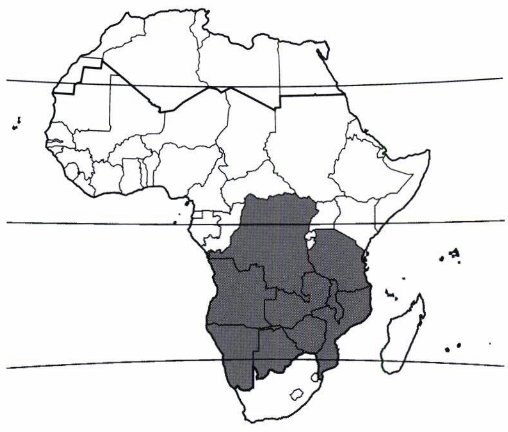
Family Euphorbiaceae

Synonyms *Ricinodendron rautanenii* Schinz (1898).

Vernacular names Mogongo, mongongo, mangetti, manketti (En). Mugongo (Fr). Omunkhete, mungomo (Po).

Origin and geographic distribution *Schinziophyton rautanenii* occurs from southern DR Congo, southern Tanzania and Angola south to Namibia, Botswana and northern South Africa. It is dominant or codominant in the vegetation of sand dune crests in the border area of Namibia and Angola extending eastwards to the Victoria Falls, Zambia and Zimbabwe. It is sometimes planted in southern DR Congo and Zambia. It has been planted on a trial basis in Israel, but productivity there seems to be very low.

Uses The fruit stones ('nuts') were, and locally still are the staple food for a number of hunter-gatherer peoples, particularly the San Bushmen in Namibia. After removal of the fruit pulp and hard shell of the stone, the kernels are boiled in water to extract oil. Traditionally the oil is spooned off the surface of the water and kept for later use in soups. Alternatively, the kernel may be roasted on live coals or pulped. The fruit pulp, which tastes like dates but is less sweet, is eaten raw or cooked, or it is used to produce a rather strong alcoholic brew as it has a high sugar content. The remains of the kernel after oil extraction are also eaten. In some southern African countries including Namibia, the trees are cut for wood (called 'mugongo' in trade) for the carving industry or for cabinet making. Since the wood is very light, it is also used for fishing floats, dart- and drawing boards, as an insulating material, and for the construction of crates and coffins. In Namibia the wood is also used for the construction of ox-drawn sledges that are used to transport goods in sandy areas. In Zambia the wood is used for carpentry and to make musical instruments, curios and toys, while the seeds are used in board games. The fruit is eaten by cattle. The inner bark is used to make strings, e.g. for nets. In traditional medicine the roots have been used to treat stomach-ache.



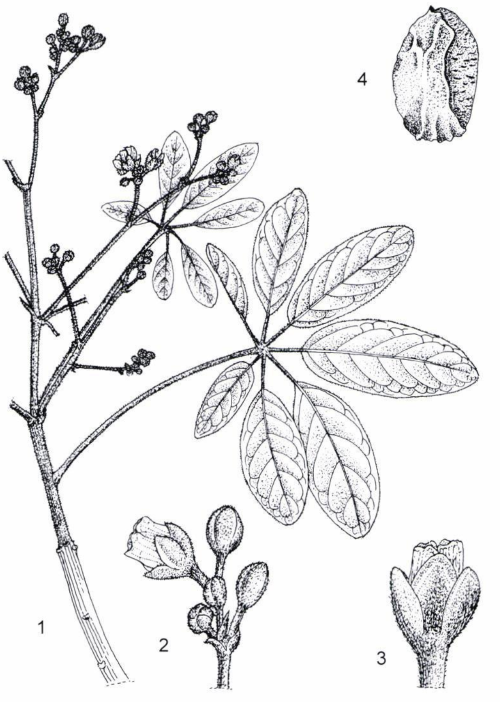
Schinziophyton rautanenii – wild

Production and international trade In the early 20th century fruit stones of *Schinziophyton rautanenii* were exported from Namibia to Great Britain and Germany, but this trade lasted for only a few years. No statistical data on production or trade of fruits, oil or timber are available.

Properties The pulp makes up about 26% of

the fresh fruit, the kernel about 9%. The nutritional composition of the fruit pulp per 100 g edible portion is: water 13.4 g, energy 1307 kJ (312 kcal), protein 6.6 g, fat 0.6 g, carbohydrate 70.2 g, fibre 3.5 g, Ca 89.6 mg, Mg 195 mg, P 46.0 mg, Fe 0.7 mg, Zn 1.4 mg, thiamin 0.28 mg, riboflavin 0.11 mg, niacin 0.12 mg, ascorbic acid 8.5 mg. The nutritional composition of the kernel per 100 g is: water 4.8 g, energy 2685 kJ (641 kcal), protein 28.8 g, fat 57.3 g, carbohydrate 2.4 g, fibre 2.7 g, Ca 452 mg, Mg 432 mg, P 839 mg, Fe 2.3 mg, Zn 3.1 mg, thiamin 0.22 mg, riboflavin 0.13 mg, niacin 0.42 mg (Wehmeier, Lee & Whiting, 1969).
Fatty acids in the oil include linoleic acid (38%), oleic acid (15%) and α-eleostearic acid (29%). In cosmetics the oil is used for its hydrating, regenerating and restructuring properties and UV protection for hair and skin. The heartwood is pale yellow to straw-coloured and indistinctly demarcated from the sapwood. The grain is straight or wavy, texture coarse. The wood air-dries rapidly with little distortion. It tends to become woolly on sawing, and sharp tools are needed to obtain a good surface. The nailing properties are good. The wood is not durable and susceptible to termite and *Lyctus* attack. It is permeable to impregnation with preservatives.

Description Dioecious shrub or small to medium-sized tree up to 20 m tall; bole up to 100 cm in diameter; bark up to 5 cm thick, whitish, pale grey or pale brown, smooth at first, later flaking; crown spreading, but rounded in denser stands; twigs thick, rusty stellate pubescent when young, exuding a white gum. Leaves alternate, digitately compound, (3–)5–7-foliolate; stipules fan-shaped, 3–5 mm × 2–3 mm, early caducous, glandular; petiole 6–25 cm long, with 2–4 prominent, usually apical glands; petiolules 0.5–1.5 cm long; leaflets elliptical-ovate to oblanceolate, rarely 3-lobed, median one 5–18 cm × 2–9 cm, lateral ones slightly smaller, base rounded to cuneate, apex obtuse to acute or shortly acuminate, entire, with glandular dots along edges, densely rusty stellate pubescent above but glabrescent, paler and longer hairy below, lateral veins in 6–16 pairs. Inflorescence a terminal panicle; bracts bristle-like or awl-shaped, 3–10 mm long; male inflorescence 10–22 cm × 4–8 cm; female inflorescence 5–6 cm × 2–3 cm. Flowers unisexual, regular, 5-merous, pale yellow to white; male flowers with pedicel 2–5 mm long, calyx lobes elliptical-oblong, c. 5 mm × 2–3 mm, stellate pubescent on both sides, petals elliptical-oblong, 6–7 mm × 2–3 mm, emarginate at apex, glabrous except at base inside, stamens 13–21, united at base; female flowers with pedicel 7–10 mm long, calyx lobes broadly ovate, 8–9 mm × 5–6 mm, stellate pubescent on both sides, petals elliptical-oblong, c. 9 mm × 4 mm, emarginate at apex, glabrous, disk shallowly cup-shaped, c. 4 mm in diameter, ovary superior, densely stellate pubescent, 1(–2)-celled, style c. 5 mm long, bifid. Fruit an ovoid-ellipsoid drupe up to 7 cm × 5 cm, green, turning grey-yellow, glabrescent, 1(–2)-seeded; wall of stone (endocarp) thick and hard, pitted. Seed compressed-ellipsoid, 2–2.5 cm × 1.5–2 cm, ridged.



Schinziophyton rautanenii – 1, flowering twig; 2, part of male inflorescence; 3, female flower; 4, fruit, showing part of stone.
Redrawn and adapted by Iskak Syamsudin

Other botanical information *Schinziophyton* consists of only a single species. It is related to *Ricinodendron heudelotii* (Baill.) Pierre ex Heckel, which differs in its sessile leaflets or slightly fused at base, larger, persistent stipules and fruits containing 2 or 3 thin-walled stones.

Growth and development When the seed has germinated, the radicle grows slowly. When it is 5–10 cm long, 5–12 secondary roots emerge in a ring from immediately above the root-tip, resembling a Medusa's head. When these roots are 20–50 mm long the plumule starts to emerge. The growth from seedling to sapling stage depends very much on the fire regime prevailing in the area. Fires reduce young saplings back to ground level as long as their bark is too thin to protect them. Trees may start flowering and fruiting when about 20 years old, and can live up to 100 years. Regular watering may speed up their development. Trees are leafless from March–May to October–November and flower in September–December, just before the onset of the rains. Fruits drop from April–May onwards when still green and ripen on the ground, turning rusty brown. Most stones contain a single seed, but around 5% of the nuts contain 2 seeds and 10% no seed. Strong winds often cause immature fruits to drop. Fruits are eaten by elephant and ostrich, and they may disperse the seeds. Due to the high sugar contents of the flesh, the fruits are often picked up and chewed by antelope and porcupine who will carry them shorter distances.

Ecology *Schinziophyton rautanenii* occurs in deciduous woodland and grassland with scattered trees, sometimes in pure stands. In the area where it occurs the mean annual temperatures are about 20°C, and the maximum daily temperatures often exceed 30°C; the plant tolerates light frost, but temperatures below 7°C kill seedlings. *Schinziophyton rautanenii* occurs at 200–1500 m altitude and grows well when the annual rainfall is 200–1000 mm. It is always found on deep sands with a 94–99% fine sand component. In the Namib desert it commonly occurs on crests of sand dunes; it is rarely found on calcareous soils and does not occur on poorly drained or waterlogged soils. Its habitat is subject to frequent fires.

Propagation and planting Seeds remain viable for up to 2 years when stored at 10°C. Artificial germination of the seed is difficult and has been the focus of several studies. The natural trigger is still not known, although some improvement in germination rate has been noted when the seed has passed through the digestive system of an elephant. In nursery conditions seeds need to be scarified. Treatment with ethylene or ethephon has given ambiguous results. Seedlings seem to grow slightly faster under moderate shade. It is not clear if this is a result of low light requirement or of reduced evaporation. Under natural conditions many seedlings are found under adult trees. Here it is not clear if this is because of an accumulation of seed, or because of better growing conditions. The plants coppice well when young. Older trees that have succumbed to fire generally do not produce coppice shoots, although saplings and even seedlings will produce new shoots when the above-ground parts are damaged. Truncheons root readily and are used for propagation. A number of cases were reported where fence posts made from freshly cut posts grew into large trees.

Management Trees of *Schinziophyton rautanenii*, even those from which fruit is regularly collected, receive very little care.

Harvesting Since the fruit ripens on the ground they are simply picked up from under the trees. Harvesting starts at the end of the rainy season when fresh fruits have fallen. Gathering continues until the end of the dry season (September–November) when half of the fruits have already lost their pulp to insects. During the rainy season (November–March), when drinking water is found more easily, nuts are collected from more remote groves.

Yield Fruit production is very closely linked to the amount of rain of the previous season, with crop yields higher in years following heavy rains. High rainfall after flowering has been found to damage the developing fruits, as do fires late in the dry season. Limited data are available on yields, although some estimates indicate yields of 200–1000 kg/ha in northern Namibia, and about 300 kg/ha in Angola.

Handling after harvest Collected fruits are mostly cooked in an iron pot. This softens the skin and makes them easy to peel. After peeling the fruits are cooked again to separate the flesh from the stones and to turn the flesh into a rich maroon pulp ready for eating. The stones are roasted in hot embers mixed with sand to facilitate cracking; excessive heat should be avoided as it spoils the taste of the kernels. After roasting the stones are cracked between two stones and are then ready for eating. The seed coat is easily removed by hand. The kernels may also be pounded and mixed with other foods, e.g. vegetables.
Logs felled for timber should be converted and dried quickly to prevent discoloration.

Genetic resources The Tree Seed Centre of the Directorate of Forestry, Windhoek, Namibia has accumulated a comprehensive seed collection. As *Schinziophyton rautanenii* is widespread and is not damaged by the collection of fruits, it does not seem to be in danger of genetic erosion.

Prospects Because of their local abundance, reliability of supply, ease of collection and good nutritional value, the kernels of *Schinziophyton rautanenii* remain an important traditional source of food in the Namib desert. The fruits are only collected from wild stands and it is unlikely that they will become important outside the area where they are used traditionally.

Major references Bolza & Keating, 1972; Graz, 2002; Lee, 1973; Peters, 1987; Radcliffe-Smith, 1996; Wehmeyer, 1976; Wehmeyer, Lee & Whiting, 1969; World Agroforestry Centre, undated.

Other references Bonifacio, Santonoi & Zanini, 2000; Léonard, 1962.

Sources of illustration Radcliffe-Smith, 1996.

Authors F.P. Graz

SESAMUM INDICUM L.

Protologue Sp. pl. 2: 634 (1753).

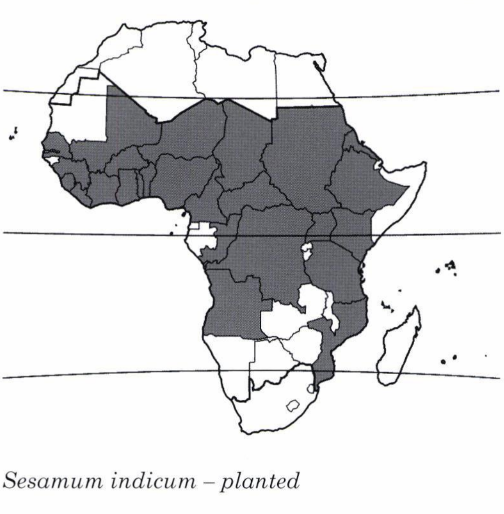
Family Pedaliaceae

Chromosome number $2n = 26$

Synonyms *Sesamum orientale* L. (1753).

Vernacular names Sesame, benne, benniseed, gingelly (En). Sésame (Fr). Gergelim, gimgelim, sésamo (Po). Simsim, ufuta, wangila (Sw).

Origin and geographic distribution Since antiquity, sesame has been used as a valued oil crop. Its origin has been disputed for more than a century. It has long been believed that it was domesticated in Africa, but interspecific hybridization and chemical evidence indicate that sesame was domesticated on the Indian subcontinent. Sesame seed found in an excavation at Harappa (Pakistan) was dated at 2000 BC. Sesame was taken to Mesopotamia in the Early Bronze Age and by 2000 BC it was a crop of great importance there. Mesopotamia became the main centre of distribution of sesame into the Mediterranean. By the second century BC it was a prominent oil crop in China. Its introduction into tropical Africa is poorly documented. Sesame was a valuable cargo in the trade between India and the Mediterranean along the southern Arabian and Red Sea coasts in the 2nd century BC and it must have been known by that time in the Horn of Africa.



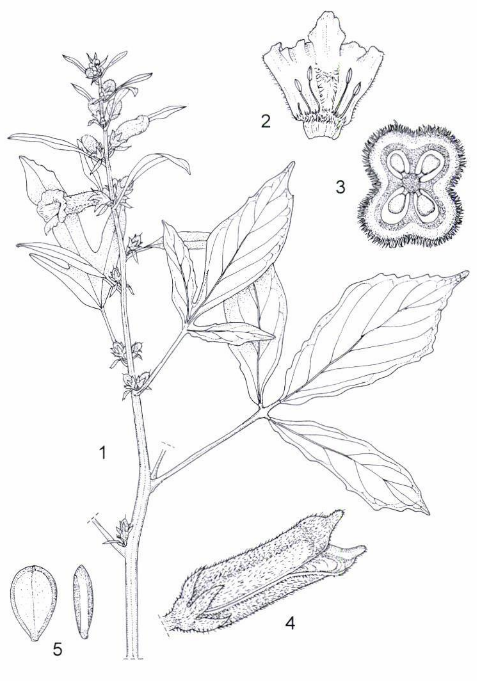
Sesamum indicum – planted

Uses Sesame seed, paste and oil are utilized in a very wide range of edible products. Crude sesame oil pressed from the seed can be used directly as cooking oil, while refined oil is used as a salad oil or wherever an edible oil of good keeping quality is needed. Sesame seeds are used in various food preparations, raw or roasted. Throughout the Arab world the seed is crushed into a tasty paste called 'tahini'. The mixture of seeds with sugar and flour is called 'halva'. Toasted seeds are consumed in soups or, mixed with caramelized sugar can be shaped into candies. Seeds are often sprinkled on cakes, rolls and cookies before baking. Oil is used in the manufacture of margarine and compound cooking fats. As salad oil it is often combined with other edible oils. In India the oil is used as a component of vegetable ghee and for anointing hair and skin. It is further used as a carrier for medicines and perfumes and as a synergist for pyrethrin-based insecticides. Poor grades are used in the production of soaps, paints, lubricants and lamp-oil. Sesame cake is an excellent livestock feed and a raw material for several foodstuffs. Young leaves are used as a soup vegetable in sub-Saharan Africa. In southern Africa the leaves are smoked as a substitute for tobacco. The ash of the stem is a substitute for salt, and is viewed as a good source of minerals. Dry stalks are used as fuel and as construction material, for building shelters. Various plant parts are used in native medicine in Africa and Asia for a variety of ailments. Mucilaginous leaves or leaf sap are used to treat fever, as a remedy for cough and sore eyes and to kill head lice; the sap is taken to facilitate childbirth, to treat dysentery and gonorrhoea and is used in dressings after circumcision. In eastern and southern Africa the leaves play a role in the treatment of snakebites and malaria, in India and China in the treatment of cancers. Ash from burned stems is used as a medicinal salt. The oil is used to treat cough and earache, and as an emmenagogue and abortifacient. Sesame seeds are valued for their laxative effect.

Production and international trade World production of sesame seed gradually increased from 1.5 million t/year in the 1960s to 3.2 million t/year (from 2.7 million ha)
in 2005, due to an increasing demand for sesame oil worldwide. Over this period, annual international trade in sesame seed increased from 150,000 t to 800,000 t, although it has been replaced for several purposes by other more easily and cheaply produced oilseeds. Africa produced an estimated 25% of the total world production over this period and contributed nearly 40% of world exports. In the period 2002–2005, China (730,000 t/year from 690,000 ha) and India (650,000 t/year from 1.5 million ha) were the main producers, followed by Myanmar (500,000 t/year from 1.3 million ha), Sudan (260,000 t/year from 1.6 million ha) and Uganda (110,000 t/year from 210,000 ha). Other important producers in Africa are Nigeria (75,000 t/year), Ethiopia (50,000 t/year), Central African Republic (42,000 t/year), Tanzania (41,000 t/year) and Chad (35,000 t/year). In recent years production has been increasing strongly in Ethiopia. In 2000–2003 the main exporting countries were Sudan (175,000 t/year), India (175,000 t/year), China (105,000 t/year) and Ethiopia (50,000 t/year); the main importers are Japan (about 150,000 t/year), South Korea (65,000–80,000 t/year) and China (45,000–100,000 t/year). Practically all world trade in sesame is as seed, and only minor quantities of oil and cake are shipped.

Properties Dry decorticated sesame seed contains per 100 g edible portion: water 3.8 g, energy 2640 kJ (631 kcal), protein 20.5 g, fat 60.2 g, carbohydrate 11.7 g, dietary fibre 11.6 g, Ca 60 mg, Mg 345 mg, P 667 mg, Fe 6.4 mg, Zn 6.7 mg, vitamin A 9 IU, thiamin 0.70 mg, riboflavin 0.09 mg, niacin 5.80 mg, folate 115 μg, and no ascorbic acid (USDA, 2005). The seed is rich in phytic and oxalic acid, which on chelating 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 of 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%), sesamol and sesaminol, which give the oil its 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 or not the seed was decorticated. The protein content of sesame cake ranges from 35% (expeller-pressed, unhulled) to 47% (hexane-extracted, decorticated). The cake is rich in calcium and phosphate, but poor in lysine. Crude fibre content in cake from unhulled seed is 5–6%, but only about 3% in cake from hulled seed.
The consumption of sesame products may cause a not very common but serious food allergy. The main allergens are seed proteins. Allergy develops mostly during adolescence or in adults and is progressive.

Description Erect, stout, aromatic, annual herb up to 2 m tall; root system with strongly tapering taproot up to 90 cm long, bearing many laterals; stem firm, square with ribs at each corner, up to 3 cm in diameter at base,



Sesamum indicum – 1, flowering branch; 2, opened corolla; 3, cross section of ovary; 4, fruit; 5, seeds.
Source: PROSEA

bright pale green, sparsely hairy to glabrous, with 4-celled glands present on all parts. Leaves decussately opposite in lower parts, arranged spirally and 3-lobed to 3-foliolate in upper parts; stipules absent; petiole up to 17 cm long, grooved above, at least at base; blade of lowest leaves ovate in outline, 10–21 cm × 5–13 cm, margin entire or partly toothed, higher leaves with narrowly elliptical lobes or leaflets 9–17 cm × 3–7 cm, margin entire or toothed, highest leaves narrowly elliptical, 5–15 cm × 1–3 cm, margin entire. Flowers in small fascicles in upper leaf axils, bisexual, zygomorphic, 5-merous, with 2 bracts at base, each bract with an axillary gland; calyx with oblong lobes 4–7 mm × 1–1.5 mm, slightly fused at base, apex acute, long-hairy; corolla campanulate, 2–3.5 cm long, base slightly bent and widened, slightly 5-lobed, with lobes c. 1 mm long, lowest lobe longer, white to violet, throat often yellow and spotted purple; stamens 4, inserted near base of corolla tube and included, the upper 2 shorter than the lower 2, with a staminode between the upper stamens; ovary superior, oblong-quadrangular, c. 5 mm × 2 mm, greyish hairy, 2-celled but each cell divided by a false septum almost to the apex; style 1 cm long, with 2-lobed stigma. Fruit an oblong-quadrangular capsule 1.5–3 cm long, hairy, with a short triangular beak at apex, grey-brown at maturity, loculicidally dehiscent, many seeded. Seeds flattened obovoid, 2–3 mm long, 0.5–1 mm thick, narrowly ridged all round, rather smooth, white, ivory, grey, beige, brown, red or black. Seedling with epigeal germination.

Other botanical information *Sesamum* comprises about 20 species, most of which are indigenous to tropical Africa. A few of the African species have spread to Asia and South America. Molecular analysis and the occurrence of fully fertile hybrids confirm the proximity between *Sesamum indicum* and its progenitor *Sesamum malabaricum* Burm. Both species have the same chromosome number. Two scientific names have long been used for sesame: *Sesamum orientale* and *Sesamum indicum*, but in 2005 the name *Sesamum indicum* was conserved against *Sesamum orientale*. Many cultivars of sesame exist. Characters which may distinguish cultivars include branching habit (branched or unbranched), leaf morphology (divided basal leaves or leaves lanceolate throughout), fruit dehiscence (dehiscent, partially dehiscent or indehiscent), and seed colour (white, ivory, grey, beige, brown, red, black).

Growth and development Germination of sesame seed 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. Roots of single-stemmed cultivars generally elongate more rapidly than those of branched ones, while the latter spread more quickly. Initial growth rates of sesame roots tend to be slower than those of groundnuts, maize or sorghum. Red-seeded cultivars of Kordofan (Sudan) are well known for their rapid root growth. 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 highly heritable cultivar characteristic. Most flowers open at 5–7 a.m., wilt after midday, and are shed at 4–6 p.m. Pollen is released shortly after the flowers open; the interval between flower opening and pollen release is a cultivar characteristic. The stigma is receptive one day before flower opening and remains receptive for another day. Under natural conditions, pollen remains viable for 24 hours. Flowers are mostly self-pollinated, but cross-pollination is possible and may reach 50%. Depending on cultivar, the crop matures in 75–150 days after sowing. Capsules near the stem base normally ripen first, those nearest the tip ripen last. Active dry matter accumulation and synthesis of oil occur 12–24 days after fruit set, but continue 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.

Ecology Sesame is a crop of the tropics and subtropics, but summer planting and 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. Sesame is sensitive to low temperatures and for this reason it is grown from sea-level to 1500 m, but in Kenya it is grown experimentally up to 1800 m altitude. Sesame is a short-day plant, but certain cultivars have become adapted to different 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. 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 temperatures below 10°C inhibit both. Established plants can withstand high moisture stress, but seedlings are extremely susceptible. Sesame produces an excellent crop with a rainfall of 500–650 mm evenly distributed during the growing season. 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 capsules begin to ripen. Heavy rain at flowering drastically reduces yield. Sesame is very susceptible to waterlogging. After stem elongation it is also susceptible to wind damage. Sesame thrives on moderately fertile and well-drained soils with pH ranging from 5.5 to 8.0, but most cultivars are sensitive to salinity. Growth and subsequent yield will be depressed on gravelly or sandy soils due to their poor moisture retention.

Propagation and planting Sesame is propagated by seed. Sesame seeds are very small, 1000 seeds weighing 2–4 g. Sesame seed can be stored for up to 2 years with little loss of viability provided it is dried to below 8% moisture content and kept in airtight containers. Seed intended for sowing should be cleaned thoroughly to remove debris and poorly filled seeds, and treated with an insecticide. Thorough seedbed preparation is desirable; land preparation as for small grains is usually adequate. 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 weed control while sesame plants are small is difficult. 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 ensures even crop emergence and growth, which facilitates subsequent tillage operations and harvesting.

As sesame is mostly a smallholder crop, sowing is usually done by hand. The seeds are often mixed with dry sand or earth to increase the volume and ensure an even seed distribution. A common seed/sand ratio is 1/3. Seed rates of 2–10 kg per ha are used in pure stands. In intercropping, the seed rate depends on the component crops in the mixture and farmer's objectives. Plant population is greatly affected by the degree of seedbed preparation and by the weather. Branching cultivars of sesame are very adaptive to spacing and yield well at densities ranging from 30,000–35,000 plants/ha. In Tanzania the highest yields in pure stands are obtained with plant populations of 170,000–200,000 plants/ha. When seeds are drilled in rows, a spacing of 35–50 cm between rows is recommended.

Husbandry Much labour is required within 2 weeks after emergence to thin seedlings to the recommended density of 10 cm between plants. Early weed control is important, and 2–3 rounds of shallow weeding are usually adequate. In Ethiopia one hand weeding increased yield of irrigated sesame by 80%. Good weed control is necessary as sesame grows slowly at first and does not compete well with weeds when young. Weeding is done by hand or with hoes; several herbicides are effective, but these are seldom used by smallholder farmers. Mechanical weeding should be done as shallow as possible to avoid damage to the roots. Growth is rapid once plants are 10 cm tall and little weeding is needed thereafter. Close row spacing can reduce late weed growth, which may be troublesome at harvest. Sesame is frequently intercropped in smallholder fields. Strip cropping with maize and sorghum is common, and protects sesame from strong winds.

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. 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. Most smallholders rarely apply fertilizer to the crop. Application of both nitrogen and phosphorus is essential on poor soils, but potassium is seldom required. In southern Tanzania applications of 20–30 kg of N and 10–15 kg of P per ha give a fair chance of an economic return. Irrigated sesame requires the equivalent of 900–1000 mm rain for optimum yields. In Asia sesame is often grown as a second crop after rice, and is then sown in the rice stubble. Besides residual soil moisture only a single irrigation is required.

Diseases and pests The most serious diseases of sesame include leaf spot diseases caused by the bacterium *Pseudomonas syringae* pv. *sesami* (synonym: *Pseudomonas sesami*) and the fungi *Cercospora sesami* and *Alter-*

naria sesami. These attack not only leaves, but also stems and green capsules. *Alternaria sesami* also causes seedling blight. Other serious diseases include blight or black shank (*Phytophthora nicotianae*), charcoal rot (*Macrophomina phaseolina*), Fusarium wilt (*Fusarium oxysporum*) and powdery mildew (*Oidium erysiphoides* and *Sphaerotheca fuliginea*). Sesame phyllody, a mycoplasma disease, causes serious damage mainly in India and Myanmar, but also in Africa. The plants become stunted and the inflorescence is changed into a growth of short, twisted leaves. Important virus diseases include cowpea aphid-borne mosaic virus (CABMV), tobacco leaf curl virus (TLCV) and peanut mottle virus (PeMoV). Sesame is generally not affected by nematodes, although damage by *Heterodera cajani* and *Pratylenchus penetrans* has been reported. Sesame is actually used to control nematode pests of other crops.

There is a great variation in the relative importance of insect pests in different African countries. Insects attacking flowers and young fruits are considered serious pests in some countries, e.g. in Sudan, while in others, e.g. in Tanzania, insects that attack foliage may cause substantial yield losses. Although sesame is attacked by a large number of insects, only 2 are consistently reported to cause serious economic damage: sesame webworm (*Antigastra catalaunalis*) which occurs in Africa and South Asia, and sesame gall midge (*Asphondylia sesami*) restricted to East Africa and southern India. *Antigastra* caterpillars roll up young leaves, web them together with silk and feed inside them. They also bore into young capsules. Larvae of *Asphondylia* feed on flower buds and young capsules, causing gall formation. Sesame flea beetle (*Alocypha bimaculata*) is the most devastating pest in south-eastern Tanzania where it attacks the foliage during the early growth stages. It has also been reported from Uganda. Cutworms (*Agrotis* spp.), devil grasshopper (*Diabolocatantops axillaris*), armyworm (*Helicoverpa fletcheri*) and green stink bug (*Nezara viridula*) occasionally cause damage, also in Africa. In stored sesame seed, khapra beetle (*Trogoderma granarium*) and bean weevil (*Callosobruchus analis*) are common.

Good crop management, including seed treatment, crop rotation, timely sowing and the use of resistant cultivars, will generally minimize the effect of leaf spot diseases and insect pests. A number of chemicals have been recommended to control diseases and insect pests but these may not be economical for smallholders. In Tanzania sesame flea beetle, for example, is controlled by spraying the young leaves with the insecticide Karate (a.i. λ-cyhalothrine) at a rate of 5 ml per litre of water. Endosulfan spraying at 5 ml per litre of water, applied weekly for three weeks, is normally effective in controlling webworm.

Harvesting Sesame is harvested 75–150 days after sowing, most commonly at 100–110 days. At maturity, leaves and stems change from green to yellow. Capsules ripen from the base of the plant to the top. Plants must be harvested before all capsules are mature, since field losses due to shattering can reach 75%, while even non-shattering types may lose 25%. Smallholder crops are usually harvested by hand and allowed to dry in stooks. After drying, sesame bundles are taken to the threshing floor, threshed and winnowed. The cleaned seed is kept in gunny bags. Non-shattering cultivars can be directly combine harvested 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 cultivar and environment. The total number of capsules is most closely correlated with seed yield, followed by the number of branches. The number of seeds per capsule, their weight, oil content and other constituents vary with capsule position, irrespective of cultivar. Seed yields of smallholder farmers seldom exceed 500 kg/ha when planted in pure stands. However, under intensive, high-input production yields can be as high as 2000 kg/ha.

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. Oil is extracted traditionally at household level by crushing the seeds with a grindstone, and thereafter pouring boiling water over the mass and skimming off the oil. This method is extremely inefficient and produces oil with poor storage quality. Hand-operated presses have recently been introduced in East Africa to improve the extraction process at village level. Large-scale oil extraction 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 being used for consumption. Further extraction of the residue gives oil that cannot be used for human consumption. Crude oil is filtered to remove impurities such as suspended meal and free fatty acids. The oil is often also bleached and deodorized to transform it into 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 accessions from outside India. Other large collections are held at the Institute of Crop Science (CAAS), Beijing (China) with 4100 accessions, the N.I. Vavilov All-Russian Scientific Research Institute of Plant Industry, St. Petersburg (Russian Federation) with 1500 accessions, the National Genebank of Kenya, KARI, Maguga (Kenya) with 1325 accessions, the Centro Nacional de Investigaciones Agropecuarias (CENIAP-INIA), Maracay (Venezuela) with 1250 accessions, the Plant Genetic Resources Conservation Unit, USDA-ARS, Griffin GA (United States) with 1200 accessions; other collections are maintained e.g. in Israel, Korea and Nigeria. The 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, adapted crop duration, 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 Corporation (San Antonio, 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. A widely grown cultivar 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 composed of 4 carpels instead of 2, and have large seeds. The modified gene has been incorporated into new cultivars.

Interspecific hybridization is possible, and crosses may produce viable seeds. Hybrids are partially fertile. Polyploidy can be induced, but colchicine-treated seeds tend to produce low yields, although the growth rate and general vigour of tetraploids can exceed those of diploids.

Prospects Although sesame is an ancient crop, there is ample scope for improvement. The oil with its characteristic taste and excellent cooking and keeping qualities, is highly appreciated in many parts of the world, including Africa. As an annual oilseed crop well adapted to dry tropical conditions, its importance in Africa shows great promise.

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Other references Agne, Rancé & Bidat E., 2003; Ashri, 1998; Bedigian, 1988; Bedigian, 1998; Bedigian, 2003b; Bedigian, 2004; Bedigian & Harlan, 1983; Bedigian et al., 1985; Bedigian, Smyth & Harlan, 1986; Bhat, Babrekar & Lakhanpaul, 1999; Grougnet et al., 2006; Hiremath & Patil, 1999; IPGRI, 1981; Kamal-Eldin, 1993; Manoharan, Dharmalingam & Manjula, 1995; Mkamilo, 2004; Nanthakumar, Singh & Vaidyanathan, 2000; Pathirana, 1995; Suja, Jayalekshmy & Arumughan, 2004; TARO, 1987; USDA, 2005; Zewdie, 1996.

Sources of illustration Weiss & de la Cruz, 2001.

Authors G.S. Mkamilo & D. Bedigian

Based on PROSEA 14: Vegetable oils and fats.

SIMMONDSIA CHINENSIS (Link) C.K.Schneid.

Protologue Ill. Handb. Laubholzk. 2(7): 141 (1907).

Family Simmondsiaceae

Chromosome number $2n = 26, 52$

Vernacular names Jojoba, goat nut (En). Jojoba (Fr). Jojoba (Po).

Origin and geographic distribution Jojoba (pronounced ho-hó-ba) is native to the Sonora and Mojave deserts in California and Arizona in the south-western United States, and adjacent parts of north-western Mexico. The similarity of jojoba wax 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 1971 gave a big impetus to the development of jojoba as an oil crop and to its distribution outside its native habitat. Production has spread to South and Central America, South Africa, Australia and Israel. Experimental plantations have been made in many countries of the drier tropics and subtropics. Extensive trial plantations have been established in Sudan; smaller ones in countries including Burkina Faso and Ghana.

Uses The seed of jojoba has long been eaten raw or parched by Indians and has been made into a well-flavoured drink similar to coffee. However, its main product now is a liquid wax obtained from the seed. The wax, often 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 suitable as components of industrial oils, as additives in high-pressure and high-temperature lubricants for transformers and gear systems, and as cutting and drawing oils in metal working. The oil or derivatives have potential as a motor fuel. Jojoba methyl-ester fuel runs more quietly than conventional diesel fuel and releases no sulphur. The liquid wax can be converted to a hard wax used e.g. in manufacturing candles. Other applications have been found in the manufacture of linoleum and printing inks. Jojoba oil is not digested by humans and has been tested as a substitute for oils and fats in low-energy foods. However, the oil causes cell damage and is no longer under consideration as a low-calorie dietary oil. The foliage and young twigs are relished by cattle, deer and goats. However, its growth rate is too low to make jojoba an important fodder crop. The presscake from the seed containing 30–35% protein is used as livestock feed. It should form only a small part of the diet as all parts of jojoba contain the appetite-depressing compound simmondsin and even after its removal the presscake is suitable only for ruminants and in limited amounts. On the other hand, simmondsin and the presscake may find application in the feed and pet-food industry as an additive to regulate intake of various feed components. Simmondsin is already marketed in sports-food supplements. The indigenous Americans traditionally use oil extracted from jojoba seed to treat sores and wounds. In Mexico the oil has been used traditionally as a medicine for cancer, kidney disorders, colds, dysuria, obesity, parturition, aching eyes and warts, and to treat baldness. Jojoba is grown in parks and gardens as an ornamental.

Production and international trade Annual world production of jojoba oil in 2000 was about 1500 t. Production is steadily increasing, currently at a rate of about 10% per year due to increased plantings and maturing plantations. The main producers and exporters are the United States and Argentina; smaller amounts are produced in Australia, Chile, Egypt, Israel, Mexico, Peru and South Africa. In the south-western United States alone, about 17,000 ha of jojoba are under cultivation.

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 seed. Since the late 1990s, the price of jojoba oil has stabilized at about US$ 11 per kg.

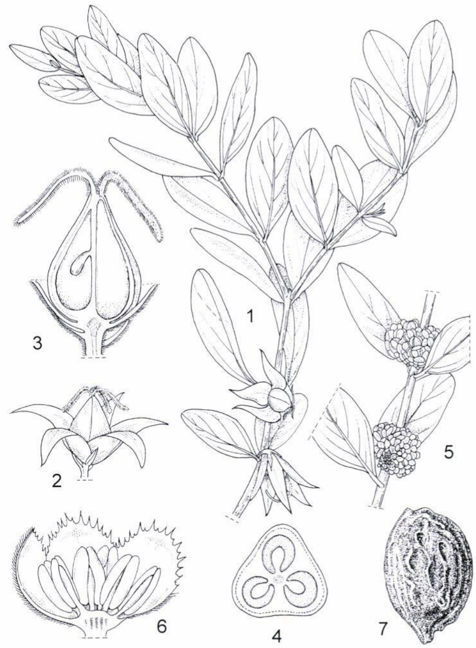
Properties Per 100 g, jojoba seed contains approximately: water 4–5 g, protein 15 g, wax 50–54 g, total carbohydrates 25–30 g, fibre 3–4 g and ash 1–2 g. Jojoba wax is clear golden-yellow and consists mainly of esters of long-chain, mono-unsaturated fatty acids and mono-unsaturated fatty alcohols, mainly eicos-11-enol and eicos-11-enoic acid (both C_{20}) and docos-13-enol and docos-13-enoic acid (both C_{22}) and smaller proportions of octadec-9-enoic acid (C_{18}) and tetracos-15-enol (C_{24}). These esters are rare in plants and substitute for common storage fats. The unsaturated bonds are susceptible to chemical reactions such as sulphurization, saturation and isomerization. The composition of jojoba wax enables it to withstand high temperatures of up to 300°C since it has a flash point of 295°C, a fire point of 338°C, and a low volatility. Jojoba wax has properties similar to the oil secreted by human skin and can be used to lubricate skin and hair for protection against e.g. ultraviolet radiation. The wax is relatively non-toxic, biodegradable and resistant to rancidity.

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 contain the appetite-depressing toxins simmondsin and related cyanomethylene-cyclohexyl glucosides. The toxic effects of jojoba seem to be predominantly related to the antifeedant and anti-appetent properties of simmondsin 2-ferulate. Seeds contain 2.25–2.34%, seed hulls 0.19%, core wood 0.45%, leaves 0.19–0.23% simmondsin. 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.

Adulterations and substitutes Jojoba 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. While commercial hunting for sperm whale is illegal, orange roughy is commonly caught in deep-sea fishing, but stocks are diminishing rapidly.

Genes encoding for the enzymes involved in long-chain fatty acid and long-chain alcohol production and the gene encoding for wax formation have been isolated from jojoba plants and have been incorporated into *Brassica* species, which are better suited to large-scale, low-cost production methods.

Description Evergreen, dioecious, multi-stemmed and profusely branching shrub up to 2.5(–6) m tall, with erect or semi-prostrate stems, young parts usually with soft hairs. Leaves decussately opposite, simple and entire, without stipules, almost sessile; blade ovate to elliptical, 1.5–4 cm × 0.5–2 cm, leathery. Flowers unisexual, regular, without petals; male flowers in axillary, dense clusters, yellowish, with c. 5 fringed sepals c. 6 mm long and 8–16 free stamens with short, stout filaments; female flowers usually solitary, greenish, with c.



Simmondsia chinensis –1, female flowering branch; 2, female flower; 3, female flower cut lengthwise; 4, ovary cut transversally; 5, male flowering branch; 6, male flower cut lengthwise; 7, seed.
Source: PROSEA

5 leaf-like sepals c. 13 mm long, ovary superior, 3-celled, styles 3, reflexed. Fruit an ovoid, obtusely triangular capsule, partly enclosed by the enlarged sepals, 3-valved, 1(–3)-seeded. Seed ovoid, 1–1.5(–3) cm long, pale brown to black; cotyledons thick, fleshy.

Other botanical information *Simmondsia*, the only genus in the *Simmondsiaceae*, comprises a single species. Formerly, it has been classified in *Buxaceae*, but it differs in flower structure, pollen morphology, embryology and phytochemistry.

Growth and development After germination jojoba forms a deeply penetrating taproot (up to 10 m), which may reach 60 cm before the emergence of the shoot. After the taproot, several deeply penetrating lateral 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 years. Jojoba follows the C_3 photosynthetic pathway.

The anatomy of the stem in *Simmondsia* is distinctive and is characterized by the absence of annual growth rings. Secondary growth occurs in a series of concentric rings. Over time, a series of cambia is formed in the secondary perivascular parenchyma that form new phloem and xylem.

In cultivation, male plants may start flowering 2 years after planting and female ones up to 1 year later. Flowering occurs on new growth only and is initiated by low temperatures. Cultivars with different chilling requirements have been selected. Flower buds may remain dormant until sufficient moisture is available. Prolonged drought may lead 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. The life span of jojoba may exceed 200 years.

Ecology The natural habitat of jojoba comprises the open parts of the Sonoran and Mojave semi deserts of southern California, Arizona and north-western Mexico. 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 in areas up to 1500 m altitude, with annual rainfall of about 250 mm in coastal areas and about 400 mm in inland areas, 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 temperature of –1°C and a maximum of 55°C. Frost damage is common in natural stands and is a major risk in cultivation. Seedlings are very susceptible to frost. The higher extreme temperatures cause 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 (pH 7.3—8.2) that are often rich in phosphorus. Some selections are tolerant of salinity; they grow and yield well in soils with an 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 annual rainfall. Rainfall higher than 750 mm is likely to increase the incidence of fungal diseases.

Propagation and planting Early jojoba plantations were established from seed collected from wild stands, but they were not economically productive. Many new plantations use cuttings or seed from selected plants. Propagation by softwood cuttings from selected shrubs that have been treated with IBA can be used. The cuttings are best planted in a nursery under mist. Cuttings take 25–40 days to strike root. Five-node cuttings taken from actively growing plants give plants with a strongly growing root system. When seed is used, germination is good even after 6 months, but viability is reduced to less than 40% after 10 years of seed storage at ambient conditions. Direct seeding in the field or transplanting of seedlings are used. In a nursery seed is sown preferably in slightly alkaline sand or in vermiculite 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. Methods of rapid in-vitro clonal propagation have been developed, but subsequent hardening of young plants is still a problem. 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 of 15 cm within the row have also been suggested and adopted recently. A proper ratio of female to male plants is 6:1. When seed is used, it is therefore advisable to initially over-plant and rogue out excess males later. The difference in time to flowering between male and female plants allows a first early roguing of male plants.

Management Weeds should be controlled prior to planting and regularly during the first 3 years after establishment. By that time jojoba plants are large enough to shade-out competing weeds. Where there are grazing or browsing animals, fencing is necessary. Pruning is required to keep the lower branches free from the ground and 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. Irrigation greatly increases growth and yields, especially in combination with NPK fertilizers. Irrigation regimes applying 500–1000 mm/year have been used in Israel. Water application should be stopped before the winter to allow the plants to go into dormancy. The response of jojoba to fertilizer application is not well documented.

Diseases and pests Jojoba is susceptible to fungal wilts such as *Verticillium*, *Fusarium*, *Pythium* and *Phytophthora* on poorly drained soils. *Phytophthora parasitica* and *Pythium aphanidermatum* in particular may cause root rot in plantations. In general, however, the diseases do not cause major economic damage. *Fusarium oxysporum*, *Fusarium solani* and other common nursery diseases have been recorded in plants that are raised in the nursery. Grazing animals and rodents are the main pests and in many areas, plantations have to be fenced. A number of insect species feed on jojoba and affect growth or production, but none of them has so far developed into a real pest.

Harvesting In many countries harvesting is done manually, but in the United States, Australia and Israel harvesting equipment adapted for jojoba is used. In orchard-like plantations or in hedgerow cultivation, seeds can be raked from under the shrubs and then picked up, provided there is no undergrowth. Jojoba seeds do not all mature simultaneously; therefore, more than one harvesting round may be necessary.

Yield In early plantations, jojoba grown from seed yielded only a few hundred kg of seed/ha and proved not economically viable. In more recent clonal plantations, yields may be about 1000 kg/ha under average rainfed conditions and 2000 kg/ha under irrigation, but yields of up to 4000 kg/ha have been reported.

Handling after harvest Jojoba seed requires cleaning and drying to 9–10% moisture content before being stored. 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. Several Regional Plant Introduction Stations also maintain some germplasm for evaluation and distribution. 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 work focuses on yield, oil content and simmondsin content. Additional breeding objectives are a high flower bud to node ratio, frost tolerance and low chilling requirements. Selection of plants that are suitable for mechanical harvesting is also ongoing. 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 Because of the present high demand for oil, jojoba can be considered a plant with a future, even though the initial great enthusiasm for jojoba as a high-return crop for dry and semi-arid areas has subsided after many failed attempts to grow it successfully and economically. New plantations coming into production will further increase supply and keep prices down. Stiff competition from genetically modified *Brassica* crops may also negatively influence the market. However, well-managed plantations and the use of high-yielding plant material adapted to local conditions should still give hope. Further testing of jojoba in drier parts of tropical Africa, such as Sudan and the Sahel zone is therefore recommended.

Major references Ash, Albiston & Cother, 2005; Benzioni, 1995; Benzioni & Forti, 1989; Botti et al., 1998; Kleiman, 1990; Naqvi & Ting, 1990; Oyen, 2001; Purcell et al., 2000; Weiss, 2000; Wisniak, 1994.

Other references Abbot et al., 1990; Bailey, 1980; Benzioni et al., 2005; Benzioni et al., 2006; Canoira et al., 2006; Cother et al., 2004; Duke, 1983c; Foster, Jahan & Smith, 2005; Hogan & Bemis, 1984; Kaufman et al., 1999; Lassner, Lardizabal & Metz, 1999; Milthorpe, 2006; Nimir & Ali-Dinar, 1991; Tobares et al., 2004; Undersander et al., 1990; Vaknin, Mills & Benzioni, 2003.

Sources of illustration Oyen, 2001.

Authors D.M. Modise

Based on PROSEA 14: Vegetable oils and fats.

SYMPHONIA LOUVELII Jum. & H.Perrier

Protologue Agric. prat. Pays chauds 21(2): 19 (1912).

Family Clusiaceae (Guttiferae)

Origin and geographic distribution *Symphonia louvelii* is endemic to northern and eastern Madagascar.

Uses The seed oil, fruit, wood and exudate of *Symphonia louvelii*, locally called 'kizavahy', and several other *Symphonia* species are used in Madagascar. Seed is collected for its oil, which is not edible, but used as hair and body oil and in pharmaceutical ointments. The fruit pulp is edible and often fermented to make a distilled drink. The wood is valued for furniture, cabinet making, joinery and ship building, but is also suitable for interior construction, flooring, boxes, crates and implements, and as firewood. The exudate obtained by incision of the bark is used to caulk boats and to fix tool handles. In traditional medicine it is used in fumigation to prevent a variety of diseases including smallpox, and it is applied externally to tumours, sores and scabies. Branches of several *Symphonia* spp. are used to make wreaths worn on the head during ceremonies and festivals.

Production and international trade The fruits are sometimes offered for sale in village markets.

Properties The seeds of *Symphonia louvelii* yield about 40% oil. The melting-point of the oil is 15–16°C. The oil contains about 65% unsaturated fatty acids, mainly oleic acid. It is suited for soap and candle production. The golden-yellow bark exudate quickly turns brown on exposure. It contains xanthones and is said to have anticancer activity.

The heartwood of Madagascan *Symphonia* spp. (called 'kijy') is buff-brown with shades of yellow or orange, and is distinctly demarcated from the sapwood. The grain is generally straight, texture moderately coarse to coarse. The wood has medium lustre and a mealy appearance, with conspicuous lines and arches on the radial surface and mottling on the tangential surface. It is moderately heavy and hard. Shrinkage during drying is considerable. Air drying of 25 mm thick boards takes about 2 months, and 80 mm thick boards 6 months. The wood works easily, and the gluing, painting and varnishing properties are good. It is flexible and has excellent steam-bending properties, which makes it a favourite wood for shipbuilding. It is only moderately durable under humid conditions or in contact with the ground, but it is not easily affected by salt water.

Botany Evergreen tree up to 20 m tall, with sticky, golden-yellow exudate, glabrous; bark smooth, yellowish; branches horizontal. Leaves opposite, simple and entire; stipules absent; petiole 2–5(–12) mm long; blade obovate-oblong to oblanceolate, 3–6 cm × 1–2.5 cm, cuneate at base, obtuse or rounded at apex, leathery, dark green, pinnately veined with 12–16 pairs of poorly visible lateral veins. Inflorescence a short terminal umbel-like cyme, 2–6-flowered. Flowers bisexual, regular, 5-merous, orange-red; pedicel 1–2 cm long; sepals ovate to almost orbicular, unequal, 4–6 mm × 4–6 mm; petals ovate to almost orbicular, 10–12 mm long, fleshy and waxy; disk cupule-like, c. 2 mm thick, undulate; stamens in 5 groups of (3–)4, basally merged into a c. 10 mm long tube, anthers with appendices as long as anthers; ovary superior, grooved, 5-celled, style elongate, with 5 short stigmas. Fruit an ovoid, fleshy berry with 5 rounded sides, up to 16 cm × 10 cm, pointed, smooth or warty, pale brown, 3–5-seeded. Seeds kidney-shaped, testa thin.

Symphonia comprises about 20 species, all except *Symphonia globulifera* L.f. endemic to Madagascar. Several species are indiscriminately exploited in Madagascar for their seed oil, edible fruit, wood and exudate, which all have similar properties. The most important species after *Symphonia louvelii* are *Symphonia clusioides* Baker from the mountains in central Madagascar, *Symphonia fasciculata* (Noronha ex Thouars) Vesque, widespread in eastern Madagascar, *Symphonia macrocarpa* Jum. & H.Perrier, which is uncommon in eastern Madagascar, *Symphonia tanalensis* Jum. & H.Perrier, occurring in central and eastern Madagascar, *Symphonia urophylla* (Decne. ex Planch. & Triana) Benth. & Hook.f. ex Vesque (synonym: *Symphonia laevis* Jum. & H.Perrier) from the mountains in central Madagascar, and *Symphonia verrucosa* (Hils. & Bojer ex Planch. & Triana) Benth. & Hook.f., which is uncommon in eastern Madagascar.

Ecology The Madagascan *Symphonia* spp. are shade-loving forest trees growing below the uppermost canopy storey. *Symphonia louvelii* occurs in moist evergreen forest, from sea-level up to 1700(–2300) m altitude.

Genetic resources and breeding The centre of diversity of *Symphonia* is Madagascar, where it is restricted to evergreen forest. With the ongoing deforestation in Madagascar, several species are probably threatened at present, e.g. those from central Madagascar, where little natural forest remains. However, no *Symphonia* species is yet included in red lists. *Symphonia louvelii* is one of the more widespread species, but its status concerning threats and conservation measures is uncertain and should be evaluated, as is the case for other *Symphonia* species.

Prospects Although *Symphonia* spp. are multipurpose trees in Madagascar, too little is known about them to evaluate their prospects. Research on all aspects is urgently needed and several species deserve domestication.

Major references Boiteau, Boiteau & Allorge-Boiteau, 1999; Guéneau, Bedel & Thiel, 1970–1975; Perrier de la Bathie, 1951; Sonntag, 1918.

Other references Decary, 1946; Styger et al., 1999.

Authors R.H.M.J. Lemmens

TELFAIRIA PEDATA (Sm. ex Sims) Hook.

Protologue Bot. Mag. 54: t. 2751–2752 (1827).

Family Cucurbitaceae

Chromosome number $2n = 22$

Vernacular names Oyster nut, Queen's nut, Zanzibar oil vine (En). Kouémé, bane, châtaigne de l'Inhambane, liane de Joliff (Fr). Castanha de Inhambane, sabina (Po). Mkweme, mkwema (Sw).

Origin and geographic distribution *Telfairia pedata* is native to mainland Tanzania and northern Mozambique and the isles of Zanzibar and Pemba. It is cultivated in Central, East and southern Africa from Rwanda and Uganda to Ethiopia and southwards through Tanzania to Zambia, Malawi, Mozambique and South Africa. It has been grown in Madagascar and Mauritius, but there its importance has declined.

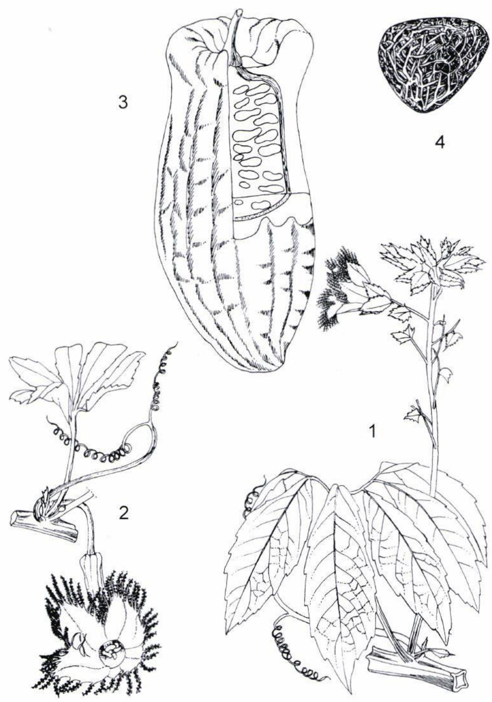
Telfairia pedata – wild and planted

Uses The seeds of *Telfairia pedata* are eaten raw, cooked or roasted and are said to taste as good as almonds or Brazil nuts. They are used in confectionery and are also pickled. In East Africa they are given to nursing mothers to improve lactation. The seed kernel contains an excellent edible oil, known as 'oyster-nut oil' or 'koémé de Zanzibar'. It is useful in cosmetics and in soap and candle making. The oil is used as medicine for stomach troubles and rheumatism in East Africa. The Wachagga of Tanzania use the seed as tonic after childbirth. After oil extraction, the presscake makes valuable feed for livestock, being rich in protein.

Production and international trade Oyster nut is an item of international trade, although the bulk of the produce is for home consumption and local trading. Data on production and trade of oyster nut are virtually non-existent.

Properties The seed shell makes up 40% of the weight of the seed. The composition of 100 g oyster nut kernel is: water 3.5 g, protein 27 g, and fat 66 g. The oil from the kernel has a pleasant, slightly sweet taste. The fatty acid composition of the oil is: oleic acid 11.5%, linoleic acid 32.5%, linolenic acid 5%, palmitic acid 24.5% and stearic acid 18%. The seed has good keeping qualities and may keep for up to eight years and still remain in excellent condition when husked.

Description Dioecious liana up to 30 m long; root system deep growing, thick, tuberous; stem initially herbaceous, ribbed, glabrous, climbing by bifid axillary tendrils, becoming woody with age and up to 10 cm in diameter; young branches glabrous and green. Leaves arranged spirally, pedately compound with 5–7 leaflets; stipules absent; petiole 2.5–10 cm long; leaflets with petiolules 1–6.5 cm long, central one largest, 5.5–14 cm × 2–7.5 cm, oblong to elliptical, acuminate, toothed especially in apical part, glabrous or slightly hairy on the main veins, lateral leaflets occasionally lobed at base. Inflorescence unisexual; male inflorescence an axillary lax raceme 6–23.5 cm long, bracts broadly ovate, 4–10 mm long, toothed, pubescent, adnate to the pedicels; female flowers solitary in leaf axils. Flowers 5-merous, pinkish purple, pedicel up to 14 cm long, receptacle campanulate, sepals triangular, 12–18 mm long, acute, pubescent and shortly



Telfairia pedata – 1, part of stem with male inflorescence; 2, part of stem with female flower; 3, fruit; 4, seed.
Redrawn and adapted by Iskak Syamsudin

laciniate, petals obovate, 2–3.5 cm long, crinkly, pinkish-purple fringed; male flowers with 3–5 free stamens; female flowers similar to male flowers, but slightly larger and with inferior, cylindrical, ribbed ovary. Fruit a drooping, ellipsoid berry, 30–90 cm × 15–25 cm, weighing up to15 kg, with a lobed expanded base and 10 blunt ribs, initially pale green but turning yellowish green at maturity, tardily dehiscent by 10 valves, many-seeded. Seeds oyster-shaped, flattened, 33–40 mm in diameter, 10–13 mm thick, enclosed in a fibrous, reticulate sheath. Seedling with epigeal germination.

Other botanical information *Telfairia* is classified in the tribe *Joliffieae* of the subfamily *Cucurbitoideae*. It comprises 3 species, of which *Telfairia occidentalis* Hook.f. (fluted pumpkin) is grown in West Africa as a vegetable. In agricultural literature the 2 species are sometimes confused.

Growth and development Seeds of oyster nut germinate 2–3 weeks after planting. Early growth is fast; plants can reach a length of 7 m in 6 months and 15 m in 18 months. Female and male plants cannot be distinguished until they flower. Flowering normally starts 15–18 months after planting and the first fruits ripen 4–6 months later. Under good conditions, 2 harvests per year are possible, and flowers and fruits can be present at the same time. Pollination is probably by insects, but apomictic seed production is likely. Under favourable conditions, plants remain productive for up to 20 years. When uncontrolled the lianas may overgrow 15–20 m tall trees and crush them by their weight.

Ecology *Telfairia pedata* is found in lowland coastal and riverine forest at elevations of up to 1100 m in areas with mean annual rainfall of 1000 mm or more. In cultivation it is found up to 2000 m altitude, but at higher altitudes yields are distinctly lower. It thrives on well-drained medium loam soils and is drought-resistant.

Propagation and planting *Telfairia pedata* is mostly propagated by seed. Seeds have short viability. Repeated soaking and drying promotes germination. In home gardens seeds are often planted directly along the drip line of large trees; for larger plantations nurseries are recommended. Vegetative propagation is effective using layering and cuttings, the latter being easily obtained by pruning. Stem cuttings root in 2–3 weeks and produce shoots 6–7 weeks after planting. Since oyster nut is dioecious, vegetative propagation will help avoid the preponderance of male plants as occurs naturally. Planting density of about 190 female plants per ha, plus 10–15 male plants per ha is required to obtain good pollination.

Management *Telfairia pedata* has been grown commercially on 2 m tall trellises. These should be very strong and durable to support the massive weight of the vines. Trellises are spaced 3–4 m apart and plants about 15 m. Per plant 1–3 stems are left to develop. In home gardens young plants may be trellised until they reach the branches of supporting trees. *Telfairia pedata* is part of the rich agroforestry systems of Mount Meru and Mount Kilimanjaro in Tanzania, where it is grown in combination with coffee and banana.

Diseases and pests Apart from general pests such as grasshoppers and termites, few diseases and pests have been recorded on *Telfairia pedata*. Cyst nematodes (*Heterodera* spp.) may attack the roots and the pentatomid shield bug (*Piezosternum calidum*) has caused serious damage in Uganda.

Harvesting When fruits ripen they split open gradually. To attain full flavour, seeds should be allowed to ripen in the fruit and be collected a week to 10 days after the fruit begins to split.

Yield *Telfairia pedata* produces 10–30 fruits in its third year. Good plantations can reach an annual seed yield of 3–7 t/ha.

Handling after harvest To remove the bitter principle, whole seeds can be soaked for 8 hours in 3 changes of water. To remove the kernel from the shell, the fibrous husk is first partly cut away, then the shell is cracked and opened using a knife. One man can shell about 2 kg of seeds per hour. Mechanical decortication is also possible. Before oil extraction, the shell around the seed should be removed carefully as the presence of even a small amount imparts a bitter taste. The difficulty of completely removing the shell makes commercial extraction difficult.

Genetic resources The area of natural distribution of *Telfairia pedata* is rather small, comprising eastern Tanzania and northern Mozambique. This may imply that natural populations can become liable to genetic erosion with ongoing habitat destruction. No germplasm collections are known to exist.

Prospects Oyster nut is of economic importance in Central and East Africa on account of the seed. There was flourishing export market to Europe, but its current importance is unknown. Collection and evaluation of germplasm is urgently needed. Management of commercial plantations and post-harvest technology deserve research attention.

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Sources of illustration Jeffrey, 1978.

Authors B.E. Okoli

TRIADICA SEBIFERA (L.) Small

Protologue Florida trees: 59 (1913).

Family Euphorbiaceae

Chromosome number $2n = 36$

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

Vernacular names Chinese tallow tree, candleberry tree, popcorn tree (En). Boiré, arbre à suif (Fr). Árvore do sebo, pau do sebo (Po).

Origin and geographic distribution *Triadica sebifera* is native to China and Japan, where it is cultivated, but more widely in former times than at present. It was widely introduced as an ornamental tree in the tropics and subtropics, e.g. in northern India, Pakistan, the southern United States and around the Black Sea. In many of these areas it has become naturalized and sometimes weedy. It has occasionally been planted in tropical Africa, where it occurs from Sudan to South Africa.

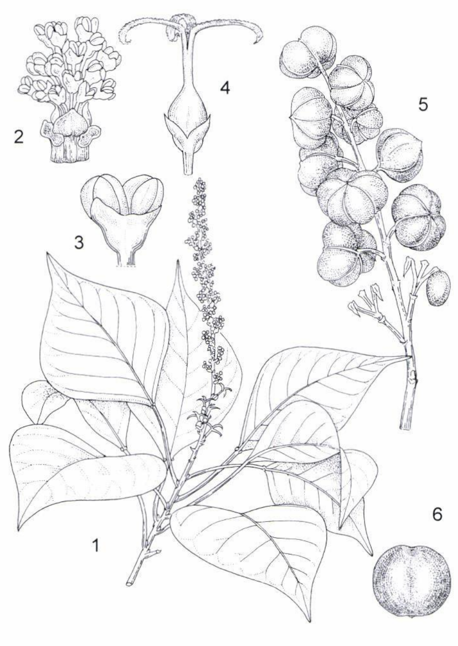
Uses The fruit of *Triadica sebifera* contains two types of fat: the white, fleshy outer seed coat (sarcotesta) yields a fat known as 'Chinese vegetable tallow' or 'pi-yu' in trade, while the seed kernel yields a drying oil called 'stillingia oil' or 'ting-yu' in trade. Chinese vegetable tallow is widely used in China for edible purposes, as a substitute for animal tallow and for lighting. Candles made by mixing 10 parts Chinese vegetable tallow with 3 parts white insect wax are reputed to remain pure white for any length of time and to burn with a clear bright flame without smell or smoke. Elsewhere, Chinese 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 Chinese vegetable 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 detoxified. The leaves contain a dye, used in Indo-China and China to dye silk black. *Triadica sebifera* 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. Its wood has been used to make various implements, toys, furniture and Chinese printing blocks. Because *Triadica sebifera* tolerates many unfavourable soil conditions and some frost, interest in it has grown again since the 1980s as a potential fuel and biomass producer on marginal soils, particularly in the south-eastern United States, but there it is now considered a noxious invasive weed. 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 Second World War, when there was a shortage of drying oil for paint, interest in stillingia oil increased and the oil reached prices of UK£ 200 per t in the world market. Experimental plantations were established in several 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. At that time China exported annually 4000–5000 t. At present, almost all stillingia oil and Chinese vegetable tallow are produced and used locally in China. The annual Chinese vegetable tallow production has been estimated to be about 50,000 t; export is almost zero at present.

Properties The air-dried seed of *Triadica sebifera* consists of: water 5%, fleshy seed coat (sarcotesta) 30%, dry seed coat (shell) 40% and kernel 30%. The sarcotesta yields 50–80% Chinese vegetable tallow (whitish, hard, edible but tasteless), while the kernel yields 50–60% stillingia oil (strong smelling, not edible, emetic and purgative). The fatty acid constituents of Chinese vegetable tallow are: lauric acid trace, myristic acid 0–4%, palmitic acid 58–72%, stearic acid 1–8%, oleic acid 20–35%, linoleic acid 0–2%. The fatty acid constituents of stillingia oil are: palmitic acid 6–9%, stearic acid 3–5%, oleic acid 7–10%, linoleic acid 24–30%, linolenic acid 41–54%. Stillingia oil also contains 2,4-decadienoic acid 4–5% and 8-hydroxy-5,6-octadienoic acid. Stillingia oil is not stable and undergoes changes even in the seed. When seed is harvested within 60 days of flowering, the oil is relatively rich in palmitic acid and poor in linolenic acid. Prolonged storage of high-linolenic stillingia oil leads to formation of estolide (ester-like compounds consisting of a fatty acid esterified with a hydroxy-fatty acid). The presence of unstable and easily oxidized estolide may explain the good drying qualities of stillingia oil. Partly due to these changes, large differences in the composition of stillingia oil have been reported. Stillingia oil is poisonous and makes Chinese vegetable tallow inedible if accidentally mixed with it. It has inflammation- and tumour-promoting properties. The leaves of *Triadica sebifera* are not browsed by cattle; they contain constituents such as gallic acid, astragalin (active against lymphatic leukaemia cells), (–)-loliolide, kaempferol, quercetin, β-sitosterol glycoside, and a phenolic glycoside with antihypertensive activity.

Triadica sebifera contains hydrolysable tannins, including geraniin 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 wood of *Triadica sebifera* is hard, with fine texture and nearly white; its density at 15% moisture content is about 500 kg/m^3.

Description Monoecious, deciduous, small tree up to 13 m tall; stem often gnarled; bark whitish grey with vertical cracks, containing white latex. Leaves alternate, simple and entire; stipules ovate to triangular, up to 2 mm long; petiole 2–7 cm long, with a pair of conspicuous glands at apex; blade broadly elliptical to obovate or nearly orbicular, up to 9.5 cm × 10 cm, base obtuse, apex acuminate, pinnately veined with 7–10 pairs of lateral veins.



Triadica sebifera – 1, flowering branch; 2, cluster of male flowers; 3, male flower; 4, female flower; 5, infructescence; 6, seed.
Source: PROSEA

Inflorescence a terminal or axillary thyrse, 4–16 cm long, yellowish green, basal part with female flowers, upper part with clusters of male flowers; bracts and bracteoles 1–2 mm long, often with a pair of glands at base. Flowers unisexual; pedicel 2–3 mm long; calyx 3-lobed; petals absent; male flowers with 2–3 stamens; female flowers with superior, 3-celled ovary, style ending in 3 stigmas 3–5 mm long. Fruit a dry, 3-lobed or grooved, nearly globose capsule, 1–1.5 cm in diameter, opening regularly and nearly simultaneously septicidally and loculicidally, 3-seeded. Seeds attached to the central columella for a considerable time after ripening, globose to flattened ovoid, 6–9 mm × 4–6 mm × 5–8 mm, covered with a whitish, waxy, persistent sarcotesta; seed coat (shell) hard, brittle, brown.

Other botanical information *Triadica* comprises 3 species, all native to eastern Asia.

Growth and development Under favourable conditions *Triadica sebifera* is a fast grower: until it is 8–10 years old, it can grow about 1 m per year; after 20 years, it may be up to 13 m tall with a stem diameter of up to 40 cm. Flowering starts 3–4 years after planting. The flowers are very fragrant and often 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 hundreds of years old. To run wild in areas where it has been introduced, *Triadica sebifera* 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.

Ecology *Triadica sebifera* occurs in subtropical to warm temperate climates. It can withstand a few degrees of frost and tolerates a wide range of soils with pH 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, and 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 *Triadica sebifera* is most commonly propagated by seed, but vegetative propagation by cuttings, layering, top-grafting and root suckers (which are formed abundantly) is also possible. The weight of 1000 seeds is about 150 g. Seeds are sown directly in the field, 3–4 per hole and at 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 has promoted germination effectively, while plants grown from suckers showed better growth than seedlings. An in-vitro multiplication technique based on axillary bud proliferation has been developed.

Management In plantations of *Triadica sebifera* trees should be pruned and trained to a convenient size for hand harvesting.

Diseases and pests *Triadica sebifera* has no serious diseases or pests. However, fungi such as *Pseudocercospora stillingiae* causing leaf spot and *Armillaria tabescens* (synonym: *Clitocybe tabescens*) causing mushroom root rot are known to attack it. In India the tree is sometimes defoliated by larvae of the moth *Achaea janata* (synonym: *Ophiusa melicerta*). The root-knot nematode *Meloidogyne javanica* has also been recorded as causing damage. Birds can inflict damage because they eat the seeds.

Harvesting *Triadica sebifera* starts bearing fruit 3–8 years after planting, although in Hawaii trees started fruiting already 18 months after sowing. In China harvesting is done during September–November when fruit bunches have turned brownish. In areas where the trees are naturally abundant, fruits are harvested from wild stands. Fruits are harvested with a sharp sickle 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 *Triadica sebifera* 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 Chinese vegetable tallow, 2–2.5 t stillingia oil, 1.5 t protein-rich presscake. In the United States *Triadica sebifera* showed itself to be an interesting woody biomass supplier for energy production on poorly drained and saline soils in the hot southern coastal region, yielding 6–10 t/ha dry biomass (leaves, wood and seed) per year.

Handling after harvest Harvested fruits of *Triadica sebifera* 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 fruits. 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 vegetable tallow; after that the seeds are crushed and pressed to collect the drying oil from the kernel. Sometimes seeds with sarcotesta are crushed and pressed and a mixture of Chinese 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 Chinese vegetable tallow and stillingia oil gave 50% more produce.

Genetic resources *Triadica sebifera* is widespread and easily runs wild, so there is no danger of genetic erosion. Germplasm collections, however, are almost non-existent.

Breeding In Taiwan there are more than 100 cultivars of *Triadica sebifera*; two important cultivars are 'Eagle-claw' and 'Grape', which differ in fruit form and maturation period.

Prospects *Triadica sebifera* is a useful tree since it produces fat, oil and fuel and is able to grow in a wide range of environments unsuited for many other plant resources. In cooler areas of Africa 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 efficient, low-cost harvesting and oil extraction methods.

Major references Aitzetmüller et al., 1992; Axtell & Fairman, 1992; Chen et al., 1987; Esser, 1999; Esser, 2002; Sharma, Rikhari & Palni, 1996; Shupet & Catallo, 2006; Umali & Jansen, 2001; Zheng et al., 2004–2005.

Other references Duke, 2001; Howes, 1950; Jeffrey & Padley, 1991; Khan, Khan & Malik, 1973; Norman, 2005; Samson, Vidrine & Robbins, 1985; Scheld & Cowles, 1981.

Sources of illustration Umali & Jansen, 2001.

Authors P.C.M. Jansen

Based on PROSEA 14: Vegetable oils and fats.

TRICHILIA DREGEANA Sond.

Protologue Harv. & Sond., Fl. cap. 1: 246 (1860).

Family Meliaceae

Chromosome number $2n$ = c. 360

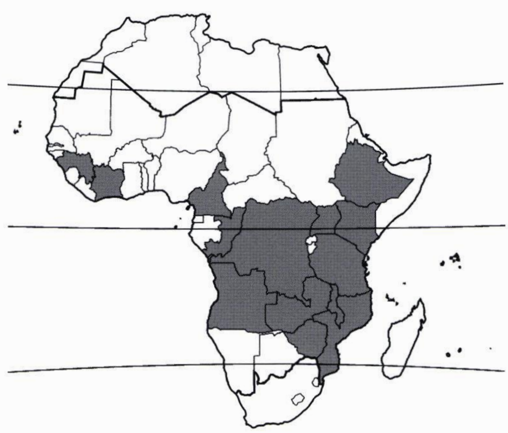
Synonyms *Trichilia splendida* A.Chev. (1911).

Vernacular names Forest mahogany, forest Natal mahogany, Cape mahogany, thunder tree, christmas bells, red ash (En). Aribanda des montagnes (Fr). Mafureira (Po). Mkungwina, mtimaji (Sw).

Origin and geographical distribution *Trichilia dregeana* has a disjunct natural distribution area in tropical Africa. It occurs from Ethiopia south to South Africa, especially in the mountain ranges of the Eastern Arc and along the Rift Valley. In West and Central Africa it occurs in areas far remote from each other, in Guinea, Côte d'Ivoire, Cameroon, in Congo, DR Congo and Angola. It is absent from the central Congolian rainforest, but is reported from the Arabian peninsula. It is planted in many countries as an ornamental.

Uses The seeds provide an oil which is used to make candles, soap and cosmetics. It is used for cooking although it is bitter. The seedcoat is poisonous and only well-prepared oil is safe for consumption. After removal of the seedcoat and boiling, the seeds are eaten as a side dish. The seed residue after oil extraction is used as animal feed or as fertilizer. Fruits are eaten in KwaZulu-Natal (South Africa). The aril is eaten, or crushed and made into a sweet drink or sauce.

Throughout Africa the seed oil, leaves, root and bark of *Trichilia dregeana* have similar medicinal uses to those of *Trichilia emetica* Vahl.



Trichilia dregeana – wild

They are used to treat a variety of complaints ranging from lumbago to leprosy and sleeplessness. The seed oil is rubbed into cuts made in the skin of a fractured limb in order to hasten healing; it is used as a massage oil to treat rheumatism and as a general body ointment. The fruit has emetic and purgative properties. Poultices made of the leaves or fruits are applied to bruises and eczema. Root decoctions are used as a general tonic, against fever and as a purgative. In Ethiopia the bark is used against scabies. Decoctions of the bark are applied in the form of an enema as a purgative and abortifacient, and to treat back pain caused by kidney problems. Bark decoctions are also drunk as a purgative or abortifacient. A bark decoction is drunk daily to treat diarrhoea. The bark is also used in the preparation of fish poison.

The wood is important for carving, especially in southern Africa, and is also used for indoor furniture, household utensils, shelving, construction, dugout canoes, firewood, and for making charcoal. *Trichilia dregeana* makes a beautiful shady avenue tree and is grown as an ornamental. A selection with small leaves and short internodes has been patented in the United States. In Ethiopia it is grown as a shade tree for coffee, or left as such when forest is cleared. The bright-coloured seeds have been used as bait for fishing.

Production and international trade *Trichilia dregeana* is of subsistence value in most parts of Africa, but the seed, roots and leaves are collected and traded locally, especially in South Africa. Seeds are harvested on a commercial scale from wild trees for the industrial production of pharmaceutical products.

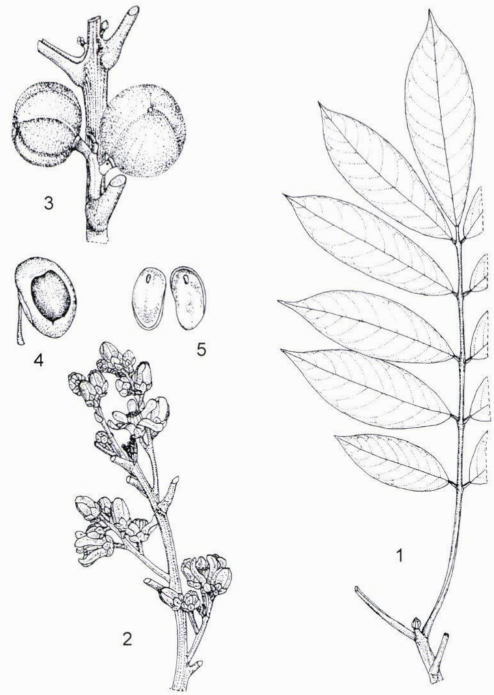
Properties The seed of *Trichilia dregeana* contains 55–65% oil. The approximate fatty acid composition of the oil is: palmitic acid 34%, stearic acid 3%, oleic acid 51%, linoleic acid 11%, linolenic acid 1%.

A large number of limonoids have been isolated from the seed, especially from the seedcoat. Limonoids are tetraterpenoids, many of which are biologically active. The limonoids in *Trichilia dregeana* are evodulone and prieurianin derivatives, including dregeanin, dregeana 1–5 and rohituka 7. Limonoids of the *Meliaceae* are well known as antifeedants and growth regulators of insects, but they also have some antimicrobial and anti-inflammatory activities and have shown cell-adhesion inhibitory properties. The bark, which is very toxic, contains inhibitors of the prostaglandin-synthesis, which play a role in inflammation and pain suppression.

The heartwood of *Trichilia dregeana* is pale brown to pink, the sapwood whitish. The wood darkens with age. When oiled, it darkens considerably, leaving little difference between heartwood and sapwood. The grain is generally straight, texture medium coarse. The wood has a distinct figure. The density at 12% moisture is about 550 kg/m^3. Drying is fast and easy with little defect. The wood is easily worked and polishes well. It is not durable and susceptible to borer attack.

Adulterations and substitutes In most regions of Africa, *Trichilia emetica* is preferred to *Trichilia dregeana* for its oil and for medicinal purposes.

Description Evergreen, dioecious, medium-sized tree up to 30(–40) m tall, variously hairy in all parts; bole cylindrical, up to 100(–200) cm in diameter, often slightly buttressed; bark 3–4 cm thick, outer bark pale grey to grey-brown, smooth, inner bark soft, cream-coloured, quickly turning pink to reddish brown; crown dense, spreading. Leaves alternate, imparipinnately compound with 2–5 pairs of leaflets; stipules absent; petiole and rachis up to 26 cm long; petiolules up to 1 cm long; leaflets opposite, obovate to oblanceolate, up to 21 cm × 8.5 cm, base rounded or cuneate, apex nearly always acute or acuminate, rarely rounded or notched, entire, pinnately veined with 8–14 pairs of lateral veins. Inflorescence an axillary or terminal panicle up to 11(–24) cm long, usually few-flowered. Flowers unisexual, male and female flowers very similar in appearance, regular, 5-merous, dirty white; pedicel up to 4(–10) mm long; calyx cup-shaped, 3.5–5.5(–7.5) mm × 5.5–9(–11) mm, usually lobed to halfway or more, lobes broadly ovate, 1–3 mm × 2–4 mm, hairy; petals free, linear, 13–22 mm long, hairy; stamens 10, 10–16 mm long, united into a tube in basal half, densely hairy inside; ovary superior, densely hairy, 3-celled, style 6–8.5 mm long, stigma head-shaped or disk-shaped; male flowers with rudimentary ovary, female flowers with non-dehiscing anthers. Fruit an obovoid to globose capsule c. 3 cm × 3 cm, slightly 3-lobed, without distinct stipe, dehiscent, up to 6-seeded. Seeds 18–25 mm × 9–15 mm, glossy black, almost completely concealed in a scarlet sarcotesta. Seedling with epigeal germination; hypocotyl up to 4 cm long, epicotyl 4–8 cm long; cotyledons sessile, fleshy; first leaves opposite and simple, subsequent leaves alternate and simple, becoming compound from c. 8th leaf.



Trichilia dregeana – 1, twig with leaf; 2, part of flowering twig; 3, fruits; 4, seed; 5, kernel. Redrawn and adapted by Iskak Syamsudin

Other botanical information *Trichilia* comprises about 90 species, most of them in tropical America. In continental Africa 18 species occur, and 6 in Madagascar. *Trichilia dregeana* is closely related and very similar to *Trichilia emetica*. The two species are often confused. The latter occurs in drier locations and can be distinguished by a distinct stipe on the fruit. *Trichilia emetica* occurs in riparian woodland or similar vegetation in drier areas from sea-level up to 1500 m altitude. Although *Trichilia dregeana* is very variable and its distribution area disrupted, morphological variation patterns in East Africa and West Africa are similar and no subspecific taxa have been recognized.

Growth and development Natural reproduction of *Trichilia dregeana* is abundant owing to regular and copious seeding from a fairly early age, comparative immunity from damage by animals and its power of recovery from injury. Seeds germinate during the early rains and seedlings attain a length of 10–20 cm by the end of the first year. In subsequent years, growth is more rapid, the mean annual girth increment being 2–2.5 cm. In Zimbabwe trees flower in September–December and fruit fall starts in May. Trees growing in the open start fruiting when about 10 years old, those in more shaded, forest-like conditions may not bear fruit before they are 20 years old.

Ecology In West Africa *Trichilia dregeana* is found in the transition zone between forest-savanna mosaic and moist evergreen forest, mostly at 800–1600 m altitude. In western DR Congo it occurs in similar vegetation, but below 500 m altitude. The distribution in Ethiopia is at 1350–2000 m altitude where annual rainfall is 1500–2500 mm, while nearer the equator in Uganda and Tanzania its distribution starts at lower altitudes. Towards South Africa it occurs at gradually lower altitudes and is found at sea-level near Durban. Though sensitive to frost, the tree recovers easily from damage. It is tolerant of fire. It is mostly found in well-watered sites, on fertile forest soil. In gardens it can be grown both in shady places and in full sunlight.

Propagation and planting *Trichilia dregeana* is easily propagated by seed, either by direct sowing or by raising seedlings in a nursery. The weight of 1000 seeds is about 1 kg. The seed must be fresh when sown as viability is lost very quickly on drying. It germinates within 2–4 weeks; removal of the fleshy outer seedcoat promotes germination. A rich mixture of sandy soil and compost with plenty of moisture is recommended. Seedlings grow best under some shade and should be protected from frost.

Management *Trichilia dregeana* is only cultivated on a small scale, mainly as a garden plant. Older plants are fast growing and require little or no management. For ornamental purposes trees may be pruned into shrubs. *Trichilia dregeana* coppices well.

Harvesting Seeds are generally collected from wild stands.

Yield Average seed yields per tree in Mozambique are about 20–25 kg/year, but in a good year a large tree may produce 180 kg. Trees that have produced heavily in one year tend to produce little in the next year.

Handling after harvest To obtain the oil, the seeds are ground and pounded. The mashed seeds are boiled in water and the oil is skimmed off.

Genetic resources *Trichilia dregeana* is widely distributed in tropical Africa and is characterized by regular and copious seeding and therefore not endangered.

Prospects The oil of *Trichilia dregeana* is gradually being replaced by other, commercially available oils, but as an ornamental amenity tree it seems to be becoming increasingly popular. Seeds might be usable as starting material for the partial synthesis of limonoids of pharmaceutical interest, so deserve further attention. Seed of *Trichilia dregeana* is recalcitrant; procedures for storing embryos are being developed, but have only shown short-term success. Research is likely to continue.

Major references CHCD, 1996; de Wilde, 1986; Gelfand et al., 1985; Grace et al., 2002; Grundy & Campbell, 1993; Katende, Birnie & Tengnäs, 1995; Mulholland, Parel & Coombes, 2000; Neuwinger, 2000; Palmer & Pitman, 1972–1974; White & Styles, 1963.

Other references Beentje, 1994; Berjak et al., 2004; Berjak & Mycock, 2004; Burkill, 1997; Burring, 2006; Choinski, 1990; Coates Palgrave, 1983; Mulholland & Taylor, 1980; Pennington & Styles, 1975; Ruffo, Birnie & Tengnäs, 2002; Song, Berjak & Pammenter, 2004; Styles & Vosa, 1971; Styles & White, 1991; van Wyk & Gericke, 2000; Wild, Biegel & Mavi, 1972.

Sources of illustration de Wilde, 1986.

Authors A. Maroyi

TRICHILIA EMETICA Vahl

Protologue Symb. bot. 1: 31 (1790).

Family Meliaceae

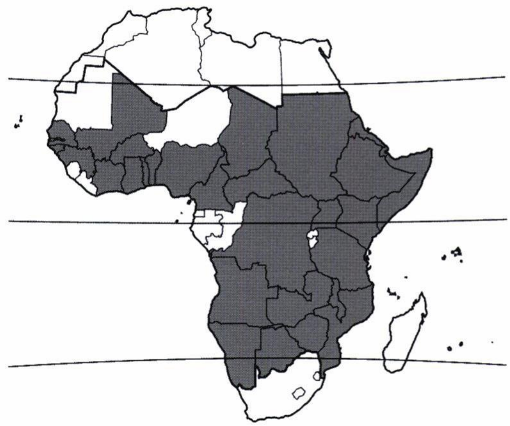
Chromosome number $2n = 50$

Synonyms *Trichilia roka* Chiov. (1932).

Vernacular names Mafura butter, Natal mahogany, Ethiopian mahogany, Christmas bells (En). Mafura (Fr). Mafurreira (Po). Mkungwina, mafura, mti maji, muwamaji, musikili, mgolimazi (Sw).

Origin and geographical distribution *Trichilia emetica* is very widely distributed in tropical Africa and occurs from Senegal east to Eritrea and south to South Africa. It also occurs naturally in Yemen and has been introduced as an ornamental into Cape Verde.

Uses The seed of *Trichilia emetica* yields two kinds of oil: 'mafura oil' from the fleshy seed envelope (sarcotesta) and 'mafura butter', also called 'mafura tallow', from the kernel. In traditional extraction they may be extracted separately, in commercial extraction they are combined to a single product. Mafura oil is edible, but mafura butter is unsuitable for consump-



Trichilia emetica – wild

tion because of its bitter taste. It is used in soap and candle making, as a body ointment, wood-oil and for medicinal purposes. The seed cake is only useful as fertilizer. In some areas the seed envelope is chewed as a substitute for kola.

The leaves are eaten by cattle and goats, and have been used as a soap substitute. The wood is one of the most important timbers used in woodcarving in southern Africa. It is also used for furniture, household articles, musical instruments, canoes, chew-sticks and as fuel. *Trichilia emetica* is grown in agroforestry as a shade tree in gardens and to control erosion. In gardens, parking lots and along roads it is grown as a fast-growing shade tree. In South Africa a pinkish dye is obtained from the bark.

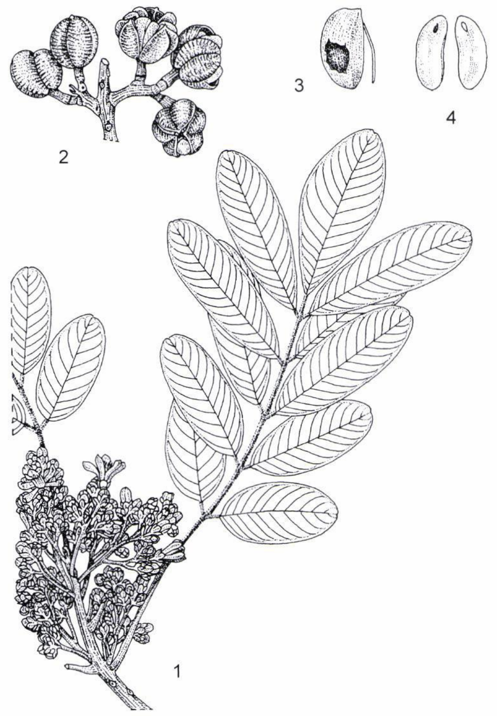
In traditional medicine, various parts of *Trichilia emetica* are used for a wide variety of complaints. The bark soaked in water is used as an emetic, for treating intestinal ailments and as a purgative. It is used in small doses only as its effects can be violent. A decoction of the bark and roots is a remedy for colds, pneumonia and for a variety of intestinal disorders including hepatitis. In Senegal a macerate of root bark is used to treat epilepsy and leprosy, while in Mali powdered root is given to treat cirrhosis, river blindness, ascariasis and dysmenorrhoea. A decoction of the roots is also used to treat infertility and to induce labour in women. Leaves are taken in southern Senegal against blennorrhoea. In Zimbabwe the bark is used to induce abortion and as fish poison. The oil is consumed to relieve rheumatism and to treat leprosy and fractures.

Production and international trade Mafura butter has long been exported from East Africa. The main exporter was Mozambique, from where exports continue on a small scale. Production in Mozambique in the period 2000–2004 was estimated at 100–300 t/year. Up-to-date information on economic production and trade for other countries is lacking.

Properties The approximate nutritional composition of the seed of *Trichilia emetica* per 100 g dry matter (58% of fresh weight) is: energy 1897 kJ (453 kcal), crude protein 17 g, fat 23 g, fibre 8 g, carbohydrate 48 g, Mg 110 mg, P 316 mg, Fe 4.3 mg (Saka & Msonthi, 1994). Per 100 g, the envelope of the seed contains 35–60 g oil, the kernel 60–65 g fat. The fatty acid composition of the fat is: palmitic acid 34%, stearic acid 3%, oleic acid 51%, linoleic acid 11% and linolenic acid 1%; another analysis indicates: myristic acid 1%, palmitic acid 53%, stearic acid 2%, oleic acid 28%, linoleic acid 16%, linolenic acid 0.3%. The seeds are poisonous and the poisonous compounds seem to be concentrated in the seedcoat. Little is known about the chemical compounds associated with the medicinal uses of the various plant parts. An aqueous extract of the leaves has shown pronounced antifungal properties against a number of plant pathogens. Crushed seed almost completely protected cowpea seed from storage pests when mixed at a dosage of 1%.

The heartwood is pale red, pinkish brown or grey-green and darkens upon exposure. It is not distinctly demarcated from the white to yellow sapwood. The wood dries fast and easily with small to moderate shrinkage rates. At 12% moisture content the density is 560–600 kg/m^3. The modulus of rupture is 50–85 N/mm^2, modulus of elasticity about 8500 N/mm^2 and shear 9–13 N/mm^2. The wood is comparatively soft and easy to work. It saws rather slowly and with moderate blunting of sawteeth. Its veneering and moulding properties are good. The wood is not durable and is susceptible to fungal attack, borers and termites. The heartwood is moderately resistant to preservation, the sapwood is permeable.

Description Evergreen or deciduous, dioecious shrub to small or medium-sized tree up to 30 m tall; bole cylindrical, up to 80 cm in diameter, swollen at base, sometimes becoming fluted with age; outer bark dark grey or brown, smooth to slightly rough, irregularly fissured. Leaves alternate, imparipinnately compound with (2–)3–6 pairs of leaflets; stipules absent; petiole and rachis up to 28 cm long; petiolules up to 5 mm long; leaflets opposite, elliptical to oblong or obovate, up to 15 cm × 6 cm, base rounded or cuneate, apex rounded or slightly notched, entire, usually hairy below, pinnately veined with (7–)10–16(–22) pairs of lateral veins. Inflorescence an axillary or terminal congested or lax panicle up to 9(–14) cm long, usually many-flowered. Flowers unisexual, male and female flowers very similar in appearance, regular, 5-merous, pale green to pale yellow, fragrant; pedicel up to 5 mm long; calyx cup-shaped, lobed nearly to the base with lobes 2–6 mm long, hairy; petals free, narrowly obovate or narrowly oblong, 9–18(–20) mm long, hairy; stamens 10, 8–12 mm long, united into a tube in basal half, densely hairy inside; ovary superior, densely hairy, 3-celled, style 4–8 mm long, stigma head-shaped or disk-shaped; male flowers with rudimentary ovary, female flowers with non-dehiscing anthers. Fruit an obovoid to globose capsule, 2–4 cm long, slightly 3-lobed, with up to 1 cm long stipe, dehiscent, up to 6-seeded. Seeds 15–20 mm long, nearly black, almost completely concealed in scarlet sarcotesta.



Trichilia emetica – *1, flowering twig; 2, fruits; 3, seed; 4, kernel.*
Redrawn and adapted by Achmad Satiri Nurhaman

Seedling with epigeal germination; hypocotyl up to 8 mm long, epicotyl 2–4 cm long; cotyledons sessile, fleshy.

Other botanical information *Trichilia* comprises about 90 species, most of them in tropical America. In continental Africa 18 species occur, in Madagascar 6. *Trichilia emetica* is closely related and very similar to *Trichilia dregeana* Sond. The two species are often confused. The latter occurs in wetter locations and can be distinguished by the absence of a stipe in the fruit. *Trichilia emetica* has two subspecies: subsp. *emetica* and subsp. *suberosa* J.J.de Wilde. Subsp. *suberosa* occurs from Senegal to Uganda; subsp. *emetica* from Eritrea and Ethiopia to South Africa. The two subspecies co-occur round Lake Victoria, where they may hybridize. Subsp. *suberosa* tends to be smaller and even shrub-like and has twigs with a corky bark and more lax inflorescences.

Growth and development *Trichilia emetica* is fast growing. Growth rates of 1 m/year in cooler climates and up to 2 m/year under optimal conditions have been recorded. Under optimal conditions trees start producing fruit when 6–8 years old, but in Zimbabwe 10 years is more common and even 20 years for trees growing in shady conditions. In southern Africa the flowering period is in August–October, fruiting in December–March; in Tanzania flowering is in July–November, fruit ripens in February–April and is collected in April–July. Seed production varies strongly from year to year. The tree coppices well.

Ecology *Trichilia emetica* grows in riverine forest and in various types of woodland. Subsp. *suberosa* occurs in open savanna woodland subject to grass fires, subsp. *emetica* on more fertile soil of river banks and floodplains. The tree grows in areas with moderate to high mean temperatures. It tolerates mean annual temperatures of 19–31°C. It is found from sea-level to 1800(–2100) m. Frost is not tolerated. It requires an annual rainfall of at least (500–)1000 mm, the lower ranges only where groundwater is available. It is capable of withstanding long periods of drought. Alluvial soils are preferred; in Tanzania it is common on vertisols. They should be well drained and have an elevated ground water table.

Propagation and planting *Trichilia emetica* regenerates naturally from seed or from suckers after wounding. Seed may be dispersed by water but also by birds, including hornbills. Adequate regeneration occurs only under a canopy; regeneration is inadequate when only a few seed trees remain in large forest gaps. Young trees may grow in deep shade under the older trees and may be found in small groups of various sizes.

Seeds are perishable and should not be allowed to dry and should be sown as soon as possible. To extract the seed, ripe fruits are spread on a mesh in the shade until all fruits have opened. Seeds are then separated and the fleshy envelope is removed by maceration in water, which greatly increases the germination rate. Subsequently the seed is spread out to allow the surface to dry. Well-prepared seed germinates within 10–20 days after sowing. One kg of fruit contains about 250 g of seed; the weight of 1000 seeds is 1–2 kg. Seedlings can be planted out when 6–8 months old and initially require shade. They are best planted out under a stand of about 30 existing trees per ha to provide shade. Recommended spacing in pure stands is 3 m × 3 m for fruit production. It can also be planted at 6 m × 6 m in agroforestry systems. Propagation is possible from cuttings. Cuttings can be taken from layered branches, roots or 1-year-old coppice shoots. They can be planted in the sun, but preferably under some shade.

Management In plantations weed growth should be controlled since seedlings are sensitive to competition. Removal of weeds before planting is needed and several weedings should be carried out in the first few years.

Pests and diseases Many mammals feed on the leaves as do the larvae of the white-barred charaxes butterfly (*Charaxes* sp.). Brown leaf scales have also been observed on leaves, resulting in circular holes of up 7 mm in diameter when the scales drop off.

Yield Seed yields of individual trees vary greatly per tree and per year and range from 20–180 kg/year, averaging 45–65 kg.

Harvesting Ripe fruits are best collected from the tree; fallen fruits are often of poor quality.

Handling after harvest The oil and fat can be extracted from the seed separately or simultaneously. Traditionally, the seeds are immersed in hot water. The seed envelope is macerated and the oil floats to the surface and is scooped off. Then the seeds are crushed and the solid fat is expressed or also separated by boiling. Solvent extraction of the fat is also possible. Commercially oil and fat are extracted together in a single operation.

Logs should be treated soon after felling to avoid losses due to blue stain.

Genetic resources Seed of *Trichilia emetica* is recalcitrant and cannot be stored for longer periods. The possibility of storing excised embryos is being investigated for *Trichilia dregeana*, which may offer possibilities for *Trichilia emetica*. No live collections of germplasm are known to exist. As *Trichilia emetica* is widespread, there is no danger of genetic erosion.

Prospects *Trichilia emetica* can be planted in plantations or agroforestry systems to attain various services and products. It is fast growing and can attain productive size within a relatively short period. The potential for production of medicines from oil, bark or roots urgently requires research attention. This tree also has potential for use as an alternative pesticide. The use of mafura butter in cosmetics deserves to be promoted.

Major references Coates Palgrave, 1983; de Wilde, 1986; FAO, 1983; Grundy & Campbell, 1993; Hines & Eckman, 1993; Jøker, 2003; Saka & Msonthi, 1994; Styles & White, 1991; White, Styles & Gonçalves, 1979.

Other references Bandeira, Albano & Barbosa, 1999; Bolza & Keating, 1972; Botha, 2004; Fupi, 1982; Germanò et al., 2001; Germanò et al., 2005; Germanò et al., 2006; Godin & Spensley, 1971; Hoet et al., 2004; IMF, 2005; Keita et al., 1995; Khumalo et al., 2002; Lovang & Wildt-Persson, 1998; Ruffo, Birnie & Tengnäs, 2002; Storrs, 1995; Venter & Venter, 1996; White & Styles, 1963.

Sources of illustration de Wilde, 1986.

Authors G.N. Mashungwa & R.M. Mmolotsi

VERNICIA MONTANA Lour.

Protologue Fl. cochinch. 2: 586 (1790).

Family Euphorbiaceae

Chromosome number $2n = 22$

Synonyms *Aleurites montana* (Lour.) E.H.Wilson (1913).

Vernacular names Wood-oil tree, mu-tree, Cantonese wood-oil tree, abrasin-oil tree (En). Abrasin, arbre à huile de bois (Fr). Falso castanheiro (Po).

Origin and geographic distribution *Vernicia montana* is native to Myanmar, Thailand, Indo-China and southern China. It has been introduced into many tropical and subtropical areas. In tropical Africa it has been introduced and has sometimes naturalized, e.g. in Kenya, Tanzania, Malawi, Zambia, Zimbabwe, Mozambique and Madagascar. On a commercial scale it has been grown in Malawi and Madagascar.

Uses The seeds of *Vernicia montana* yield a quick-drying oil called 'abrasin oil' or 'Chinese wood oil'. Because of its similarity to 'tung oil' from *Vernicia fordii* (Hemsl.) Airy Shaw, the oils 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 processed into soap or 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 poisonous 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 wood is only suitable for simple construction, corestock for plywood, paper pulp and firewood. *Vernicia montana* is sometimes planted as an ornamental and shade tree.

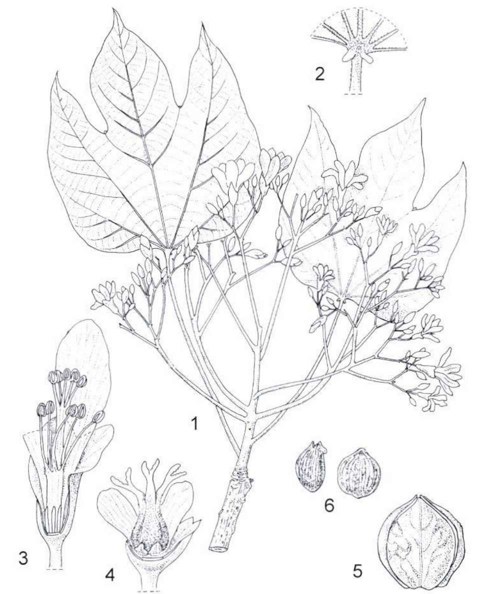
Production and international trade The oils from *Vernicia montana* and *Vernicia fordii* are traded together as tung oil. Annual world production of *Vernicia* fruits in the late 1990s was about 500,000 t from 170,000 ha, yielding 90,000 t oil. China produced 85% of the world production of which about 25% was exported. Since then the share of China has further increased. In 2004 it exported 19,000 t of oil, Paraguay 3600 t and Argentina 1300 t. Tung oil production in Malawi started in the 1930s. Exports grew to 1800 t in 1965, but then gradually declined to less than 400 t in the period 1975–1985 and to almost nil in the 1990s. Exports from Madagascar reached a peak of 1200 t in the late 1960s, but then also collapsed rapidly. Prices have fluctuated from over US$ 3000 per t at the end of 1993 to US$ 1200 two years later, they now average about US$ 1350.

Properties The fruit of *Vernicia montana* contains per 100 g 14–20 g of a drying oil. The oil is 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, 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 fatty acid composition of the oil is: α-eleostearic acid 75–80%, 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.

The wood is white, soft and perishable.

Description. Dioecious or sometimes monoecious, deciduous or evergreen shrub or small tree up to 15 m tall; young shoots, leaves and young fruits reddish brown hairy. Leaves alternate, simple; stipules lanceolate, 2–4 mm long, early caducous, leaving fairly prominent scars; petiole up to 25 cm long, grooved, with 2 stalked glands at junction with blade; blade ovate to broadly ovate or 3–5-palmately lobed, up to 20 cm × 18 cm, acuminate at apex, margins entire. Inflorescence a terminal, usually unisexual panicle composed of cymes; male inflorescence 15 cm × 15–20 cm, female inflorescence resembling the male one but often smaller. Flowers unisexual, showy; calyx covering bud and rupturing into 2(–3), often unequal lobes; petals 5(–6), free, oblanceolate to spatulate, 1.5–2.5 cm long, white, clawed; disk of 5–6(–7) erect glands up to 4 mm long; male flower with (7–)8–12(–14) stamens in 2 whorls, united into a c. 2 cm long column; female flowers with superior ovary, densely hairy, 3(–5)-celled, styles c. 8 mm long, united at base, 2-lobed. Fruit an ovoid to globose capsule c. 3.5 cm × 4 cm, apex pointed, with 3(–5) distinct longitudinal ridges and few transverse ribs, tardily dehiscent, glabrescent. Seeds obovoid to globose, 2–2.5 cm × 2–2.5 cm, pointed, brown with longitudinal beige variegations, smooth, hilum large. Seedling with epigeal germination; cotyledons broad, flat.



Vernicia montana – 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, seeds.
Source: PROSEA

Other botanical information The genera *Aleurites*, *Reutealis* and *Vernicia* are closely related and have long been combined in *Aleurites*. *Vernicia* comprises 3 species originating from Asia. *Vernicia cordata* (Thunb.) Airy Shaw from Japan has been introduced into Senegal. It yields 'Japanese wood oil'. *Vernicia fordii* originates from central and western China and has been cultivated for its oil in many subtropical areas. It has been tested at higher altitudes in the tropics (e.g. Malawi and Madagascar), but there *Vernicia montana* performs better.

Growth and development Two branching patterns occur in *Vernicia montana*, recognized in Malawi as types A and B. Similar types are also recognized in Indonesia as the Indo-China type and the China type. Type A is a fast-growing tree with a tall, straight trunk forming tiers of 5 spreading branches at regular intervals. Secondary branches form at relatively long intervals. Trees take 3–5 years to come into bearing. Type B is more shrub-like. When the main stem has produced 1 or 2 tiers of branches, it looses its dominance. Secondary branches are formed at short intervals. The trees come into bearing after 3 years. From the B type, several high-yielding vigorously growing clones have been selected.

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. The number of fruits set is generally high, but about 80% may abort during development.

Where *Vernicia fordii* and *Vernicia montana* grow together and flower simultaneously, hybridization is common, but the hybrids have no agronomic advantages.

Ecology *Vernicia montana* is planted in areas with annual rainfall of 850–2000 mm and average annual temperatures of 15–27°C. In tropical areas it is planted at altitudes of 800–2000 m. Its requirement of low temperatures for flower initiation is less than that of *Vernicia fordii* and it is sensitive to frost. *Vernicia montana* is often grown on slopes, but grows well on flat land provided it is well-drained. It prefers slightly acid soils and is susceptible to accumulations of ash; it 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 onto seedling rootstock. Fresh seed germinates quickly, but germination of older seed may take 2–3 months unless it is scarified. The weight of 100 seeds is about 325 g. When de loop of the hypocotyl becomes visible above the ground, seedlings are transferred from the germination bed to the nursery. Seedlings are transplanted into the field when they are 1 year old. In Malawi budding is done in the nursery. The simple shield method of budding at a height of 5–7.5 cm above the ground is commonly applied. In China planting density is about 600 trees/ha; in Malawi early plantations were established at about 7.5 m × 7.5 m, but in later plantings the plant density was increased. 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 been developed.

Management Young trees of *Vernicia montana* are often intercropped with food crops such as maize, groundnut or soya bean in China. In Malawi intercropping with annuals or planting of cover crops was common. Prolonged intercropping with annual crops may cause damage to the shallow root system of *Vernicia montana*, but in China even mature trees are sometimes intercropped with winter crops. Regular weeding around the plants is needed also for ease of harvesting. In hedgerow systems, pruning and training are recommended to obtain a frame of a few main branches and open crown. Little is known about the fertilizer requirements. In Malawi application of 50 kg N/ha as sulphate of ammonium gave yield increases of 400–1000 kg dry seed/ha. Application of the press cake as fertilizer has also given good results.

Seedling trees that do not produce well can be cut back and scions from high-yielding material can be grafted into the stump.

Diseases and pests In China anthracnose caused by *Glomerella cingulata* (synonym: *Colletotrichum gloeosporioides*) sometimes causes severe losses. Other important diseases include root rot caused by *Fusarium solani* and brown leaf spot caused by *Mycosphaerella aleuritides*. In Malawi the main diseases of *Vernicia montana* are die-back caused by *Botryosphaeria ribis* and root rot caused by *Armillaria mellea*. 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 animals. *Vernicia montana* is resistant to the thrips *Selenothrips rubrocinctus*, which causes damage in *Vernicia fordii* in China.

Harvesting Harvesting by manual collection of fallen fruits is most common, but in China green fruits are also picked from the trees. 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 Average yields of *Aleurites montana* are 3.5 t/ha in China and 1.8 t/ha in Malawi. In Malawi annual yields of air-dry seed of the best clonal material gradually increase from 280 kg/ha in 3–6-year-old plantations to 2200 kg/ha in 11–14-year-old plantations and 3000 kg/ha in 20-years-old plantations; yields of plantations of unselected seedling material are about half these amounts.

Handling after harvest In China the fruit is traditionally collected when still green, placed in heaps and covered with straw or grass. The fruit pulp is allowed to rot until the seeds can be easily removed. The seeds are then crushed in a mill and roasted for a short time in shallow iron pans. The crushed mass is then thoroughly steamed and subsequently the fluid is pressed out of the cake yielding commercial 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 *Vernicia montana* is 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*.

Breeding Selection work has been done in Malawi, but was discontinued. Breeding and selection programmes have been implemented in China and Taiwan.

Prospects In spite of the excellent quality of tung oil as a wood oil or a raw material for paint production, the decline of the tung oil production in all countries except China indicates that prospects to revive former plantations or establish new ones are bleak.

Major references Aguilar & Ong, 2001; Hill, 1965; Hill, 1966; Hill & Spurling, 1966; Phiri, 1985; Radcliffe-Smith, 1987; Radcliffe-Smith, 1996; Stuppy et al., 1999; Webster, Wiehe & Smee, 1950.

Other references Airy Shaw, 1967; Chen-Fei, 1998; Duke, 1983a; Foster, 1962; National Early Warning Unit, 1997; Purseglove, 1968; Radunz, He & Schmid, 1998; Sengers & Koster, 1998; Spurling & Spurling, 1974; Wit, 1950.

Sources of illustration Aguilar & Ong, 2001.

Authors L.P.A. Oyen

Based on PROSEA 14: Vegetable oils and fats.

VERNONIA GALAMENSIS (Cass.) Less.

Protologue Linnaea 4: 314 (1829).

Family Asteraceae (Compositae)

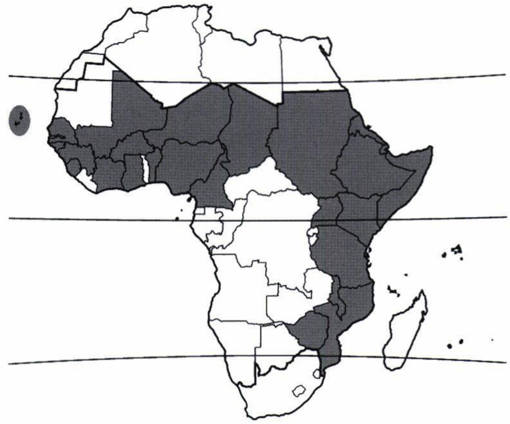
Chromosome number $2n = 18$

Synonyms *Centrapalus galamensis* Cass. (1817), *Vernonia pauciflora* (Willd.) Less. (1829) non (Pursh.) Poir., *Centrapalus pauciflorus* (Willd.) H.Rob. (1999).

Vernacular names Ironweed, vernonia (En).

Origin and geographic distribution *Vernonia galamensis* occurs naturally from Cape Verde and Senegal east to Eritrea and through East Africa south to Mozambique. The greatest diversity is found in East Africa, in West Africa only a single variety occurs. In the 1950s *Vernonia anthelmintica* (L.) Willd. was noted as a potential source of vernolic acid, but efforts to domesticate it have failed. In 1964 in semi-arid areas of eastern Ethiopia specimens of *Vernonia galamensis* were collected that combined a high vernolic acid content with a promising seed yield and good seed retention. *Vernonia galamensis* is now being developed as a potential industrial oil crop in several parts of the world.

Uses Traditionally, *Vernonia galamensis* is considered a weed. The high oil content of the seed and the high content of vernolic acid in the oil make it a potential oil crop. The oil, called 'vernonia oil' can be used in the chemical (glue, paint and plastics), pharmaceutical and agro-industrial industries. In the paint industry it is being tested as a component of low volatile-organic-solvent paints. As a component of heat-baked films and coatings, vernonia oil provides outstanding adhesion, flexibility and chipping resistance, and good resistance to



Vernonia galamensis – wild

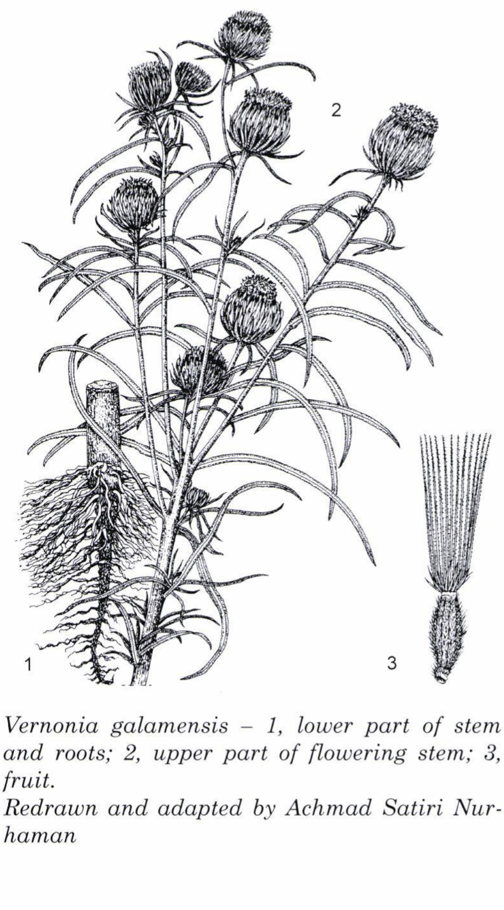
alkaline, acid and non-polar solvents. In plastics it can be used as a plasticizer of PVC and as a structural component of polymers. The presscake is suitable as animal feed.
The leaves have been smoked as a substitute for tobacco in Ethiopia. In Tanzania the leaves are cooked in porridge, or drunk as a tea to treat chest pain. In Kenya the plant is used to treat stomach pain.

Production and international trade Recently, commercial production of *Vernonia galamensis* has started in Ethiopia by Vernique Biotech. However, large-scale commercial production is still in its infancy and no data on production are available.

Properties The seed contains per 100 g: 20–27 g protein and 36–45 g oil. The average fatty acid composition of seed-oil samples from Ethiopia is (ranges between brackets): vernolic acid 74% (34–87%), palmitic acid 3% (2–8%), stearic acid 3% (1–7%), arachidic acid traces, oleic acid 5% (2–18%), linoleic acid 14% (7–35%). The presscake contains per 100 g: crude protein 44 g, crude fibre 11 g, ash 19 g, carbohydrate 7 g. The leaves contain a small amount of oil. The fatty acid composition of the leaf oil is: palmitic acid 12–22%, linolenic acid 41–59%, parinaric acid 8–17%; vernolic acid is only found in traces in the leaves.
Vernolic acid (cis-12,13-epoxy-cis-9-octadecenoic acid or 12,13-epoxyoleic acid) is characterized by its chemically active epoxy group. Much of the vernolic acid occurs as the triglyceride trivernolin, which has a lower viscosity than chemically prepared epoxy-oils. Because of their chemical structure, vernolic acid and trivernolin can undergo chemical reactions characteristic of ester groups, double bonds and epoxy groups. The low viscosity of the oil makes it a solvent in alkyd-resin paints. It is non-volatile, but polymerizes and becomes part of the paint coat.

Adulterations and substitutes Epoxy fatty acids for industrial purposes are mostly made industrially from petroleum products or from soya bean oil or linseed oil. Unless vernolic acid from *Vernonia galamensis* can be produced more cheaply, soya bean oil and linseed oil will remain the preferred raw materials for most purposes, but when low viscosity is required vernolic acid from *Vernonia galamensis* is economically more attractive than the more viscous epoxy oils derived from soya bean or linseed oil. Vernolic acid is present in smaller amounts in several other plants, bacteria and fungi. Apart from *Vernonia anthelmintica*, it was discovered in *Stokesia laevis* (Hill) Greene and *Euphorbia lagascae* Spreng. Efforts are underway to transfer genes encoding for a high vernolic acid content into *Brassica* and soya bean oil crops. However, the expression rate of the genes is much lower than in *Vernonia galamensis* and hence the economic potential of the transgenic crops is still not clear.

Description Usually annual herb up to 3(–5) m tall, but mostly much smaller; stems ribbed, finely to coarsely hairy, sometimes branching near the top. Leaves alternate, rather crowded, simple, sessile; blade elliptical to linear, up to 25 cm × 5 cm, base cuneate, apex acuminate, margins toothed, hairy on both surfaces, but glabrescent. Inflorescence a head, solitary or few to many in a terminal, lax to rather dense, leafy cyme; peduncle stout, pubescent; involucre ovoid to nearly globose, 8–25 mm × 1–15 mm, involucral bracts in 4–6 rows, pale green often with darker tip, outer ones linear, short, middle ones often hardened at base, tips usually leaf-like, inner ones oblong to narrow-lanceolate and acuminate, somewhat dry membranous. Flowers normally bisexual and



Vernonia galamensis – 1, lower part of stem and roots; 2, upper part of flowering stem; 3, fruit.
Redrawn and adapted by Achmad Satiri Nurhaman

fertile, long exserted; corolla 7.5–16 mm long, lower half tubular, gradually expanding above, bright blue to pale mauve, pink, purple, violet or almost white, sometimes flushed pale yellow or green, lobes 5, linear, 2–7 mm long, glandular; stamens 5, slightly exserted, anthers united into a tube; ovary inferior, style exserted, 2-branched. Fruit a narrowly obovoid achene up to 8 mm long, with 10 equal, narrow ribs, dark brown to black, densely appressed hairy; pappus in 2 whorls, outer pappus of up to 2 mm long barbed bristles, inner pappus of up to 11 mm long barbed bristles.

Other botanical information *Vernonia* comprises close to 1000 species. Most of them occur in South America; more than 300 species have been described from Africa with about one-third occurring in Madagascar and about 50 in Ethiopia. Recently it has been proposed that the Old World species of *Vernonia* be transferred to other genera; *Vernonia galamensis* then becomes *Centrapalus pauciflorus* (Willd.) H.Rob.

Vernonia galamensis is very variable; its centre of diversity is in Ethiopia, Kenya and Tanzania. To account for the morphological variability, 10 subspecific taxa (subspecies and varieties) have been described that are separated geographically or ecologically. Due to the high oil and vernolic acid content and its relatively low shattering nature, subsp. *galamensis* var. *ethiopica* M.G.Gilbert has been the focus of research aiming at domestication and commercialization.

Growth and development Seed may show some dormancy for a few months after maturation; thereafter germination takes about 10 days. Plants form a single unbranched stem ending in an inflorescence. Growth is indeterminate. Some plants may reach a height of only 20 cm and form only a single flowerhead, while others become vigorous, more than 2.5 m tall shrubs with many branches and flowerheads. Flowering is induced by short days, but plants have been found in subsp. *galamensis* var. *petitiana* (A.Rich.) M.G.Gilbert in southern and northern Ethiopia and Kenya that are only weakly quantitatively sensitive to daylength.

In an experiment with selections of var. *ethiopica* at different locations in Ethiopia, flowering started 87–117 days after sowing, and seeds matured after 161–261 days. When growing conditions permit, branching starts after formation of the main inflorescence and occurs only at the higher nodes; these branches may also form flowerheads. As a result ripening of the heads of a plant may be uneven. Shattering of mature fruiting heads occurs in most types, but types with limited shattering have been identified. *Vernonia galamensis* is self-fertile, but rates of outcrossing of up to 16% have been found.

Ecology *Vernonia galamensis* is adapted to the semi-arid tropics where it is found in dry bushland, but more often in ruderal places and as a weed of cultivation, up to 2000(–2500) m altitude. Only subsp. *afromontana* (R.E.Fr.) M.G.Gilbert var. *afromontana* occurs in montane forest, often in undisturbed areas. Rainfall may be as low as (250–)500 mm for some types, but as high as 1850 mm for other ones. In cultivation, *Vernonia galamensis* requires a rainy season that provides sufficient moisture to permit the main flowerheads to develop; a longer rainy season that permits secondary flowerheads to develop will result in poor uniformity of maturation and a risk of seed shattering. The plants tolerate substantial shading, which may make cultivation in agroforestry systems possible. A well-drained soil with pH 5.0–8.5 is preferred. On poorly drained soils, growth of the main stem stops before flowering; branches develop from the base of the plant, but they also wither and die.

Propagation and planting *Vernonia galamensis* is propagated by seed. As the seed is small, a firm, level seedbed is required. In experimental plantings in the United States plant spacings of 90–100 cm between rows and 15–30 cm within the row have given good results. In Ethiopia high yields for var. *ethiopica* were obtained at 40 cm between and 10 cm within rows. The weight of 1000 seeds is (2.5–)3.4–4.3 g; in var. *afromontana* larger seeds have been recorded, 1000 seeds weighing 5.4 g. The number of seeds per head averages about 240.

Management Seedling growth is slow and weeding is important. Pre-sowing herbicides have been applied successfully. Topping of young plants may reduce the risk of lodging and enhance uniform maturation. In a trial in Zimbabwe, plants of var. *ethiopica* topped at a height of 15 cm led to the development of 18–20 main branches per plant, each with 3–5 flowerheads. At harvesting, plant heights were less, lodging was significantly reduced and seed maturity more uniform. In var. *petitiana*, which tends to be shorter, the effect of topping was less pronounced. Fertilizer recommendations are not yet available, but in experiments in the United States, N applications of 100 kg/ha have given good results. In Ethiopia 150 kg N/ha caused lodging. Application of K and P gave little response.

Diseases and pests A leaf blight caused by *Alternaria alternata*, a root rot caused by a complex of *Fusarium solani*, *Rhizoctonia solani* and *Sclerotium rolfsii* and rust caused by *Puccinia* sp. have been observed where *Vernonia galamensis* has been grown for several years. Selections differed markedly in susceptibility. In Ethiopia a moderate incidence of helmet bug (*Captosoma* sp.) has been observed on maturing flowerheads and on young shoots, leaves and growing points, sometimes resulting in profuse branching of the stem. Harlequin bug (*Bagrada* sp.) infestation, which causes wilting, may also develop into a serious pest. *Cuscuta campestris* Yunk. has been found as a parasitic weed on *Vernonia galamensis* under natural and under field conditions.

Harvesting *Vernonia galamensis* matures unevenly and several harvesting rounds are often necessary. Harvesting of heads is done when the involucres surrounding the seeds are dry and spread out to release the fully mature seeds. At this stage seeds are 90% black in colour and firm. In var. *ethiopica* selections have been found with seed that remains on the plant for about 30 days after maturity. Growers can therefore postpone the harvest of a heterogeneous crop until most seeds are ripe.

Yield In the United States experimental seed yields of up to 2500 kg/ha from the best germplasm have been recorded. The best yields recorded in Ethiopia from local selections are 4000 kg/ha of seed, equivalent to 1625 kg/ha of oil.

Handling after harvest After the harvest, first the seeds are separated from the heads, then the pappus is removed from the seed. These are laborious and labour intensive operations if carried out manually.

Genetic resources Var. *ethiopica* is considered most promising as it has a high yield potential, high oil content, high vernolic acid content and good seed retention. Daylength-neutral types were found in var. *petitiana* in northern and southern Ethiopia and in Kenya. They are being used in breeding programmes in the United States.

Germplasm collections are maintained at the North Central Regional Plant Introduction Station, Ames, Iowa, United States (53 accessions) and at the National Genebank, KARI, Muguga, Kenya (38 accessions). Germplasm collection has covered most of Ethiopia. Nearly 500 accessions were collected from a wide range of habitats from1250 m to 2050 m altitude. They are being maintained and evaluated by the Alemaya University and Ethiopian Institute for Agricultural Research through its research stations in the country. The Ethiopian Institute of Biodiversity Conservation and Research holds a collection of 14 accessions.

Breeding In the United States, where daylength-neutral plants are needed, the focus of breeding work is on hybrids of var. *ethiopica* and var. *petitiana* to obtain high-yielding, daylength neutral types with good seed retention and non-dormant seed. Several generations of these selections have been produced and are being evaluated. Some breeding work, focussing on the characterization of germplasm, is being conducted in Ethiopia.

Prospects Especially for semi-arid tropical areas, *Vernonia galamensis* remains a promising oil plant, yielding an industrial raw material that can only partially be replaced by chemically prepared products. Its success, however, depends on the economic yields that can be obtained with improved selections and on the further development of industrial applications requiring the specific qualities of vernolic acid.

In general, this crop is suitable for cultivation in semi-arid and arid areas and can serve as a new cash crop, and hence create diversification of agricultural products for the farmers in developing countries of the tropics.

Major references Baye, 2002; Baye, 2004; Baye & Becker, 2005a; Baye & Becker, 2005b; Baye, Kebede & Belete, 2001; Gilbert, 1986; Jeffrey, 1988; Perdue, Carlson & Gilbert, 1986; Shimelis, Labuschagne & Hugo, 2006; Trumbo, Rudelich & Mote, 1999.

Other references Baye & Becker, 2004; Baye, Becker & Witzke-Ehbrecht, 2005; Beentje, 2000; Beentje et al., 2005; Bhardwaj et al., 2000; Carlson et al., 1981; Dierig & Thompson, 1993; Metzger & Bornscheuer, 2006; Robinson, 1999; Tefera & Baye, 2003; Teynor et al., 1992; Thompson et al., 1994; Thompson, Dierig & Kleiman, 1994.

Sources of illustration Gilbert, 1986.

Authors Tesfaye M. Baye & L.P.A. Oyen

VITELLARIA PARADOXA C.F.Gaertn.

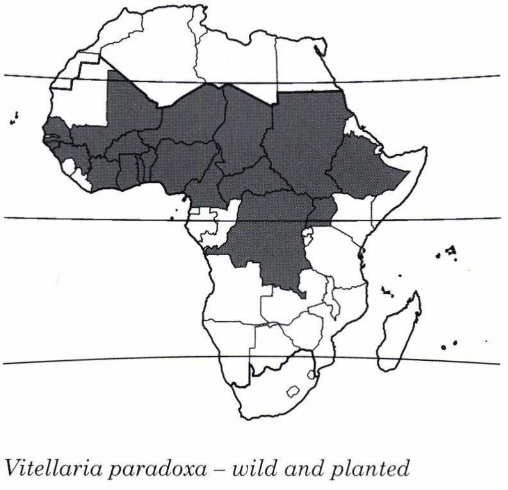
Protologue Suppl. carp.: 131, t. 205 (1807).
Family Sapotaceae
Chromosome number $2n = 24$

Synonyms *Butyrospermum niloticum* Kotschy (1865), *Butyrospermum parkii* (G.Don) Kotschy (1865), *Butyrospermum paradoxum* (C.F.Gaertn.) Hepper (1962).

Vernacular names Shea butter tree, shea tree, bambouk butter tree, galam butter tree (En). Karité, arbre à beurre (Fr). Cárei, carité (Po).

Origin and geographic distribution *Vitellaria paradoxa* is indigenous to the Guinea and Sudan savanna zone from Senegal to Sudan, and to western Ethiopia and Uganda, in a belt 500–700 km wide. It is found in the interior, separated from the Gulf of Guinea by forest; only in Ghana and Nigeria does it occur within 50 km from the coast.

Uses The kernel of the seed (often incorrectly called 'nut') contains a vegetable fat known as shea butter. High quality shea butter is consumed throughout West Africa as a cooking fat. Refined fat has been marketed as margarine and baking fat. It is used for pastries and confectionery because it makes the dough pliable. It is a substitute for cocoa butter, which has similar properties. Many cosmetic products, especially moisturizers, lotions and lipsticks, have shea butter as a base because its high unsaponifiable matter content imparts excellent moisturizing characteristics. Low-quality shea butter, often mixed with other oils, is a base material for soap. It is also very suitable for making candles because of its high melting point.



Vitellaria paradoxa – wild and planted

Shea butter is a suitable base for topical medicines. Its application relieves rheumatic and joint pains and heals wounds, swellings, dermatitis, bruises and other skin problems. It is used traditionally to relieve inflammation of the nostrils. Shea butter is given externally and internally to horses to treat sores and galls.

As a waterproofing agent, shea butter is used as daubing for earthen walls, doors and windows. The black sticky residue, left after oil extraction, is used to fill cracks in walls and also as a waterproofing material.

Waste water from shea butter production has pesticidal properties and has been mixed with stored cowpea seeds in Burkina Faso to protect them from being eaten by the weevil *Callosobruchus maculatus*. The press cake is unsuitable as livestock feed because it contains antinutritional compounds. However, detoxified meal can be given as feed in low proportions. In Europe the cake is utilized as a non-nutritional bulk for compound cakes. The press cake and the husks are also potential fertilizers and fuels.

The flowers and fruits are important foods. The flowers are sometimes made into fritters. In spite of their slightly laxative properties, mature fresh fruits are commonly eaten in savanna regions as they ripen during the land preparation and planting season. The sweet pulp of fallen ripe fruits can also be fed to livestock.

The leaves are used to treat stomach-ache. They are also added to vapour baths to treat headache and as an eye bath. Leaves soaked in water produce a good lather for washing. Ground roots and bark are used to treat diarrhoea, jaundice and stomach-ache. Roots are used as veterinary medicine for horses.

Bark infusions have medicinal and antimicrobial properties, e.g. against dysentery. They are applied as an eyewash to counteract spitting-cobra venom. A bark decoction has been used in baths to facilitate childbirth and stimulate lactation among feeding mothers.

The reddish latex (gutta shea or red kano rubber) which exudes from deep cuts in the bark is made into glue, chewing gum and balls for children's games. Musicians use it to repair drums.

Only unproductive and unhealthy trees are cut for timber. The wood is used for poles, house posts, rafters, flooring, domestic utensils and furniture. It is an excellent fuelwood, burning with great heat, and a source of charcoal.

Shea butter tree is an important source of honey. Beehives placed in its branches are assured a good supply of nectar and pollen. The widely collected edible and protein-rich caterpillar of *Cirina butyrospermi* feeds solely on its leaves.

The tree is considered sacred by many tribes. The oil is placed in ritual shrines and used for anointing. In some areas leaves are hung in doorways to protect newborn babies, and are also used in making masks.

Production and international trade *Vitellaria paradoxa* is one of the most important sources of vegetable oil in rural areas of the savanna zone of West Africa. The bulk of the seed produced is for home consumption and local trading. Nigeria is the leading producer of seeds: 355,000 t in 1999, 58% of the African production, but 10,000 t lower than in 1996. Mali and Burkina Faso are other leading producers; at the end of the 1990s they produced 85,000 t/year and 70,000 t/year, respectively, followed by Ghana (55,000 t), Côte d'Ivoire (20,000 t), Benin (15,000 t) and Togo (6500 t). Up-to-date statistics on seed production are not available for most countries. Reports on Burkina Faso show a remarkable increase in production to 222,000 t in 2005. Similar trends probably take place in other West African countries.

In 1998, Africa exported 56,000 t seeds, valued at US$ 10.5 million, of which 60% came from Ghana. Benin's exports decreased from 15,000 t in 1995 to 5600 t in 1998, Togo had only a slight decrease from 6500 t in 1994 to 5100 t in 1998, whereas exports from Burkina Faso increased from 5000 t in 1994 to 7600 t in 1997 and then to 26,600 in 2003. No export data have been reported for Nigeria since 1995. Processed shea butter exports in 1998 for the whole of Africa totalled 1200 t, worth US$ 571,000. Benin was top exporter (1000 t, valued at US$ 400,000), followed by Côte d'Ivoire (200 t) and Burkina Faso (30 t). African exports of shea butter have increased to 3200 t in year 2000.

Major seed importers in recent years were Belgium, Denmark, Japan, the Netherlands, Sweden and the United Kingdom.

Properties Shea butter from fresh seeds is white, odourless and of high quality, while that from stale seeds is dark, and tastes bitter. The approximate chemical composition of the kernel per 100 g dry matter is: fat 31–62 g, protein 7–9 g, carbohydrate 31–38 g, unsaponifiable matter 2.5–12 g. The fatty acid composition of shea butter is approximately: lauric acid trace, myristic acid trace, palmitic acid 4–8%, stearic acid 31–45%, oleic acid 43–56%, linoleic acid 4–8%, linolenic acid trace and arachidic acid 1–2%. The chemical properties of shea butter vary across its distribution range, Burkina Faso and Uganda representing the two extremes. The highest oleic acid content was found in Uganda (57%), the lowest in Burkina Faso (45%), while shea butter from the Mossi plateau in Burkina Faso has the highest proportion of stearic acid (45%) and that from Uganda the lowest (31%).

Shea butter is a useful cocoa butter substitute because it has a similar melting point (32–45°C) and high amounts of di-stearin (30%) and some stearo-palmitine (6.5%) which make it blend with cocoa butter without altering flow properties.

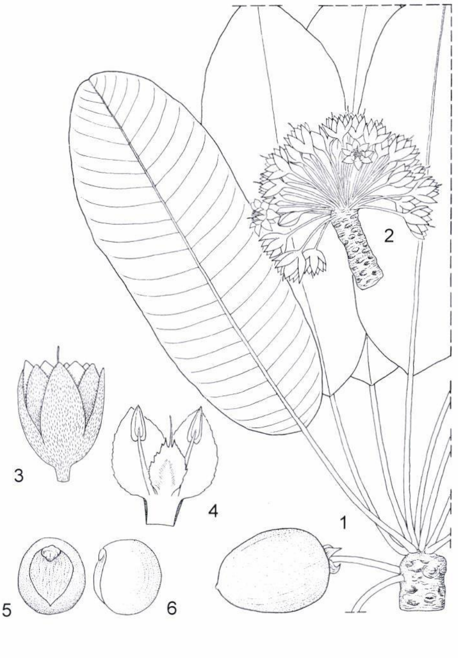
The high proportion of unsaponifiable matter, consisting of 60–70% triterpene alcohols, gives shea butter creams good penetrative properties that are particularly useful in cosmetics. Allantoin, another unsaponifiable compound, is responsible for the anti-inflammatory and healing effect on the skin. It is used in toothpastes and other oral hygiene products, in shampoos, lipsticks, cosmetic lotions and creams, and other cosmetic and pharmaceutical products. Clinical tests with patients suffering from rhinitis, and having moderate to severe nasal congestion, showed that shea butter may relieve nasal congestion better than conventional nasal drops.

The seed cake is a potential source of feed for livestock. Per 100 g dry matter it contains: protein 8–25 g, fat 2–20 g, carbohydrate 48–67.5 g, fibre 5–12 g. However, it has low digestibility and toxic properties attributed to saponins or tannins. Mouldy seeds contain relatively low quantities of aflatoxin, while commercial samples have a maximum of 20 µg aflatoxin B_1 per kg.

The fruit pulp contains per 100 g: glucose 1–2 g, fructose 1–2 g, sucrose 1–2 g, ascorbic acid 200 mg, Ca 36 mg, Mg 26 mg, Fe 2 mg, and trace amounts of Zn, Mn and Cu. Sweetness of the pulp is the main quality criterion.

The wood of *Vitellaria paradoxa* is moderately heavy (density about 720 kg/m^3 at 12% moisture content) and hard. It is liable to crack on drying and needs to be seasoned slowly. It is difficult to work and tends to split on sawing, but it polishes well. It glues, nails and screws well, but pre-boring is recommended to avoid splitting. It is durable and resistant to termites. Both sapwood and heartwood are resistant to impregnation with preservatives.

Description Small to medium-sized deciduous tree up to 15(–25) m tall; taproot up to 1(–2) m long, lateral roots shallow, concentrated at a depth of 10 cm and extending up to 20 m outward from the tree, secondary lateral roots growing downwards to the same depth as the tap root; bole short, usually 3–4 m long, up to 100 cm in diameter; bark blackish, greyish or reddish, rough, deeply fissured and splitting regularly into corky square or rectangular scales, producing white latex when cut; crown round to spindle-, umbrella- or broom-shaped; young branches initially pubescent and reddish but becoming glabrous, flowering branches stout, up to 1.5 cm in diameter, with numerous leaf scars. Leaves arranged spirally, mostly in dense clusters at the tips of branches, simple; stipules small and caducous; petiole 3–10 cm long; blade lanceolate to ovate-oblong, 10–25 cm × 4–14 cm, base cuneate to rounded or slightly cordate, apex rounded to acute, margins entire to wavy, leathery, glabrescent to



Vitellaria paradoxa – 1, tip of branch with leaves and fruit; 2, tip of branch with inflorescence; 3, flower; 4, part of corolla with staminode and 2 stamens; 5, seed in front view; 6, seed in side view.
Redrawn and adapted by M.M. Spitteler

slightly hairy at both surfaces, pinnately veined with regularly and closely spaced veins. Inflorescence a dense fascicle at the end of a twig, (8–)30–40(–100)-flowered. Flowers bisexual, regular, white or creamy white, fragrant; pedicel up to 3 cm long; sepals free, in 2 whorls of (3–)4, 1–1.5 cm long, pubescent; corolla with short tube and (6–)8 lobes about as long as sepals, contorted in bud; stamens (6–)8, inserted at top of corolla tube, free, staminodes (6–)8, alternating with the stamens, petal-like, with a filiform point; ovary superior, globose to ovoid, pubescent, (5–)6–8(–10)-celled, style long and slender. Fruit a globose to ellipsoid berry 4–5(–8) cm × 2.5–5 cm, weight (10–)20–30(–57) g, initially green but turning yellowish green or brown on maturity, 1(–2)-seeded. Seed globose or broadly ellipsoid, 3–5 cm × 2–3.5 cm, weight (5–)8–10(–16) g; seed coat rather thin, shining, with broad scar; kernel consisting of two thick, fleshy, closely adpressed cotyledons and not-exserted radicle. Seedling with hypogeal germination with cotyledons remaining in the seed; epicotyl 3–4 cm long, bearing stipulate rudimentary leaves.

Other botanical information *Vitellaria* comprises a single species. Two subspecies are recognized in *Vitellaria paradoxa*: subsp. *paradoxa* (synonym: *Butyrospermum parkii* (G.Don) Kotschy) and subsp. *nilotica* (Kotschy) A.N.Henry, Chithra & N.C.Nair (synonym: *Butyrospermum niloticum* Kotschy). Subsp. *paradoxa* has a less dense and shorter indumentum, and slightly smaller flowers than subsp. *nilotica*. The former occurs from Senegal to the Central African Republic, the latter is found in Sudan and Uganda with small populations in Ethiopia and DR Congo. The ranges of the two subspecies do not overlap, although they come to within 175 km of each other at the divide between the drainage basins of Lake Chad and the Congo River to the west, and the Nile to the east and north-east.

Growth and development Seeds of *Vitellaria paradoxa* are recalcitrant. After water absorption, the seed coat breaks and 2 days later a structure (sometimes called a 'pseudo-radicle', but anatomically the fused petioles of the cotyledons) emerges and grows downwards into the soil. When it is 7–8 cm long a shoot with rudimentary leaves arises from it and grows upwards to the soil surface. The structure itself continues to grow downwards, forming the taproot with a corky surface and lateral roots. When the shoot pushes through the soil surface it starts developing normal leaves. The taproot and secondary root system strongly develop during the first few years of growth. This enables the seedling to produce new shoots when the original ones are damaged by drought or fire. Early stem growth is slow; branching occurs after 4–7 years. *Vitellaria paradoxa* begins flowering at 10–25 years. Early flowers may be sterile. Maturity is reached at 20–45 years. The lifespan is 200–300 years.

Growth occurs in flushes, and according to Aubréville's model. A flush starts with the formation of a short, thick shoot on which a tuft of leaves develops. Branches owe their characteristic appearance to sympodial growth, producing twigs with alternating long, thin sections and short, compact ones. Leaves and flowers develop on the short, thick terminal section characterized by very short internodes and prominent leaf scars. When leaf development stops, growth of the branch continues from an axillary bud.

Leaf fall, flowering, flushing and the onset of fruiting occur during the dry season. Leaves drop mostly at the beginning of the dry season. Trees are rarely completely leafless, or only for relatively short periods. Flowering occurs from the beginning to the middle of the dry season (between November and January depending on latitude). In Uganda, where rainfall is bimodal, there is also a single flowering season, which peaks in February. Fire may cause defoliation followed by earlier flowering. Flowers attain full size about 3 weeks after their appearance. They are protogynous; styles are exserted from the unopened flowers before the pollen matures. Pollination is by insects (e.g. bees) or by wind. About 25% of the flowers set fruit. Fruits develop in 4–6 months; maturation peaks in the rainy season. Fruiting cycles are variable, 2–5 years long.

Ecology *Vitellaria paradoxa* is characteristic of West African savanna, but is also present in the southern Sahel. Subsp. *paradoxa* grows mostly at 100–600 m altitude (mean annual temperatures 25–29°C), although it also occurs up to 1300 m; subsp. *nilotica* occurs at 450–1600 m. Subsp. *paradoxa* grows in areas with mean annual rainfall of 600–1400 mm and 5–8 months dry season (precipitation less than 50 mm); subsp. *nilotica* grows in areas with mean annual rainfall of 900–1400 mm, with 3–5 dry months.

Vitellaria paradoxa grows on a variety of soils, such as clay, sandy clay, sand, stony soil and laterites. It prefers colluvial slopes with moderately moist, deep soils, rich in organic matter.

Propagation and planting *Vitellaria paradoxa* is propagated by seed. Seeds should not be dried, but sown as soon as possible because their viability is very short. When fresh seed is used, germination is 90–97% at 25–30°C. Storing seed at 25°C for 70 days and 140 days resulted in 96% and 88% germination, respectively. Seed can be planted directly in the field or in the nursery. Seed-beds are made of a mixture of organic compost and sand. Seeds are planted at 1–5 cm depth and 20 cm × 15 cm spacing or in polythene bags. After 1 year, seedlings are transplanted in the nursery or planted directly in the field. Those grown in polythene bags are transplanted after 1–2 years.

Vegetative propagation has only been successful in experiments. Grafting can accelerate the fruiting of *Vitellaria paradoxa*. In experiments in Burkina Faso, some grafted seedlings started to bear fruit one year after grafting. Latex exudation interferes with rooting of cuttings and with grafting. A 25% success rate can be achieved in grafting if the scion is soaked in water for a few hours to allow the latex to drain. Marcotting has been tried with some success; growth hormones improved the success rate.

Field spacing depends on the cropping system; recommendations vary from 25 trees per ha (20 m × 20 m) to 100 trees per ha (10 m × 10 m). Mulching and weeding encourage seedling growth. Young plants should be protected from livestock and fires. Slow growth and late maturation have discouraged the planting of *Vitellaria paradoxa* in plantations.

Management Shea butter tree has been protected by farmers for many centuries in the West African savanna, particularly where cattle are scarce. Productive shea butter trees are retained when new fields are cleared, giving rise to the so-called '*Vitellaria* parkland' in Sudan, in which more than 40% of the trees are *Vitellaria paradoxa*. Natural regeneration is favoured by fallow of at least 5 years. Shortening the fallow period leads to insufficient regeneration. In areas of cultivation, shea butter tree is found in association with annual crops, such as pearl millet, sorghum, groundnut, cotton, cassava, yams and vegetables.

Pruning, weeding, applying manure or fertilizer, and removing dead and diseased trees can markedly increase productivity. Recommended fertilizer applications are 2.5 kg ammonium sulphate, 1.5 kg calcium phosphate and 1.5 kg potassium chloride for 10 trees. Although *Vitellaria paradoxa* is fire tolerant, its growth and fruiting are affected by fire, so trees must be protected by ring weeding. Overgrazing by livestock should be prevented.

Diseases and pests Two fungal diseases are potentially important: *Pestalotia heterospora* causes leaf spot, while *Fusicladium butyrospermi* causes dark patches on branches. In Ghana *Botryodiplodia* spp. also causes leaf spot.

There are numerous insect pests, the most important being *Curimosphena senegalensis* (synonym: *Himatismus senegalensis*) which attacks young shoots, *Xyloctonus scolytoides* which tunnels through the bark of twigs impeding growth of leaves and flower buds, *Nephopteryx* sp. which damages fruits, and *Cirina butyrospermi* which causes defoliation. Fruits are attacked by maize cob borer *Mussidia nigrivenella* and the fruit fly *Ceratitis silvestrii*, which feeds on the pulp of maturing fruits. Shea butter tree is a host of the nematode *Aphasmatylenchus straturatus*, which also affects intercropped legumes. Trees are often hosts to strangler figs (*Ficus* spp.) and hemiparasitic plants (*Tapinanthus* spp.). In Burkina Faso and Mali, up to 95% of the trees are infested. Unless controlled by removing and burning affected branches, infestation will eventually kill the trees.

Harvesting Fruits are gathered in the wet season, usually in June–August depending on latitude. Harvesting continues for about 2.5 months, and is done mostly by women and children. Fallen fruits are collected from the ground because it is difficult to distinguish between ripening and fully mature fruit. Harvesting rights depend on tenure. A woman collects 20–45 kg of fruits per day, depending on ethnic group, proximity of trees to the village, and distance between trees. Fruits are brought back to the village in head-loads of about 25 kg.

Yield Productivity of shea butter trees is variable. In a sample taken in Burkina Faso, the best 25% of the trees produced 60% of the yield, while the poorest 30% of trees produced little fruit. A good tree can bear on average 15–30 kg fruits per year. In a good year this may be as much as 50 kg, but then only about 15 kg in the next two years. Although a clear production cycle is not confirmed, observations show a tendency for *Vitellaria paradoxa* to give only 1 good harvest per 3–4 years.

Handling after harvest In rural areas, seeds are traditionally processed by hot water extraction, usually the job of women. The fruit pulp is first removed for food, or by fermentation or boiling. The seeds are then boiled and later sun- or kiln-dried. Sun-drying may take 5–10 days. Seeds are cracked using mortar and pestle, or stones; the kernels are removed by trampling and redried before being crushed, ground and kneaded to form a paste; the paste is put in water, heated or boiled and the boiling mass is churned until a grey, oily fat separates from the emulsion. The fat is skimmed off from the surface and washed to remove impurities. The congealed fat may subsequently undergo further refining before being moulded in to various forms. This traditional method of processing is inefficient and labour intensive. Mechanization of the various operations, in particular the use of hydraulic or continuous screw expellers or application of solvent extraction, will improve oil extraction efficiency considerably. Pretreatment of the kernel paste with enzymes (e.g. proteases and cellulases) may also result in higher extraction rates.

Genetic resources There are indications that genetic variation in *Vitellaria paradoxa* is higher within populations than between them and selection of many individual trees from a limited number of populations would probably adequately capture the genetic variability, especially for fruit traits. However, differences between populations have also been found, e.g. in the fatty acid composition. The genetic diversity is gradually being lost because of bush fires and overgrazing. *Vitellaria paradoxa* is designated as one of the African forest genetic resource priorities. It is the subject of in situ conservation and germplasm exploration. Local and regional germplasm collections have been made by the Institut National de l'Environnement et de Recherches Agricoles (INERA) and the Centre National de Semences Forestières (CNSF) in Burkina Faso, the Cooperative Office for Voluntary Organisations of Uganda and the World Agroforestry Centre (ICRAF) in Mali. There are also local collections; those of Ghana's Cocoa Research Institute were analyzed for fruit and seed size and fat content.

Breeding The Cocoa Research Institute of Ghana has started a breeding programme to select and breed cultivars that establish easily in the field and have seeds with high fat content. The long juvenile phase and the difficulty of vegetative propagation of *Vitellaria paradoxa* make breeding a long-term process.

Prospects Shea butter tree is of great economic importance in the Guinea and Sudan savanna zones. It grows over a wide area, regenerates well, is traditionally managed and protected by farmers. However, natural regeneration and sustainability of seed production are threatened by agricultural intensification in the area. Progress made on grafting techniques suggest that selected vegetative material with specific fruit or butter qualities can be multiplied for small scale clonal plantations to meet market demand for high quality fruit or butter production. *Vitellaria paradoxa* has a niche in the international markets as a cocoa butter substitute in the food, cosmetic and pharmaceutical industries. Recent studies on the variation in fat composition across the species distribution range indicate that the soft shea butter from Uganda is preferred for cosmetic purposes, while shea butter with a higher stearic acid content as found in Burkina Faso is more suitable for the chocolate industry. Shea butter is increasingly popular as an ingredient in cosmetics and soaps, especially in European countries and the United States. Now that the European Union allows the use of 5% cocoa butter substitutes in chocolate, chocolate and confectionery products account for 95% of the shea butter demand, with only 5 percent currently used for cosmetic and pharmaceutic products. It is likely that the overall demand for shea butter will continue to rise in the world market as a result of progress made in better knowledge of its various properties.

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Other references Agyemang Dwomoh, 2003; de Beij, 1986; Di Vincenzo et al., 2005; Gamene, 1997; Heine, 1963; IPGRI & INIA, 2006; Jackson, 1968; Lamien et al., 2007; Maranz et al., 2004b; Maranz & Wiesman, 2003; Okullo, Hall & Obua, 2004; Sanou, Lovett & Bouvet, 2005; Sanou et al., 2004; Sanou et al., 2006; Tano-Debrah, Yoshimura & Ohta, 1996; Teklehaimanot, 2004.

Sources of illustration Aubréville, 1964.

Authors A. Nikiema & B.E. Umali

Vegetable oils with other primary use

List of species in other commodity groups (parenthesis), which are used for their oil. Synonyms are given in the indented lines (10 May 2007).
The names listed here have not been repeated in the Index of scientific plant names (p. 230).

Abroma angusta (fibres)
Acanthosicyos horridus (vegetables)
Adansonia digitata (vegetables)
Afraegle paniculata (fruits)
Afzelia pachyloba (timbers)
Anacardium occidentale (fruits)
Annona muricata (fruits)
Annona senegalensis (fruits)
  Annona arenaria
  Annona chrysophylla
Annona squamosa (fruits)
Anthrocaryon nannanii (timbers)
Aphanamixis polystachya (medicinal plants)
  Aglaia polystachya
Aptandra zenkeri (timbers)
Argemone mexicana (medicinal plants)
  Argemone ochroleuca
Autranella congolensis (timbers)
  Mimusops letestui
Avena sativa (cereals and pulses)
Averrhoa carambola (fruits)
Azadirachta indica (auxiliary plants)
Baillonella toxisperma (timbers)
  Mimusops djave
Balanites aegyptiaca (fruits)
Balanites wilsoniana (essential oils and exudates)
Bauhinia petersiana (cereals and pulses)
  Bauhinia macrantha
Bauhinia purpurea (ornamentals)
Bauhinia variegata (ornamentals)
Blighia sapida (fruits)
Bombax buonopozense (fibres)
Borassus aethiopum (fruits)
Brassica napus (vegetables)
Brassica rapa (vegetables)
  Brassica campestris
  Brassica chinensis
Brochoneura dardainei (spices and condiments)
Brochoneura voury (spices and condiments)
  Myristica voury
Caesalpinia bonduc (medicinal plants)
Calophyllum inophyllum (timbers)
Calophyllum tacamahaca (medicinal plants)
Canarium schweinfurthii (essential oils and exudates)
Cannabis sativa (medicinal plants)
  Cannabis indica
Carapa procera (medicinal plants)
  Carapa grandiflora
Cardiospermum grandiflorum (medicinal plants)
Cardiospermum halicacabum (medicinal plants)
Ceiba pentandra (timbers, fibres)
  Eriodendron anfractuosum
Celtis toka (auxiliary plants)
  Celtis integrifolia
Ceratotheca sesamoides (vegetables)
  Ceratotheca melanosperma
  Sesamum heudelotii
Chloroxylon swietenia (timbers)
Chrysobalanus icaco (fruits)
  Chrysobalanus ellipticus
  Chrysobalanus orbicularis
Chrysophyllum africanum (timbers)
  Chrysophyllum edule
Chrysophyllum lacourtianum (timbers)
Cinnamomum camphora (essential oils and exudates)
Citrullus colocynthis (medicinal plants)
  Colocynthis vulgaris
Citrullus lanatus (vegetables)
  Citrullus vulgaris
  Colocynthis citrullus
  Momordica lanata
Citrus aurantium (fruits)
Cleome gynandra (vegetables)
  Cleome pentaphylla
  Gynandropsis gynandra
  Gynandropsis pentaphylla
Cleome monophylla (vegetables)
Cochlospermum religiosum (essential oils and exudates)
  Cochlospermum gossypium
Coelocaryon preussii (timbers)
Combretum coccineum (medicinal plants)
  Combretum pachycladum
  Poivrea coccinea
Cordeauxia edulis (cereals and pulses)
Coula edulis (fruits)
Croton megalobotrys (timbers)
Cucumeropsis mannii (vegetables)
  Cucumeropsis edulis
Cucumis melo (vegetables)

Cucumis laevigatus
Cucumis sativus (vegetables)
Cucurbita maxima (vegetables)
Cucurbita moschata (vegetables)
Cucurbita pepo var. *moschata*
Cucurbita pepo (vegetables)
Cyperus esculentus (carbohydrates)
Dacryodes edulis (fruits)
Pachylobus edulis
Pachylobus saphu
Dacryodes klaineana (timbers)
Pachylobus deliciosus
Dalbergia sissoo (timbers)
Daniellia thurifera (timbers)
Dilobeia thouarsii (timbers)
Dypsis decipiens (ornamentals)
Chrysalidocarpus decipiens
Eruca vesicaria (vegetables)
Eruca sativa
Erucastrum arabicum (vegetables)
Brassica schimperi
Euphorbia enterophora (medicinal plants)
Gaertnera liberiensis (timbers)
Garcinia mangostana (fruits)
Garcinia orthoclada (medicinal plants)
Ochrocarpos orthocladus
Garcinia verrucosa (fruits)
Garcinia xanthochymus (fruits)
Xanthochymus pictorius
Gossypium arboreum (fibres)
Gossypium barbadense (fibres)
Gossypium herbaceum (fibres)
Guizotia scabra (vegetables)
Heisteria zimmereri (timbers)
Hevea brasiliensis (essential oils and exudates)
Hibiscus cannabinus (vegetables)
Hibiscus sabdariffa subsp. *cannabinus*
Hibiscus sabdariffa (vegetables)
Hildegardia barteri (auxiliary plants)
Hyphaene coriacea (carbohydrates)
Hyphaene hildebrandtii
Hyphaene natalensis
Hyphaene shatan
Hyptis spicigera (medicinal plants)
Hyptis suaveolens (medicinal plants)
Impatiens balsamina (ornamentals)
Indigofera leptoclada (medicinal plants)
Jatropha multifida (ornamentals)
Khaya senegalensis (timbers)
Klainedoxa gabonensis (timbers)
Labramia bojeri (fruits)
Lagenaria siceraria (vegetables)
Cucurbita lagenaria
Cucurbita siceraria
Lagenaria leucantha
Lagenaria vulgaris
Lannea acida (medicinal plants)
Lecomtedoxa nogo (timbers)
Lecomtedoxa heitziana.
Walkeria heitziana
Leonotis nepetifolia (medicinal plants)
Leonotis africana
Lepidium sativum (vegetables)
Lophira alata (timbers)
Lophira procera
Luffa acutangula (vegetables)
Cucumis acutangulus
Luffa cylindrica (fibres)
Luffa aegyptiaca
Maesa lanceolata (medicinal plants)
Maesa nuda (medicinal plants)
Mammea africana (timbers)
Melia azedarach (auxiliary plants)
Mesua ferrea (ornamentals)
Mimosa pudica (medicinal plants)
Mimusops elengi (timbers)
Monodora tenuifolia (spices and condiments)
Moringa hildebrandtii (medicinal plants)
Moringa oleifera (vegetables)
Moringa pterygosperma
Moringa stenopetala (vegetables)
Mucuna sloanei (dyes and tannins)
Mucuna urens
Myrica humilis (medicinal plants)
Myrica arborea
Myrica kandtiana
Myrica kilimandscharica
Myrica meyeri-johannis
Myrica salicifolia
Myrica serrata (medicinal plants)
Myrica microbracteata
Neocarya macrophylla (fruits)
Parinari macrophylla
Neolemonniera clitandrifolia (timbers)
Sideroxylon aylmeri
Ochna pulchra (timbers)
Odyendyea gabonensis (timbers)
Quassia gabonensis
Olea capensis (timbers)
Olea guineensis
Olea hochstetteri
Olea lancea
Olea welwitschii
Oncoba spinosa (timbers)
Oryza sativa (cereals and pulses)
Pachira glabra (fruits)
Bombacopsis glabra
Pappea capensis (fruits)
Pappea ugandensis
Parinari curatellifolia (fruits)
Parinari mobola
Parinari excelsa (timbers)

Parinari holstii
Parkia bicolor (timbers)
Passiflora edulis (fruits)
Persea americana (fruits)
Persea gratissima
Piliostigma thonningii (fibres)
Bauhinia thonningii
Pithecellobium dulce (auxiliary plants)
Plantago major (medicinal plants)
Poga oleosa (timbers)
Polygala butyracea (fibres)
Pongamia pinnata (medicinal plants)
Pouteria adolfi-friedericii (timbers)
Aningeria adolfi-friedericii
Prosopis africana (fuel plants)
Prunus persica (fruits)
Amygdalus persica
Persica vulgaris
Psophocarpus tetragonolobus (vegetables)
Quassia undulata (timbers)
Hannoa ferruginea
Hannoa klaineana
Hannoa undulata
Raphia farinifera (fibres)
Raphia ruffia
Raphia humilis (essential oils and exudates)
Ravenala madagascariensis (ornamentals)
Requienia obcordata (forages)
Tephrosia obcordata
Saccharum officinarum (carbohydrates)
Salvia nilotica (medicinal plants)
Salvia schimperi (spices and condiments)
Schleichera trijuga (fuel plants)
Schleichera oleosa
Sclerocarya birrea (fruits)
Poupartia birrea
Poupartia caffra
Sclerocarya caffra
Scyphocephalium mannii (timbers)
Scyphocephalium ochocoa
Securidaca longipedunculata (medicinal plants)
Sesamum alatum (vegetables)
Sesamum angustifolium (vegetables)
Sesamum calycinum var. *angustifolium*
Sesamum radiatum (vegetables)
Sesamum triphyllum (fibres)
Setaria italica (cereals and pulses)
Staudtia kamerunensis (timbers)
Staudtia gabonensis
Staudtia stipitata
Swietenia macrophylla (timbers)
Swietenia mahagoni (timbers)
Telfairia occidentalis (vegetables)
Tephrosia platycarpa (medicinal plants)
Tephrosia flexuosa
Terminalia catappa (ornamentals)
Tetracarpidium conophorum (fruits)
Plukenetia conophora
Tetrorchidium didymostemon (medicinal plants)
Tetrorchidium minus
Theobroma cacao (stimulants)
Thespesia lampas (ornamentals)
Azanza lampas
Thevetia peruviana (medicinal plants)
Cascabela thevetia
Thevetia neriifolia
Thymus vulgaris (spices and condiments)
Tieghemella africana (timbers)
Baillonella africana
Dumoria africana
Mimusops africana
Tieghemella heckelii (timbers)
Baillonella heckelii
Dumoria heckelii
Mimusops heckelii
Treculia africana (fruits)
Treculia madagascarica
Treculia mollis
Treculia perrieri
Trema orientalis (auxiliary plants)
Trema guineensis
Trichilia gilletii (medicinal plants)
Trigonella foenum-graecum (spices and condiments)
Tylosema esculentum (cereals and pulses)
Bauhinia esculenta
Voacanga thouarsii (medicinal plants)
Orchipeda thouarsii
Ximenia americana (fruits)
Ximenia caffra (fruits)
Xylocarpus granatum (dyes and tannins)
Carapa granatum
Carapa obovata
Xylocarpus obovatus
Zanthoxylum gilletii (timbers)
Fagara macrophylla
Fagara melanorhachis
Zanthoxylum tessmannii
Zea mays (cereals and pulses)

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PROTA

Plant Resources of Tropical Africa

Ressources végétales de l'Afrique tropicale

PROTA in short

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partageons les connaissances au profit des communautés rurales

sharing knowledge, improving rural livelihoods

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The Technical Centre for Agricultural and Rural Cooperation (CTA) was established in 1983 under the Lomé Convention between the ACP (African, Caribbean and Pacific) Group of States and the European Union Member States. Since 2000, it has operated within the framework of the ACP-EC Cotonou Agreement.

CTA's tasks are to develop and provide services that improve access to information for agricultural and rural development, and to strengthen the capacity of ACP countries to produce, acquire, exchange and utilise information in this area. CTA's programmes are designed to: provide a wide range of information products and services and enhance awareness of relevant information sources; promote the integrated use of appropriate communication channels and intensify contacts and information exchange (particularly intra-ACP); and develop ACP capacity to generate and manage agricultural information and to formulate ICM strategies, including those relevant to science and technology. CTA's work incorporates new developments in methodologies and cross-cutting issues such as gender and social capital.

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PROTA, short for 'Plant Resources of Tropical Africa', is an international programme focused on the 7,000 useful plants of Tropical Africa. Its purpose is to make available the wealth of dispersed knowledge on these plant resources for education, extension, research and industry through Internet databases, books, CD-Roms, and derived products such as brochures, leaflets, and manuals. A thorough knowledge of the plant resources is essential for arriving at ecologically balanced and sustainable land-use systems. A large international team of experts is contributing the texts on particular species. All species are described according to a standard format with details on uses, trade, properties, botany, ecology, agronomy or sylviculture, genetic resources, breeding, prospects and literature. In the printed series the species are grouped into commodity groups. More information on www.prota.org. 'Protabase' can be searched at: database.prota.org/search.htm.

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PROTA 14 deals with the plants of Tropical Africa yielding vegetable oils or fats. PROTA's database 'SPECIESLIST' presents 249 species used as such, but only 65 are 'primary use' vegetable oil plants, qualifying for treatment in this volume. The other 184 species have been listed as 'Vegetable oil plants with other primary use' and referred to other Handbook volumes.
The 65 'primary use' vegetable oils are described in 48 review articles, implying that 17 species have no separate article due to lack of information; they are only mentioned in the articles of related species.

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