Plant Resources of South-East Asia

No 19

Essential-oil plants

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Foreword

People have always been intrigued by the sensual impact of odour and flavour. The elusiveness of odour has given it symbolic and mythical meaning. Odours were thought to protect and heal and to form a link with ancestors and gods. Odour influences appetite and hence food consumption, and it subliminally guides our emotions and memories.

The plant kingdom provides a multitude of flavours and fragrances which have found their way into everyday life. Although the use of fresh fragrant flowers is still very important in South-East Asia, the most important sources of flavour and fragrance materials worldwide are essential oils: the volatile aromatic oily liquids obtained from odoriferous plant parts -- whether flowers, fruits, leaves, roots, or wood. They are applied as a flavouring for foods, soft drinks and confectionaries, in pharmaceutical products, and as fragrances in perfumes, cosmetics, and household and industrial products.

This volume focuses on plants yielding essential oils used as fragrance materials. It complements the Prosea volumes on edible fruits and nuts, medicinal and poisonous plants, spices, and plants producing exudates, which deal with plants that produce essential oils as important by-products.

Fragrance materials play a much more important and varied role in life than is often realized. Incense is burnt in religious ceremonies all over the world. In luxury perfumery, fragrance is used to subtly please the senses of the user and those nearby. Fragrance materials play a dual role in body care products. Many such products e.g. aftershaves and anti-perspirants, are actually also perfumery products, but others such as creams, shampoos and deodorants have essential oils added to them to make their use more pleasant. Functional perfumery covers a very wide range of products -- from soaps and detergents, to domestic cleaning products. Marketing often emphasizes the pleasurable consequences of using such products, as much as their effectiveness. The odour is then an important component of a comprehensive marketing strategy.

Recent advances in physico-chemical separation and analysis techniques have greatly extended the knowledge about the chemical composition of essential oils. But though the fragrance materials used in many cosmetic and household products are now largely synthetic, natural essential oils still play a central role in food and luxury perfumery, as the richness of their odour is unrivalled by synthetics.

Essential-oil plants are grown in nearly all latitudes, with tradition, labour costs and trade patterns being just as important as physical conditions and plant requirements. In Europe, Grasse (France) is synonymous with essential-oil plants (notably lavender). Elsewhere in the world, Hainan (China), Mauritius and Nosy Bé (Malagasy Republic) are prime producers. South-East Asia is already a major player in the production of several essential oils, including am-

brette seed oil, cajeput oil, cananga oil, citronella oil, lemongrass oil, sandalwood oil, vetiver oil and ylang-ylang oil, and is also the source of many spices that yield essential oils used in the perfume industry. The potential to expand the production of essential oils in South-East Asia seems great, as the area has a well-developed market for agricultural products, skilled industrious labour and relatively low wages, combined with a wide range of ecological conditions.
Like all Prosea publications, this volume is the result of the efforts of an international team of scientists, including botanists, agronomists, chemists and representatives of the perfumery industry. I hope that the information presented will focus attention on the potential for developing essential-oil crops, especially in South-East Asia.

Wageningen, November 1998

Professor Dr. C. Veerman
Chairman Executive Board
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1 Introduction

1.1 Definition and selection of species

An essential oil is a mixture of fragrant, volatile compounds, named after the aromatic plant material of a single type and identity from which it has been derived by a physical process and whose odour it has. This definition indicates that a given essential oil is always derived from a single species or variety. The opposite is not necessarily true: a single species may yield several essential oils because it may consist of several genetically defined chemotypes. *Cinnamomum camphora* (L.) J.S. Presl, for example, comprises several chemotypes each yielding a specific essential oil (Jantan & Goh, 1992). Also, various parts of a plant may yield different essential oils. The best example is *Citrus* L., where the flowers, fruits and leaves of many species and cultivar groups yield essential oils, each with its own characteristic olfactive qualities (Boelens, 1991). To add to the variability, ecological conditions influence many aspects of plant growth and may influence the composition of an essential oil. In trade, the origin of an oil is therefore often indicated by its name, e.g. Rose oil Bulgaria and Geranium oil Bourbon.

The definition given above states that an essential oil is derived by a physical process, i.e. it has not been purposely changed chemically. In industry, some essential oils are separated into chemical constituents that are either used directly or may be processed into different aroma chemicals. Such chemically isolated or changed products will not be considered further here. However, the physical process by which essential oils are obtained may also influence the chemical composition of an essential oil. Water distillation, steam distillation, hydrodiffusion, expression and solvent extraction produce different essential oils from the same plant material, because not all components are extracted equally well by each process or because individual components may undergo changes during the process. Such differences are generally minor, but are important for the quality of the essential oil, especially in luxury perfumery.

No definition is without exceptions. Oil of wintergreen, obtained from *Gaultheria* spp., for instance, is much richer in methyl salicylate than the living plant. After harvesting, the plant material is fermented for some time and during this process enzymes convert precursors into methyl salicylate (Arctander, 1960).

Essential oils have many functions for people. Most obvious is their role in fragrance materials, but they are equally important as flavouring materials and in medicine. The distinction between these uses can be vague. Perfumes are often used to favourably influence mood; aromatherapy goes further, by exploiting this to create a soothing, tranquillizing or healing effect on a patient (Lis-Balchin, 1997). In traditional medicine, essential oils are important in driving out diseases. In medical practice in Asia they are also widely applied, but in

Western medicine they are currently used mainly to improve the taste of drugs and as household preparations e.g. as disinfectants, against colds and in liniments against muscle pains. However, essential oils are also sources of many constituents that are used for more specific purposes. Linalool, one of the most widely ocurring compounds in essential oils, is an important source material for the production of vitamin E; citral, another important component of several essential oils, has long been used to produce vitamin A. The distinction between spices and fragrance materials is clearer. Spices have primarily a culinary use, to enhance the tastiness of foods, whereas fragrance materials appeal more directly to the sense of smell. However, many essential oils obtained from plants primarily used as a spice e.g. clove, ginger and cinnamon, also play a major role in luxury perfumery, cosmetics and functional perfumery. The reverse is almost equally true. Lavender leaves in a salad may add to its attractiveness, but the essential oil distilled from the flowering branches is primarily used to compose perfumes, cosmetics and industrial aroma products. Lemongrass oil is an important aroma product, whereas the leaves and leaf bases have an important culinary use in Indonesia and elsewhere. Citrus oils are indispensable for perfumery, but also for the flavouring of soft drinks. Rose petals are the source of one of the most important and costly essential oils, but because of their delicious smell and taste they are also made into confectionaries (Weiss, 1997).

Fragrant woods are important sources of aroma materials. Some of them yield fragrant exudates, such as the resins opopanax and myrrh from *Commiphora* spp., benzoin from *Styrax benzoin* Dryander and balsam from *Myroxylon* spp. Other fragrant woods such as *Cinnamomum camphora* and *Santalum album* L. yield their aromatic constituents on distillation and are thus considered sources of essential oils.

It is the plants used primarily for their essential oil that are covered in this volume. Plants yielding essential oil but with another primary use are dealt with in various other volumes of the Prosea Handbook, including the volumes: Edible fruits and nuts, Medicinal and poisonous plants and Spices (which includes culinary herbs), while a small number of species is treated in the volume: Plants producing exudates. The present volume deals with essential-oil plants that are grown or could be grown in South-East Asia. It includes a few plants that play a central role in the fragrance industry worldwide but are currently not grown for their essential oil in South-East Asia. At first sight, the selection of species for this volume may seem imbalanced: 2 groups of essential-oil yielding plants of major economic importance, *Mentha* and *Citrus* spp., appear to have been omitted or not dealt with properly. However, all *Mentha* spp. are covered in the volume on Medicinal and poisonous plants, and most *Citrus* spp. appear in the volume on Edible fruits and nuts. On the other hand, *Jasminum*, *Lavandula* and *Rosa* spp., which are mainly grown as ornamentals in South-East Asia, are included here because of the great importance of their essential oils on a world scale.

In total, 29 genera, species or cultivar groups are dealt with in Chapter 2, covering the major essential-oil plants grown or used in South-East Asia. Chapter 3 covers the essential-oil plants that are grown on a minor scale only, and also a few plants that do not currently occur naturally or in cultivation in South-East Asia, but are potentially suitable. Chapter 4 lists species that produce essential oil but have another primary use and have been assigned to other volumes of this Handbook.

1.2 Role of essential oils

1.2.1 History of essential oils and their production

The use of essential-oil plants for their pleasant fragrance is as old as human civilization. Incense and myrrh are the oldest known aromatic materials; they are mentioned in Assyrian clay tablets. Aromatic materials were widespread in Pharaonic Egypt as fragrance materials and to embalm corpses. Their role in embalming is well documented and the compounds used can be detected even today. The early use of fragrance materials is also well documented in the Indian Vedic literature. Hundreds of aromatic substances and their uses (mainly religious and medicinal) have been listed. Other classical sources are the Gilgamesh Epic, the Bible and Greek authors such as Herodotus and Hippocrates. Theophrastus (372–287 BC) gave the first detailed description of the procedure for preparing perfumes using extraction with fat. It is to Paracelsus (1493–1541) that we owe the term 'essential' in essential oil. He expounded the theory of the 'quinta essentia', believing that this quintessence was the truly effective element in a medical preparation; its isolation is an important goal of pharmaceutical science to this day (Teisseire, 1994).

Until the Middle Ages, distillation of fragrant plant materials was mainly used to prepare fragrant waters, the essential oil often being considered a waste product. Production technology was developed probably simultaneously in the Middle East and in India. In the 12th Century, primitive distillation equipment was improved by the addition of a condenser and the invention of steam distillation. The condenser greatly improves the efficiency of a still, whereas steam distillation prevents the plant material overheating and possibly leading to the formation of unwanted by-products. The first description of distillation of a true essential oil is generally attributed to Arnold de Villanova in the late 13th Century. Three centuries later, the publication of 2 books in Germany marked an important step forward in the understanding of perfume production. The first gave a detailed account of the distillation of spike lavender in France; the second added descriptions of the distillation of lavender and mentioned the use of 'exotic' essential oils from anise, cinnamon, clove, mace, and nutmeg. In the Middle East and the Mediterranean several other processes for the production of essential oil were developed or perfected: enfleurage, extraction and expression. In India an independent technology was developed for the production of 'attars'.

The development of the modern perfumery industry started in Grasse (France). This town had long been an important link in the trade between Italy and France and was also a centre of leather production and manufacturing of gloves. The fashion of perfuming gloves in the 17th Century led to the establishment of a perfume industry in Grasse, first on an artisanal scale but later as a modern industry. The area around the town became a centre of cultivation of cassie flower (*Acacia farnesiana* (L.) Willd.), geranium (*Pelargonium* L'Hérit.), jasmine (*Jasminum grandiflorum* L.), lavender (*Lavandula* L.), rose (*Rosa* L.), sour or bitter orange (*Citrus aurantium* L.) and tuberose (*Polianthes* *tuberosa* L.). Important contributions were made here to the development of industrial enfleurage and distillation equipment. Later, production of most essential-oil crops was transferred to countries where labour is cheaper and the centre of production and trade of luxury perfumes moved to Paris, which is still the world centre of perfumery. Further refinements in production technology also took place in France. At the beginning of the 19th Century it became possible to distil and purify alcohol to a product free of off-odours on an industrial scale. This made possible the development of alcohol-based or luxury perfumery as it is known today. Around 1870, Louis-Maximin Roure used this purified alcohol to extract the fragrant principles from 'pomades' and became the first to produce 'absolutes'. Just before his death in the 1880s he was the first to build an installation for hydrocarbon extraction of fragrant plant material on an industrial scale. He also planned to produce absolutes from the 'concrete' obtained by this process.

The development of organic chemistry from the end of the 19th Century completely changed the fragrance industry. Fragrance compounds were a major research subject in organic chemistry, as can be seen from the Nobel prizes awarded for research involving aroma chemicals. Kékulé (1873) coined the term 'terpene' to describe hydrocarbons of molecular formula $C_{10}H_{16}$ to which many aroma chemicals conform. Wallach, who received a Nobel prize for his work in 1910, identified many of the terpenes and recognized isoprene as the basic building block of terpenes. A second Nobel prize, for the work on terpenes, was awarded in 1947 to Robinson, who studied the condensation of isoprene. During the same period another group of aroma compounds was investigated by Ruzicka, who studied macrocyclic compounds with a characteristic musk odour and who received a Nobel prize for his work in 1939.

Organic chemistry made possible the isolation of individual chemicals from essential oils, their synthesis and the development of many new aroma compounds. The synthetic compounds not only allowed the production of cheap aroma materials which greatly extended their use into everyday products such as soaps, detergents and air fresheners, but also enhanced the development of new perfumes by subtly changing the fragrance of natural products. The development, for instance, of the famous perfume Chanel No 5 in 1921 was made possible by the application of synthetic fatty aldehydes. Important discoveries have been the syntheses of: piperonal or heliotropin whose odour is reminiscent of the flowers and essential oil from heliotrope (*Heliotropium peruvianum* L.) and coumarin, which occurs naturally e.g. in Tonka bean (*Dipteryx odorata* (Aubl.) Willd.) from salicylic acid. Ionones can be synthesized from citral or hydroxycitronellal. The odour of ionones from citral resembles that of orris (*Iris* spp.) and violet (*Viola odorata* L.), while those synthesized from hydroxycitronellal are reminiscent of lily of the valley (*Convallaria majalis* L.) (Teisseire, 1994).

1.2.2 Uses

While fresh fragrant flowers are widely grown and traded and the odour of burning incense pervades any temple and shrine, especially in Asia, it is the use of essential-oil plants in fragrance materials that is most important worldwide. There is a vast range of uses of fragrance products. The most appealing use is in luxury perfumery, where the use of the most exquisite, rare and costly materials is combined with all the cunning of product promotion to create products that are associated with the best moments in life. However, most uses of essential oils are more down to earth and are part of everyday life. Perfumery can be divided into several types, each using a range of products with respect to their application. The main groups are: luxury or alcoholic, cosmetic, functional and industrial or technical perfumery (Table 1).

Table 1. Classification of fragrance products.

luxury perfumery	'extrait' perfume or 'parfum', containing 15–30% perfume oil in high grade (90%) alcohol; 'eau de parfum', consisting of 15–18% perfume oil in 80–90% alcohol; 'eau de toilette' or toilet water, having 4–8% perfume oil in 80% alcohol; aftershave perfumes, containing 3–5% perfume oil in 70% alcohol; eau-de-cologne, consisting of 3–5% perfume oil in 70% alcohol, fresher and more volatile than similar 'parfums' and 'eaux de parfum'; splash colognes are toilet waters containing only 1–3% perfume oil in very dilute alcohol.
cosmetic perfumery	body care products, e.g. creams and lotions containing 0.5–2% perfume oil; hair care products, e.g. shampoos and conditioners having 0.5–2% perfume oil; deodorants, containing 0.5–1% perfume oil.
functional perfumery	soaps containing 1–2% perfume oil; detergents containing 0.1–0.5% perfume oil; bathing products containing 0.1–0.5% perfume oil; house-cleaning products containing 0.2–0.5% perfume oil.
technical perfumery	aroma compounds added to hazardous products, e.g. cooking gas; compounds masking unpleasant odours of products, e.g. plastics.

Source: Adapted from Curtis & Williams, 1994; Müller & Bräuer, 1992.

In luxury perfumery the main purpose is to enhance one's personal fragrance. Cosmetics or body and hair care products have another primary use, but imparting a pleasant personal fragrance is an essential quality. In functional perfumery the role of the fragrance compound is less pronounced; it mainly adds to the perceived quality of products such as soaps and detergents. In technical perfumery, odour may be added to a product to make it easier to recognize (e.g. natural gas) or to mask an unpleasant odour (e.g. plastics).

In industry, the purpose of adding fragrance to cosmetics, soaps and detergents is to promote their sales through the sense of smell. The odour should not only be pleasant, but should enhance the perceived performance of the product. Advertising plays a major role in our perception of odours. Such is the power of advertising that associating an odour with famous personalities or with exotic holiday destinations seems more important for the success of certain fragrance materials than the characteristics of the odour itself. So strong is this associative power that several essential oils once widely used in luxury perfumes have fallen out of fashion through their current association with soaps and detergents, as has happened with citronella oil.

In cosmetics, soaps and other utility products, only cheaper natural essential oils are used and these are almost always supplemented with synthetic aroma chemicals. This contrasts with the use of essential oils as flavour materials. In foods, regulations on the use of synthetic compounds are much stricter and the premium paid for natural products much higher.

1.3 Production techniques

Three distinct processes are used to produce essential oils: solvent extraction, expression and distillation. Solvent extraction of essential oils developed from the much older practice of mixing fragrant flowers with fatty oils to extract their fragrance. This principle led to the development of the 'enfleurage' technique, which allows efficient extraction of essential oil from delicate flowers that continue to produce aroma compounds for a long time. Solvent extraction is an industrial process in which highly purified, volatile hydrocarbons are used to dissolve aroma compounds from plant material, followed by the removal of the solvent by distillation.

Expression is used to obtain the essential oils from the peel of citrus fruits. It was originally a household industry using only very simple tools, but it has been superseded by large-scale industrial processes. Most citrus peel oils are produced as by-products of the citrus juice industry; only *Citrus bergamia* Risso & Poiteau and some cultivars of *Citrus aurantium* are grown especially for their peel oil.

Several forms of distillation are applied to produce essential oils, the most important being water distillation, steam distillation and hydrodiffusion. Water distillation or hydrodistillation is a very old process for the production of essential oil and has undergone centuries of improvement. Small-scale traditional water distillation apparatus is still being operated alongside large industrial equipment, for example in Mauritius, where *Pelargonium* is grown in small fields on poorly accessible hilly land. There it is more economical to operate small and simple portable stills than to move a bulky crop to a central still. The quality of the essential oil from Mauritius is maintained by traders who mix oil from several suppliers to obtain a standard quality. Steam distillation is a similar process, but hot steam is forced through the plant material to extract the essential oil. Large-scale industrial systems, e.g. continuous distillation systems and the use of harvesting containers that can double as distillation vessels, have been developed alongside small, traditional systems. Hydrodiffusion is a recent process in which low-temperature, low-pressure steam is used to extract the essential oils.

1.3.1 Enfleurage

One of the oldest techniques employed to capture the true odour of the most delicate flowers is 'enfleurage'. The technique originated in Asia, where it was a common household practice to place fresh flowers in fat or oil to capture their fragrance. In the mid-18th Century it was developed into a large-scale, commercial process in Grasse (France) where in its heyday thousands of women were employed in large enfleurage factories. The enfleurage process is mainly advantageous for flowers that continue to produce aroma compounds for several days after they have been picked. Jasmine, for example, produces 4–5 times more essential oil than is present at any time in the fresh flower, tuberose up to 12 times more. Using enfleurage, the yield of essential oil from these flowers is higher than when using extraction processes with volatile solvents or distillation. Currently, the technique has almost died out because of the very high labour cost involved. Only for the production of the highest quality tuberose oil is the process still occasionally used, and then only on a very small scale.

In 'enfleurage' a single layer flowers is placed on a tray covered beforehand with a thin layer of grease, which absorbs the volatile compounds from the flowers. Several chassis are stacked so that all aroma compounds emitted are absorbed by the grease. Pieces of cotton cloth soaked in oil and laid out on a metallic grid are used as an alternative to greased glass. The absorption takes 1–3 days, after which the flowers are replaced with fresh ones until the grease is saturated. The resulting product is called 'pomade' and was either used directly in cosmetics, but more commonly washed with alcohol. The resulting solution is known as an 'extrait' or 'absolute de pomade'.

Enfleurage was used to preserve the true odour of delicate flowers, such as cassie flower (*Acacia farnesiana*), heliotrope (*Heliotropium peruvianum*), jasmine (*Jasminum grandiflorum*), jonquil (*Narcissus jonquilla* L.), sour or bitter orange blossom (*Citrus aurantium*), tuberose (*Polianthes tuberosa*) and violet (*Viola odorata*).

In 'hot enfleurage' flowers are placed in linen bags, which are then dipped in melted fat, vegetable oil or mineral oil heated to about 50–60°C. After a maximum of 12 hours the bags are removed and replaced with fresh ones. When the oil is saturated it is pressed from the bags mechanically. The highest quality 'pomade' is obtained when the flowers are in contact with the absorbent for the maximum time (Gildemeister & Hoffmann, 1956–1966).

Efforts to extract the true odour of flowers recently resulted in a new technique: headspace analysis. This technique is used on flowers with a very attractive scent that produce too little essential oil to extract economically, such as lily of the valley and many orchids. A live flower still attached to the plant is carefully enclosed in a flask. The air in the flask then becomes saturated with the volatile compounds the flower emits. A sample of the air is fed directly into very sensitive analysing equipment, or the volatile compounds are first concentrated by condensation or adsorption. The technique is now so sensitive that even fluctuations in character and intensity of the odour can be recorded. As the amount of volatile compounds produced by these flowers is minute, the sole objective of these analyses is to obtain accurate analytical data on the odour that can help in reconstituting the odour of these flowers artificially. However, as the human nose is still about 1000 times more sensitive than modern analysers, it is not yet possible to capture the full richness of the scent of many flowers in compounded fragrance materials. The technique has also been used to find new aroma chemicals. A large number of very interesting, previously unknown compounds have been identified, several of which can be made synthetically (Kaiser, 1991; Raguso et al., 1998).

1.3.2 Solvent extraction

Extraction of aromatic plant materials with volatile solvents was developed in the mid-19th Century from hot enfleurage. Large-scale experiments were conducted independently by several workers, one of whom, named Garnier, obtained a patent for a novel type of extractor that became widely used first in France and subsequently in the rest of the world. This method gradually replaced the method of enfleurage.

The principle of solvent extraction is simple. Fresh aromatic plant material, e.g. flowers or comminuted leaves, is put into an extraction vat. A carefully purified volatile solvent is gradually fed into the top of the vat and allowed to seep through the plant material. The solvent penetrates the plant material and dissolves the aroma compounds, together with waxes, albuminous and colouring matter. The solvent with the dissolved compounds is subsequently transferred to an evaporator where the solvent is distilled off at a low temperature under partial vacuum, yielding a 'concrete'. Repeated washing of the concrete with alcohol to remove waxes and other inert matter produces an 'absolute'. The extraction procedure is repeated several times until all aroma compounds have been extracted. In the processing of spices a very similar process is used. The resulting extract containing fragrance compounds, waxes, resins and dye compounds are called oleoresins.

The solvent used should be carefully selected. It should quickly dissolve the odoriferous compounds, yet as little as possible of inert matter such as waxes, pigments and albumen. It must not absorb water, because this is difficult to remove from the extract. Frequently used solvents are petroleum ether (a mixture of mainly pentane and hexane obtained by fractionation of crude petroleum), benzene and alcohol, while for the extraction of spices hexane and dichloromethane are commonly applied. One solvent that has gained importance in recent years is carbon dioxide in liquid or supercritical form. Extraction with carbon dioxide is a costly process but has several advantages over extraction with other solvents. It is odourless, tasteless and non-toxic, and noncombustible. Because of its low viscosity it readily penetrates plant material and because of its low boiling point it is easily removed from the extract. The selectivity of the carbon dioxide extraction can be influenced by varying the temperature and pressure.

Solvent extraction is generally a more costly process than water or steam distillation. The process does not lend itself to simple, small-scale processing units, but requires large factories. Many solvents are highly flammable and costly when highly purified; they should be carefully recycled to avoid environmental pollution. Extracted flower oils are usually darker in colour and are more difficult to dissolve in alcohol than distilled ones. Advantages of extraction are that the process can be influenced more precisely and that, in general, the concretes and absolutes obtained, match the olfactive characteristics of the plant material more closely (Arnaudo, 1991; Schügerl, 1994).

1.3.3 Expression

Expression is used to obtain citrus peel oils, e.g. bergamot, grapefruit, lemon, lime, orange, tangerine. Many components of the essential oils from citrus fruits are delicate and suffer significantly from heat degradation when exposed to steam distillation. A 'cold expression' process is used therefore to obtain essential oils from citrus fruits; distillation is only used to valorize the residues of juice production, and even these distillations occur under vacuum at a maximum temperature of only 50°C, to minimize degradation. The only exception is lime (*Citrus aurantifolia* (Christm.) Swingle). The oil distilled from the rind of lime is commonly traded and its fragrance has become accepted as the typical lime odour. Cold pressed lime oil is a minor product only.

In all 'cold expression' methods the fruit peel is compressed, lacerated or abraded to rupture the oil cells in the exocarp and to release the essential oil. Two methods, both developed in Italy, have been used since early times: the 'spugna' or 'sponge method' and the 'scodella' or 'spoon method'. Modern expression methods are based on the same principles as these traditional methods.

In the 'spugna' method, fruits were halved and the juicy pulp was removed with a spoon-shaped knife. The peel was placed in warm water; the albedo or oilless mesocarp then absorbed water, effectively toughening it against fracture. This toughening was necessary to preserve the integrity of the peel during the second part of the process. This started with retrieving the peels from the water and pressing them individually against a small sponge with sufficient force to turn the peel inside out. Pressing and turning the peel ruptured the oil glands, which released the essential oil into the absorbent sponge. To retrieve the essential oil, the sponge was periodically squeezed over a collecting vessel or 'concolina'.

The 'scodella' method used a funnel-shaped or inverted bell-shaped bowl. The wide part of the bowl was covered with points, the narrower part was used as a funnel. Entire fruits were turned and pressed against the points, tearing the exocarp with the oil cells. The mixture of essential oil released together with cell contents and raspings was collected in the bottom of the funnel, from which it was periodically removed into a receptacle where separation of the oil would take place.

The 'pellatrice' method was developed from the 'scodella' method. A slowly turning Archimedean screw with an abrasive surface takes entire fruits from a container to a set of high speed rollers also covered with abrasive spikes. En route, the fruits are washed by a spray of constantly recycled water. The mixture of water, essential oil and detritus is collected and passed through a separator where any solids are removed. The mixture is then separated in a series of centrifuges to obtain the pure essential oil. The 'pellatrice' method is commonly employed in the production of bergamot oil. It has been refined into several continuous methods. In one of these, the 'Brown Process', the equipment consists of an elevator that feeds whole fruits to an extractor. The extractor comprises a tank in which a series of rollers covered with sharp points are placed. The rollers all rotate in the same direction, alternatingly at a high and a moderate speed, and also move laterally. As the fruits are moved through the tank by the rollers, they become thoroughly lacerated, which liberates the oil from the glands. The oil and debris are washed off with water flowing counter-currently through the tank, forming an emulsion of oil and water. Subsequently, the oil and water clinging to the fruits is removed by special rollers in a drying unit. The emulsion collected from the tank and the dryer is filtered and separated in a centrifuge (Arnaudo, 1991; Lawrence, 1995).

The 'sfumatrice' system is a refinement of the 'spugna' method. Fruits that have been halved and whose juice has been expressed are immersed in a solution of calcium carbonate and water for 24 hours to harden the peel and to facilitate expression of the oil. This also reduces degradation of the oil which occurs in an acid medium. The peels are then squeezed and contorted between a transport belt with elastic elements and ribbed rollers. As in the 'pellatrice' method, the essential oil is removed by sprays of water and subsequently separated by centrifuges.

A further refinement of the 'sfumatrice' method is the continouously operating 'F.M.C. in line extractor' of the Food Machinery and Chemical Co. Currently over half of all citrus peel oil is produced by this method. The equipment processes whole fruits and simultaneously extracts the fruit juice and the peel oil. The fruit is placed between 2 cups consisting of metal fingers. A small disk of peel is then cut from the bottom of the fruit. When the top cup is forced down, the fingers of the 2 cups interlock and squeeze the fruit, pressing out the juice. The pressure of the interlocking metal fingers also bursts the oil glands in the peel. The oil is washed off the fruit by strong water jets. Finally, the mixture of oils and water is collected and separated in a centrifuge (Arnaudo, 1991; Lawrence, 1995).

1.3.4 Distillation

The oldest distillation equipment known dates from the 4th Century AD. It used the familiar process of condensation of vapours on the lid of a cooking pot; the main modification was a rim around the inside of the lid, to collect and remove the condensate. A mixture of water and the material to be distilled was heated in the pot or vat by direct fire. Where this material came into contact with the hot wall of the pot, charring occurred, causing some of the compounds to decompose. In the 11th Century, the Iranian physician Abu Cina (known in Europe as Avicenna) added a frame to the vat, fixed above the level of the water, on which the material to be distilled was placed. In this way the material came into contact with steam only, and fewer degradation products were formed. This improvement later led to the development of steam distillation. A final major improvement made in the 12th Century was the addition of a condenser in which the vapour could be cooled and condensed rapidly. This greatly improved the efficiency of the distillation process.

There are three methods of distillation: water distillation, steam distillation and hydrodiffusion.

The principle of water distillation is to boil and vaporize a suspension of aromatic plant material and water in a vat so that its vapours can be condensed and collected. The essential oil, which is immiscible with water, is then separated by gravity in a 'Florentine flask'. The water in the still must be kept in motion to prevent the plant material from clogging together and settling at the bottom of the still. This would result in a low yield of essential oil, charring of the plant material and degradation of thermo-instable compounds, resulting in 'still odours'.

Water distillation is still applied in traditional field stills, but is mainly used for the distillation of floral materials such as flowers of *Cananga odorata* (Lamk) Hook.f. & Thomson, *Rosa* spp., *Iris* spp. and *Citrus* spp. that clog together in other distillation procedures. The main drawback of water distillation is that large amounts of water have to be heated. For roses, for example, 400 kg of flowers are added to 1600 l of water in a 3000 l still.

A special form of water distillation is used in India to produce 'attars'. It is a large and mostly traditional industry. Direct-fired stills of 100–160 kg capacity are used to process floral or herbal material. The peculiarity of the process is that the distillate is not cooled in a condenser, but collected directly in a receiver containing a base material. The mixture of base material, aroma materials and water is left to cool and the water is drained off. The base material with dissolved aroma materials is stored in leather containers. Leather is used, as it retains the oils but allows any remaining water to evaporate. For high quality attars sandalwood oil is the preferred base material; liquid paraffin is used for cheaper products. Attars typically contain the extract of a single plant; only 'hina attar' is a compounded perfumery product. Popular attars are made of *Anthocephalus cadamba* (Roxb.) Miquel, *Jasminum sambac* (L.) Aiton, *Lawsonia inermis* L., *Pandanus odoratissimus* L.f., *Rosa* L. cv. group Damascena and the wild form of *Vetiveria zizanioides* (L.) Nash. A special attar is distilled from the baked earth of the region around Kannauj near Lucknow in Uttar Pradesh, the main centre of attar production (Kapoor, 1991).

Water and steam distillation (also named 'wet steam' distillation) is a method that has characteristics of both water distillation and steam distillation. With this method, a metal grid is placed in the still above the level of the water and the plant material is placed on the grid. Direct contact between the water and the plant material is thus avoided. As only the water is heated, the risk of charring and the formation of 'still odours' is reduced, but the hot walls of the still may cause some damage. Water and steam distillation are used for many types of plant material, e.g. lavender, thyme and peppermint.

Cohobation is a procedure that can be used with water distillation and with water and steam distillation. After removal of the essential oil, the distillate water which still contains water-soluble aroma compounds is returned to the still and is used again. This may be repeated several times. When the concentration of aroma compounds has reached the desired level, the water is drained from the still. It is either traded as such or the aroma compounds are removed from the water by extraction. Cohobation increases the yield of partially water-soluble compounds, but increases the risk of hydrolysis and degradation of aroma compounds. It is common practice in the distillation of rose flowers, where the distillate water is an important product of the distillation, and in the production of 'attars'.

In steam distillation (sometimes called 'dry steam' distillation), a separate steam generator is attached to the still. As in steam and water distillation, plant material is placed on a grid in the distillation vat, but no water is added. Steam produced in the generator is forced through the material to be distilled. High pressure steam is often used, e.g. steam of 5–10 bar pressure at 150–200°C. The duration of the distillation process depends on the steam temperature and the ease with which the essential oil can be removed from the plant material. Plants in which the oil is stored in hair glands can be distilled very easily; those in which the oil is stored in or below the epidermis require more intensive distillation. The main advantages of steam distillation are that the amount of steam used and its temperature can be readily controlled. As the vat walls do not become hotter than the temperature of the steam, the risk of charring is minimal. Steam distillation is suitable for the production of most essential oils, except those from delicate flowers. The only precaution necessary when distilling leafy material is to ensure that it is not cut too fine, since this may cause 'channelling', resulting in poor distillation yields. Channelling occurs when the plant material becomes too compact. The steam then forces its way through via a few large channels, instead of moving through the entire mass of plant material. Steam distillation is sometimes conducted under reduced pressure, to lower the distillation temperature (Lawrence, 1995).

Equipment that overcomes the time-consuming loading and emptying of the still was developed during the 1980s and 1990s. In the United States, a system has been built in which the container that is used to collect mint (*Mentha* spp.) in the field doubles as a distillation vat in the distillery. This avoids the labour intensive operations of discharging the container and loading the still. In France, the Russian Federation and the United States, installations for 'continuous distillation' have been developed. In these, plant material is moved slowly through a distillation unit, while steam is forced through it in the opposite direction. The flow of steam and the feeding and removal of plant material are carefully coordinated to ensure a high extraction efficiency and a low consumption of steam. Auxiliary equipment e.g. to clean the oil and to dry the spent plant material is often integrated in the system.

Hydrodiffusion is a distillation method developed in the 1980s. Low pressure steam (<0.1 bar) is used and the volatile components are extracted from the plant material mainly by osmosis. In this method a distillation vat is filled with comminuted plant material. Steam is fed to the still but, unlike steam distillation, it is fed from the top of the still and moves downwards through the plant material by gravity. After passing through the plant material, the steam and volatile compounds flow through a condenser placed at the bottom of the still and are collected in an oil separator. Hydrodiffusion has shown excellent results under experimental conditions: short distillation times, low steam consumption, high yields of high-quality oil and absence of high temperatures. Under commercial conditions, however, performance has been less impressive (Boelens at al., 1987; Lawrence, 1995).

1.3.5 Purification

After distillation, the distillate is collected in a 'Florentine flask', where the water and essential oil fractions are allowed to separate. The flask has a spout at the top and the bottom so that the water and oil can be tapped off separately. Subsequently, traces of water are often removed from the oil and the oil may be rectified, i.e. unwanted compounds may be removed by fractional distillation. Vacuum distillation and molecular distillation may be used, to avoid degradation of thermo-instable compounds. Rectification is used e.g. in the production of terpeneless citrus peel oil, geranium oil and bay leaf oil. From these oils the

terpenes are removed, leaving the more strongly odorous oxygenated terpene derivatives behind at a higher concentration.
For industrial purposes, specific compounds may be distilled from the essential oil, e.g. the essential oils from *Litsea cubeba* (Lour.) Persoon and *Cymbopogon citratus* (DC.) Stapf are major sources of natural citral and the oil of *Corymbia citriodora* (Hook.) K.D. Hill & L.A.S. Johnson of citronellal.

1.4 Properties

1.4.1 Odours and odour description

The sense of smell is crucial in the study of flavours and fragrances. This sense is unique among the senses because it is very subjective and lacks objective standards. Smells are often described in terms of sensations related to other odours or to experiences of the other senses. The memory of these odours and associated experiences is very personal and an odour that is repulsive to some may be attractive to others. However, classifications of odours have been developed. They are based either on comparison with common fragrance materials or on odour concepts that have to be acquired by experience.
The sense of smell is one of two discriminatory chemical senses through which information about the chemical composition of the environment can be obtained. Whereas the second chemical sense, taste, recognizes only 4 conditions (bitter, salty, sour, sweet), the sense of smell recognizes an immense number of odours and odour compounds. For perfumery, it is unfortunate, but at the same time challenging, that odour sensations cannot be described in absolute terms, but have to be related to memories of the same odour or to sensations from the other senses. Odours may be described in relation to touch (soft, harsh), sight (the smell of a forest), or even hearing (an aroma associated with the sound of the sea). Descriptive language is the only means of communicating odour sensation from one person to another because odour quality cannot be measured or expressed independently of individual human experiences.
Although 'artificial noses' linked by computer to automated perfumery laboratories are in use today, most fragrance compounds continue to be created by perfumers. To communicate with colleagues, technicians, marketing staff and with their customers, perfumers need an odour vocabulary in which each term conveys the same meaning to all its users.
Systems of characterization of odours can be developed by two different methods. A qualitative description of an odour or odour pattern can be obtained either by a 'reference procedure' i.e. by direct comparison with the odour of a series of known chemicals or by a 'semantic procedure' i.e. in a verbal descriptive way. The latter procedure is preferred by perfumers, flavourists and food technologists, such as wine, tea and coffee tasters. A standardized vocabulary to descibe odours is used in which each term is precisely defined, in stead of spontaneous but subjective everyday language. In these classifications, terms such as 'animal', 'green' and 'metallic' have a specific connotation that anyone dealing with odours has to acquire. Although it takes years of practice to become a perfumery expert or 'nose', some conscious attention to odours and their description will quickly put one on the right track. Several systems have been developed. Linnaeus was the first to propose a logical and objective classification of

odours using 7 classes based on the odours of selected plants. The American Society for Testing and Material (ASTM) designed a system using a large number of classes that was later simplified. A classification of odour qualities and similarity coefficients is given in Table 2. In this table, most terms describe an odour that has little in common with other odours described by the other terms. However, terms that have some similarity with neighbouring ones are linked, the link representing the statistically established degree of similarity. The descriptions used in this volume largely follow this classification. (Harper, Bate Smith & Land, 1968; Müller & Lamparsky, 1994; Ohloff, 1990).

Table 2. Classification of odour qualities and similarity coefficients.

	bitter almond		sulphury		sandalwood
	nut	0.3	fruity		powder-like
0.4	banana	0.3	floral		lily
	pineapple		green		woody
0.1	apple		tea		piney
	ethereal	0.2	metallic	0.3	camphor
0.3	brandy		geranium		mint
0.1	wine	0.1	jasmin		hay
	grape		lilac	0.3	tobacco
	citrus		anise		smoke
	aldehydic		lily of the valley	0.2	tar
	wax	0.1	orange blossom		medicinal
	fat		mimosa		phenolic
0.3	butter		violet	0.1	aromatic
	cream	0.2	rose	0.2	herbal
0.1	root		honey		spicy
	moss	0.1	ambergris		pepper
	leather		musty	0.2	balsamic
0.3	earth	0.2	animal		vanilla
	mushroom		musk		caramel

Source: Ohloff, 1990.

1.4.2 Physical characteristics

Until a few decades ago, measurements of physical characteristics supplemented with simple chemical analyses were the only means to characterize samples of essential oils and to compare them with standard samples. The origin, quality, possible adulterations and extensions had to be detected by these methods. It is only since the 1980s that the use of capillary gas-liquid chromatography and mass spectrometry has enabled more detailed analyses to be done.

The physical characteristics most commonly used to characterize essential oils are relative density, refractive index, miscibility and optical rotation.
Relative density is the ratio of mass and volume of a substance. Refractive index refers to the property of transparent materials to deflect light by a specific degree when it enters such materials at an oblique angle from another material with a different density. Miscibility of essential oils refers to the solubility of an essential oil in a solvent. It is usually measured with aqueous alcohol as the solvent. The amount of essential oil soluble in a given amount of alcohol of a given concentration is recorded. An oil may be fully soluble in pure alcohol, but only slightly soluble in a mixture of alcohol and water.
Molecules with an asymmetrical structure rotate the plane of polarization of polarized light. Pure, optically active compounds deflect the plane of polarized light by a characteristic angle. Optical isomers, which are identical molecules but each other's mirror images, rotate the plane of polarization in opposite directions. Optical rotation provides a measure of the relative concentration of isomers of optically active compounds. In synthetic asymmetric compounds, optical isomers are almost always present in equal amounts, resulting in an optical rotation of 0°. The optical rotation of essential oils and of individual compounds of the oils is often highly characteristic of the oil and even of its origin.
Several quality control institutes have specifications with which essential oils must comply. The most important ones are the ISO standards of the International Organization for Standardization and EOA standards of the Essential Oil Association of the United States. Standards organizations use rigorously defined methods of analysis. As each organization uses is own methods, slight differences in values may occur, making direct comparisons of data difficult. An overview of standard values established for the essential oils covered in this volume is given in the Table on standard physical properties of some essential oils (see p. 221).

1.4.3 Chemical components

Essential oils are complex mixtures of sometimes hundreds of chemical compounds. To give an indication of their composition and complexity, examples are given in Composition of essential-oil samples (see p. 205). Most of these compounds can be grouped into a few major classes, but there are also many components of essential oils that bear little resemblance to these classes. In the overview of important and characteristic components given below compounds are classified into 4 major groups: aliphatic compounds, terpenes and terpene derivatives, benzene derivatives and miscellaneous compounds.

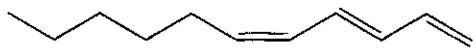
Aliphatic compounds

Aliphatic compounds are acyclic organic compounds. The chain of C-atoms in these compounds may be straight or branched and some of the bonds between C-atoms may be unsaturated. Aliphatic hydrocarbons occur abundantly in foodstuffs such as fruit, but contribute to their odour to a limited extent only. The highly unsaturated hydrocarbons 1,3-trans-5-cis-undecatriene and 1,3-trans-5-trans-undecatriene, however, contribute significantly to the odour of galbanum oil.

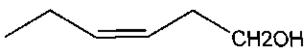
The odour of most aliphatic alcohols is weak and their role as components in fragrance compositions is limited. An exception is 3-octanol, occurring in mushrooms and imparting their characteristic smell. A few unsaturated alcohols are more important. Cis-3-hexen-1-ol or leaf alcohol, which has the characteristic odour of freshly cut grass, forms a large proportion of the essential oils from the leaves of *Robinia pseudoacacia* L., mulberry (*Morus* spp.) and from green tea. Its isomer cis-2-hexen-1-ol occurs in many fruits and has a sweeter aroma. Lavender oil and mushrooms contain 1-octen-3-ol, a compound with an intense mushroom and earthy-forest odour.
Aliphatic aldehydes are important compounds in perfumery and flavouring. The series n-octanal, n-nonanal, n-decanal and n-undecanal, for instance, occurs in citrus oils. The unsaturated trans-2-hexenal, or leaf aldehyde, occurs in many leaf oils and has a sharp herbal-green, somewhat pungent, odour.
Of the aliphatic ketones, only 3-hydroxy-2-butanone (acetoin) and diacetyl (2,3-butanedione) are widely occurring natural isolates that play a role in flavouring. Both have a buttery aroma.
Aliphatic esters are important flavour and fragrance compounds occurring widely in nature. In perfumery, acetates of alcohols up to C_6 are used for their fruity notes, C_8–C_{12} acetates for their blossom fragrance, C_{12} acetate also for its conifer notes, while esters of acids of longer chain length have a more fatty-soapy odour. Structural formulas of some aliphatic fragrance compounds are given in Figure 1.

Terpenes and terpene derivatives

Terpenes constitute a widely represented group of substances. Although they show wide structural diversity, they share a common characteristic: they are built from 2 (monoterpenes), 3 (sesquiterpenes) or more isoprene (C_5H_8) units. Isoprene is one of the basic compounds in animal and plant biochemistry from which carotenoids, steroids and rubber are also formed. It is formed from acetyl-CoA that plays a role in the synthesis and oxidation of sugars. The terpene hydrocarbons contribute to the odour and taste of essential oils to a limited extent only, but their oxygenated derivatives are among the most important aroma chemicals.
Monoterpenes conform to the molecular formula $C_{10}H_{16}$ and can be acyclic, monocyclic, or bicyclic. There are even a few tricyclic monoterpenes: cyclofenchene and tricyclene. Acyclic monoterpenes are relatively unstable and some have a slightly agressive odour, because of their strongly unsaturated structure. Examples of acyclic monoterpenes include myrcene and ocimene.
Cyclic monoterpenes occur in essential oils, sometimes in considerable amounts. By themselves they generally contribute relatively little to the odour of a fragrance or flavour product, but often serve as starting materials for the biological or chemical synthesis of flavour and fragrance compounds. Examples of monocyclic terpenes include α-terpinene, γ-terpinene or para-menthadiene, limonene, α-phellandrene, β-phellandrene, and terpinolene. There are 5 types of bicyclic terpenes, characterized by: thuyene, carene, pinene, camphene and fenchene. Of the bicyclic terpenes, the α-pinene and β-pinene are technologically the most important by far. Structural formulas of some monoterpenes are given in Figure 2.



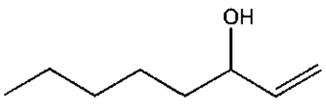
1,3-trans-5-cis-undecatriene



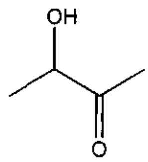
cis-3-hexen-1-ol


1,3-trans-5-trans-undecatriene

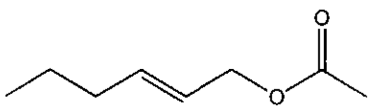
n-octanal



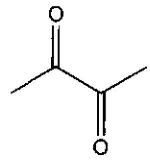
1-octen-3-ol



acetoin



trans-2-hexenyl acetate



diacetyl

Figure 1. Some aliphatic fragrance compounds.

Sesquiterpenes are compounds generated from 3 isoprene units and conforming to the formula: $C_{15}H_{24}$. As there are so many, it is impossible to generalize about their molecular structure. Farnesene is perhaps the most simple, acyclic example; many sesquiterpenes are bicyclic, having two C_6-rings or a C_6 and a C_5 ring; an extreme example is the monocyclic humulene with a C_{11}-ring.
In fragrance products in which the essential oil is dissolved in diluted alcohol, e.g. 'eau-de-Cologne', the terpenes present would give rise to problems of separation. To overcome this difficulty, terpeneless oils, i.e. essential oils from which the terpenes have been removed, are used. Terpeneless oils have the added advantage of a stronger characteristic odour. Structural formulas of some sesquiterpenes are given in Figure 3.
Oxygenated derivatives of monoterpenes and sesquiterpenes are more important than the terpene hydrocarbons as aroma chemicals. The characteristic odour of many essential oils is representative of the combined odours of the oxygenated compounds. Important groups of oxygenated compounds are alcohols, aldehydes and ethers, ketones, acids and esters.
Acyclic monoterpene alcohols and acyclic sesquiterpene alcohols occur in many essential oils and contribute strongly to their characteristic odour. Some of them, such as citronellol, geraniol, linalool and nerol are also synthesized from turpentine on an industrial scale. In many parts of the world these alcohols take up the production capacity of entire chemical factories. The synthetic products may differ in their odour qualities from compounds isolated from

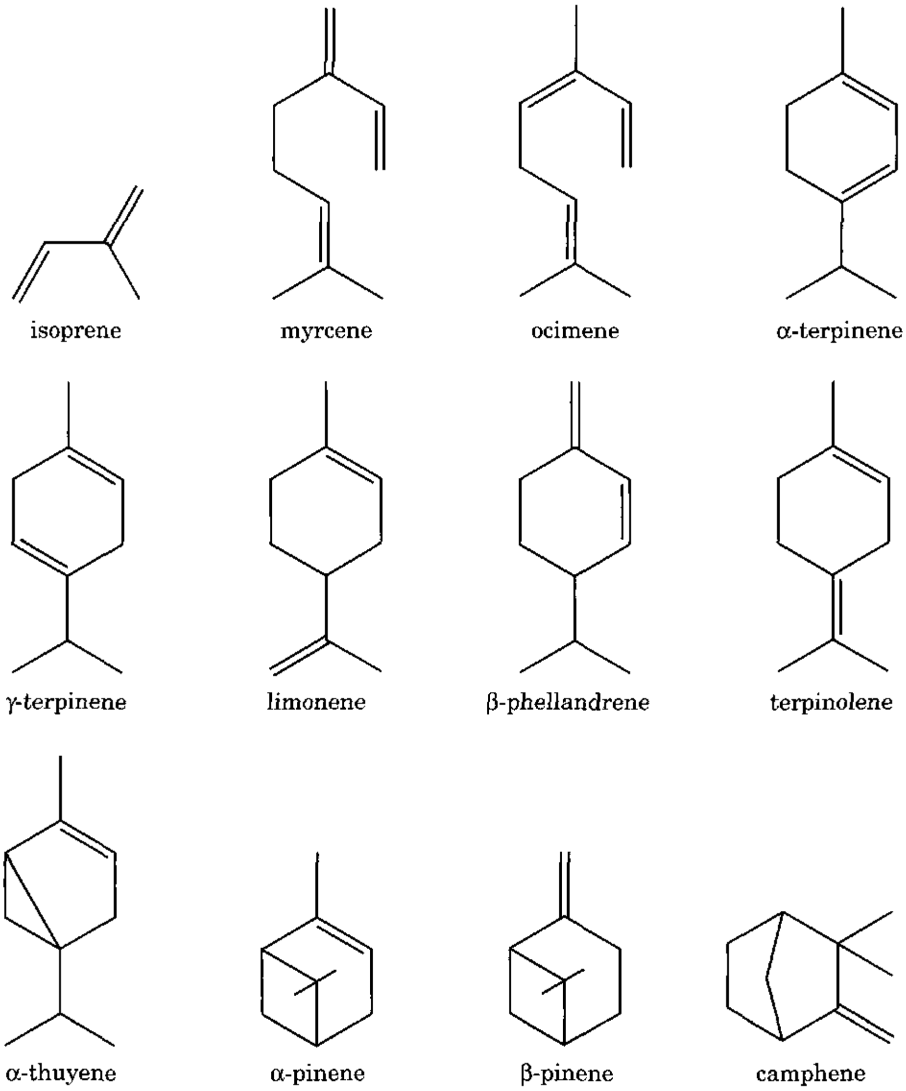


Figure 2. Examples of monoterpenes.

plant sources, since it is difficult to separate the desired products from compounds with similar physical properties but different odour characteristics, such as enantiomers. Lavandulol differs in structure from most terpene alcohols, as the isoprene units are not arranged in the usual head-to-tail manner. Structural formulas of several important acyclic terpene alcohols are given in Figure 4.

The most important aldehydes derived from acyclic monoterpenes and sesquiterpenes are citral and citronellal. They are major components of essential oils from *Cymbopogon* spp. and *Litsea cubeba* and hold key positions in many flavour and fragrance materials. Both are important starting materials for the synthesis of other aroma compounds. Both optical isomers of citronellal

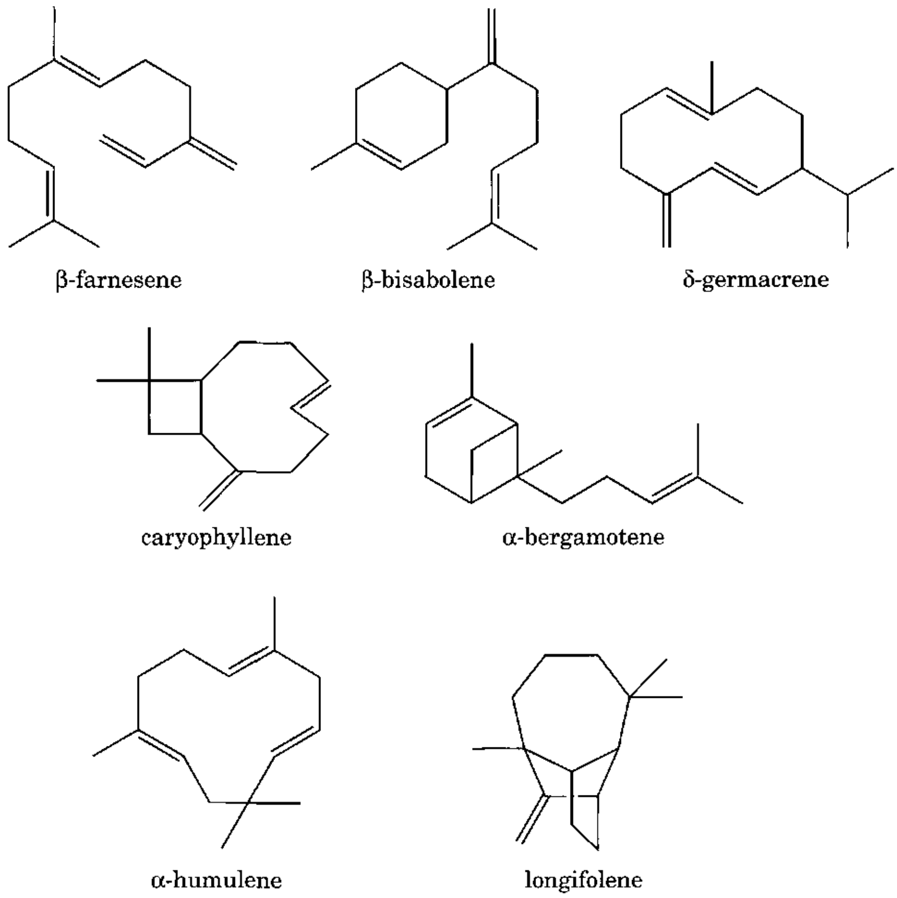


Figure 3. Examples of sesquiterpenes.

occur in nature; (+)-citronellal occurs in *Cymbopogon* spp., (−)-citronellal in *Backhousia citriodora* F. Muell., whereas *Corymbia citriodora* oil contains a racemic mixture. One of its derivatives is hydroxydihydrocitronellal (also named hydroxycitronellal). It is a widely used fragrance compound, but has not yet been found in nature. Structural formulas of some acyclic terpene derivatives are given in Figure 5.

Cyclic terpene derivatives are so numerous and diverse that only a few important examples can be given here. Whereas cyclic terpene aldehydes occur in essential oil in low concentrations only, cyclic ketones are more important. Menthone and carvone, which both have the para-menthane structure, are commercially important flavour and fragrance compounds. Menthone is a constituent of the essential oil of *Mentha* ×*piperita* L. and *Pelargonium* cv. group Rosat, carvone is found in *Carum carvi* L. and *Mentha spicata* L., *Anethum* spp. and *Cymbopogon martini* (Roxb.) J.F. Watson. Camphor is the main constituent of the essential oil from *Cinnamomum camphora* and formerly a source material for the synthesis of celluloid and smokeless gunpowder. Ionones and homologeous compounds are an important group of terpenoid aroma chemicals. They are derived from carotenoids and are present in essential oils in small amounts

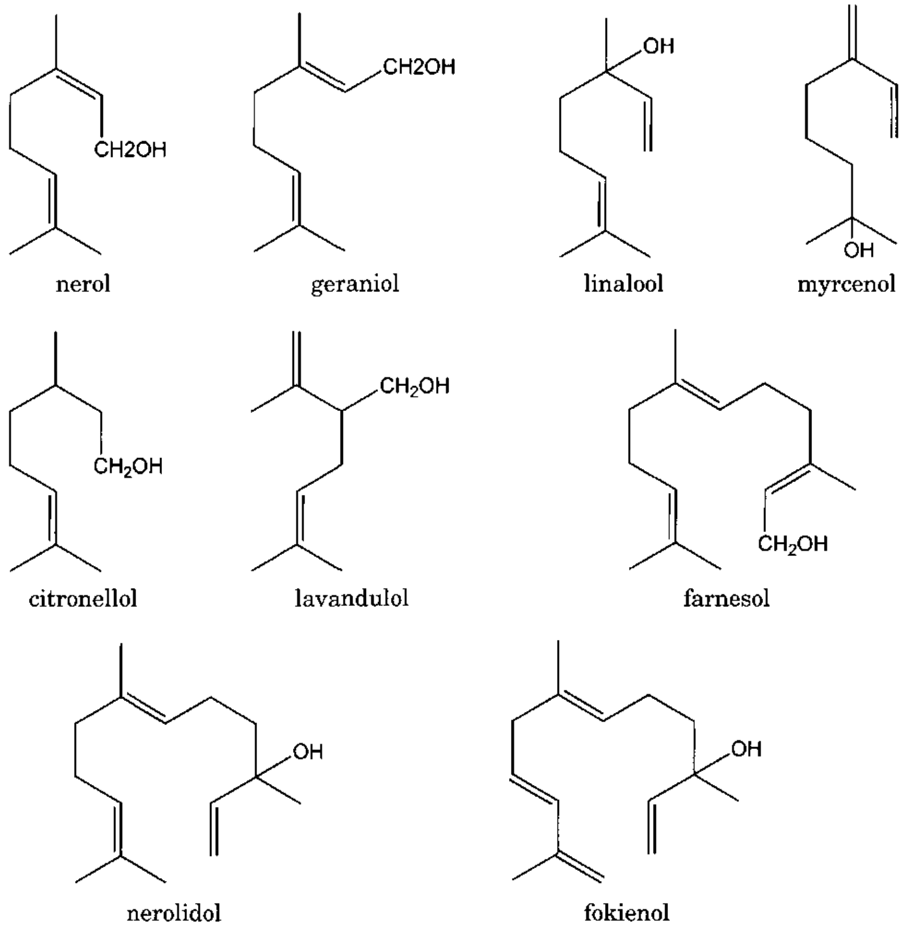


Figure 4. Some acyclic terpene alcohols.

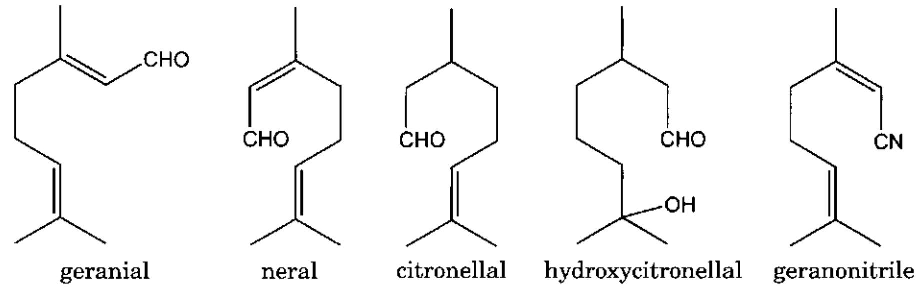


Figure 5. Some acyclic terpene derivatives.

only. Several ionones have odour notes reminiscent of *Viola odorata*. Damascones are isomers of ionones: β-damascenone is one of the characteristic components of Bulgarian rose oil.

The cyclic sesquiterpenoid nootkatone is one of the characteristic or 'character

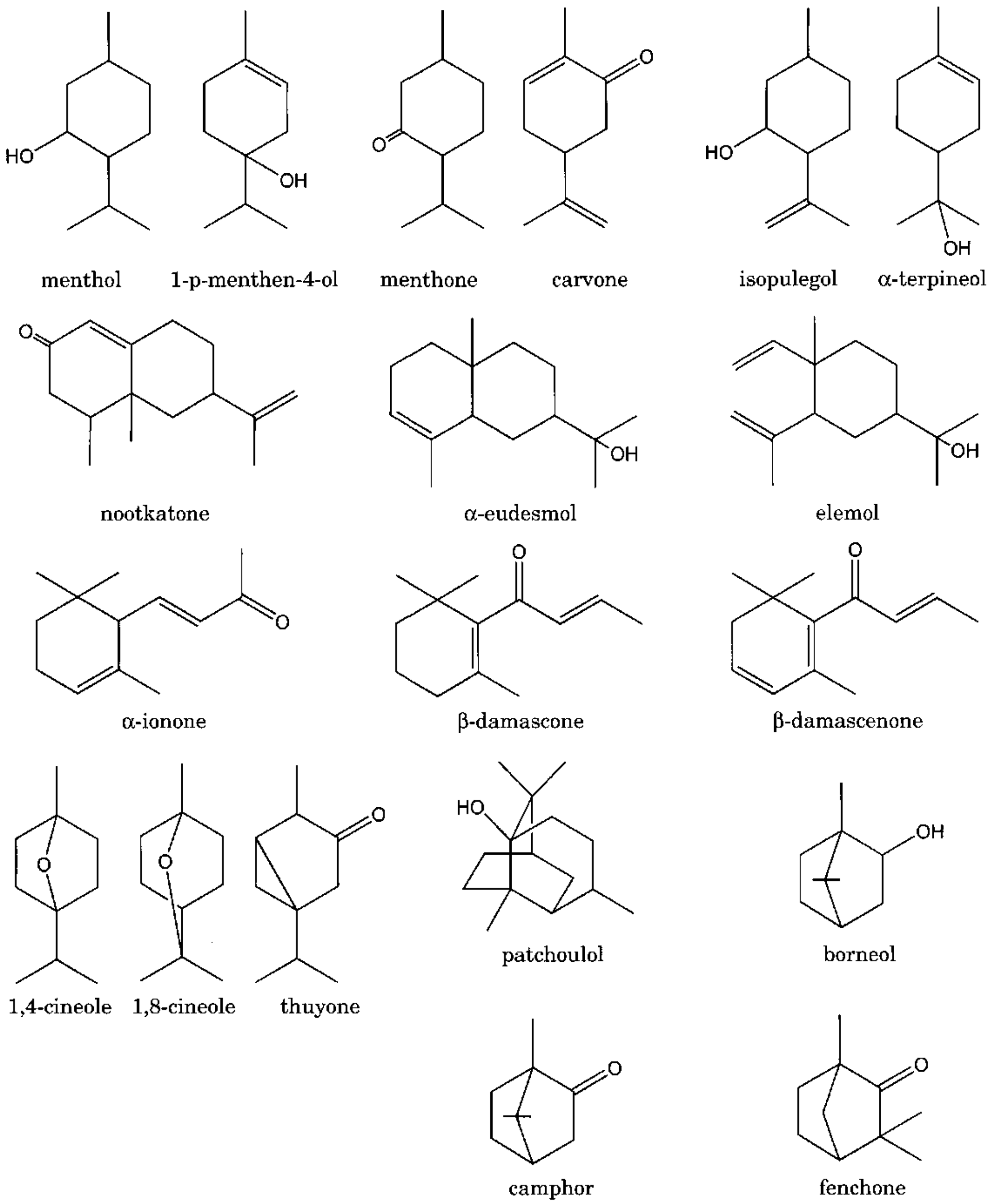


Figure 6. Examples of cyclic terpene derivatives.

impact' components of the grapefruit aroma. Structural formulas of examples of cyclic terpene derivatives are given in Figure 6.

Esters of terpene alcohols and lower fatty acids, in particular acetates, are highly important as flavour as well as fragrance materials. The esters of acyclic

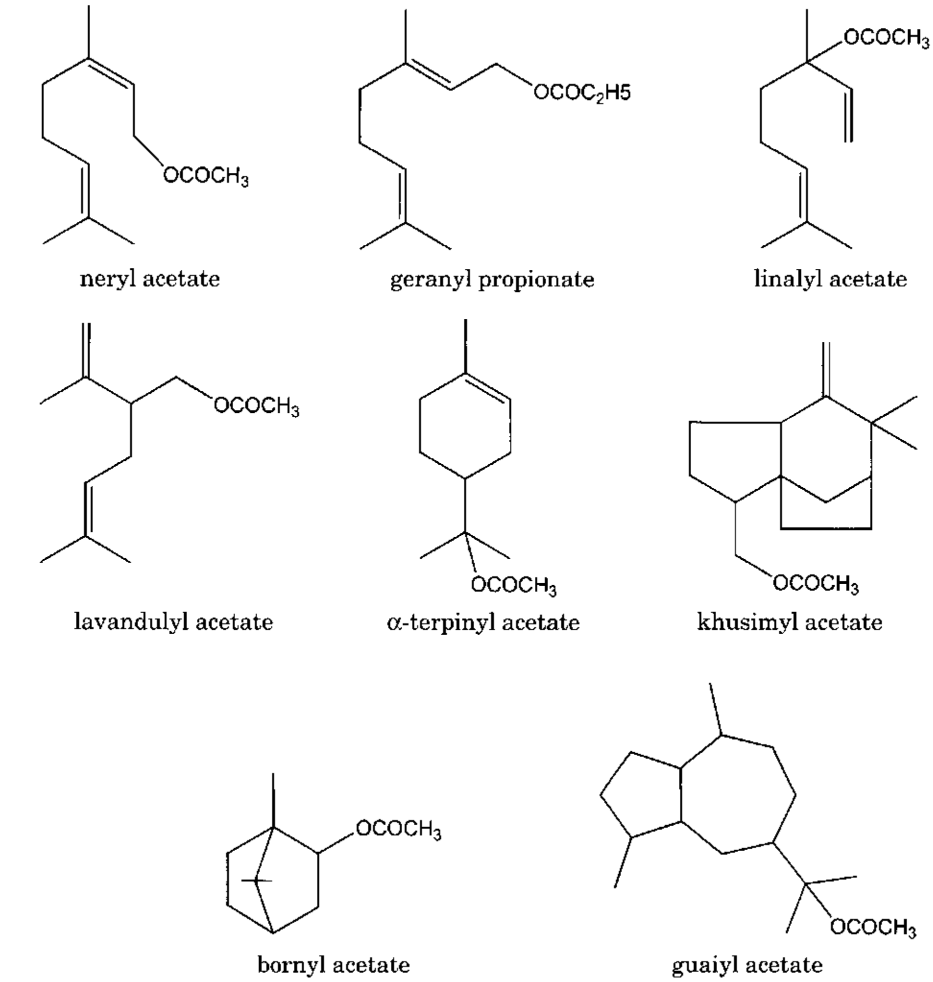


Figure 7. Examples of terpene esters.

terpene alcohols citronellol, geraniol and linalool occur in a large number of essential oils, sometimes in large amounts. As isolated compounds they are used in reconstituting such oils and other aroma compositions. Esters of cyclic terpene alcohols, such as α-terpinyl acetate, menthyl acetate, bornyl acetate, and a few acetates of sesquiterpene alcohols, such as guaiyl acetate, cedryl acetate and vetyveryl acetate, are also important components of essential oils and are applied extensively in flavour and fragrance materials. Alcohols are often acetylated in essential oils, to modify their olfactive characteristics, as for instance with vetiver oil. Structural formulas of some terpene esters are given in Figure 7.

Benzene derivatives

In chemistry, benzene derivatives or benzenoids (often confusingly named aromatic compounds) are compounds containing a characteristic benzene ring, of-

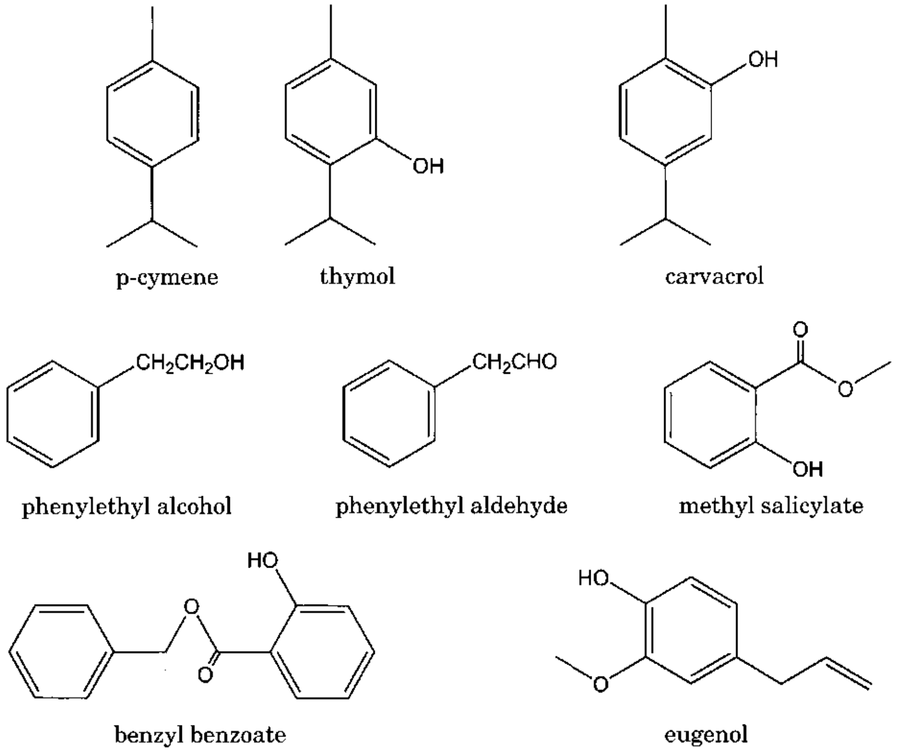


Figure 8. Some benzenoid fragrance compounds.

ten represented as a C_6 ring with 3 double bonds alternating with single bonds between the C-atoms. It is a very large and varied group that includes many natural and synthetic flavour and fragrance compounds. The most important hydrocarbon derived from benzene is para-cymene; it occurs in many essential oils and has a weak citrus odour when pure. Of the benzenoid alcohols and aldehydes, important components of essential oils are phenylethyl alcohol, cinnamic alcohol, cinnamic aldehyde, phenylacetaldehyde. Most aromatic ketones that are important in the flavour and fragrance industry are synthetics.
Esters of aromatic alcohols and aliphatic acids are of interest in flavours and fragrances because of their characteristic odour properties. Benzyl acetate is the main component of jasmine oil and gardenia oil, phenylethyl acetate is an aroma compound found in several essential oils and in many fruits, benzyl benzoate is a major component of Peru balsam and is a commonly used fixative and modifier of heavy blossom fragrances in perfumery. Some benzenoid fragrance coumpounds are represented in Figure 8.

Miscellaneous compounds

Only a few of the many other fragrance compounds in other groups can be given as examples. Their structural formulas are given in Figure 9. Several nitrogen compounds impart characteristic sensory properties to essential oils, even

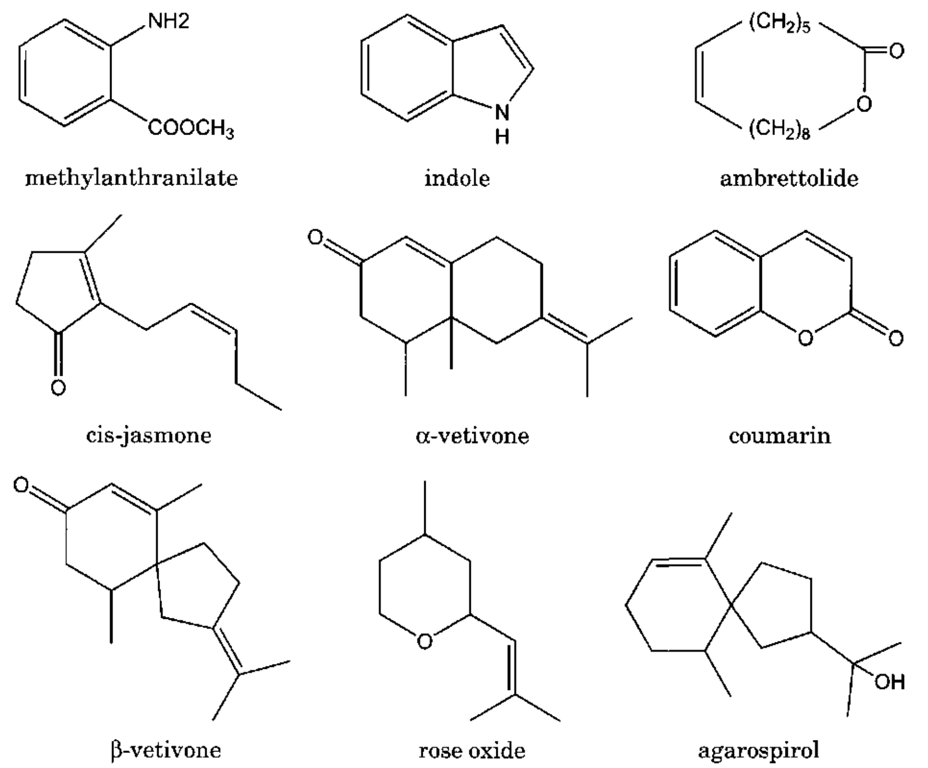


Figure 9. Miscellaneous fragrance compounds.

when they are present in essential oils, concretes and absolutes in concentrations of less than 0.1%. Isolated or synthetic nitrogen compounds are used in industry to modify jasmine oil, lavandin oil and petitgrain oil. Sulphur compounds are rare in essential oils, but more common in animal odours. Examples of sulphur compounds are found in the essential oils of garlic, mustard and *Ferula assa-foetida* L. Synthetic sulphur compounds are used in industry to modify buchu, galbanum, blackcurrant and rose oil. (Bauer, Garbe & Surburg, 1997).

1.4.4 Quality control

Verification of the genuineness of essential oils

Until a few decades ago, the human nose, supported by the measurement of a number of physical characteristics and a few chemical analyses, was the chief means of verifying the density, purity and naturalness of essential oils. The development of capillary gas chromatography/mass spectrometry (GC/MS) methods has greatly improved knowledge of the chemical composition of essential oils. Currently, compounds present in as little as 1 ppb (part per billion) can be detected and identified, making it easier to distinguish between a pure natural essential oil and oils to which foreign compounds have been added. As both the pathways of synthesizing chemical compounds and the by-products of these processes are well known, demonstration of their presence in an essential oil can be proof that the oil has been adulterated.

Developments in the chemistry of optical isomers further enhanced the possibilities of identifying added compounds in essential oils. Most of the assymmetric, optically active compounds in natural essential oils are represented by only a single isomer, or else both isomers are present in a proportion that may vary within a narrow range only. The addition of the compound obtained from another essential oil will often change this proportion. As chemically synthesized compounds are only rarely optically active, their presence can be accurately demonstrated.

However, the high prices paid for pure natural essential oils are encouraging increasingly sophisticated adulteration practices to be developed, and methods for detecting them have to keep pace. The adulteration of an essential oil with compounds chemically synthesized from carbon compounds derived from petroleum or coal can be detected by measuring the amount of radioactive carbon (^{14}C) in the components of the oil. The atmosphere contains mainly ^{12}C but also traces of ^{14}C. The latter is produced by irradiation and subsequently decays slowly. Compounds synthesized by plants from atmospheric carbon dioxide contain ^{14}C, whereas almost all the ^{14}C in fossil material and in chemical compounds derived from it has decayed. Modern mass spectroscopy equipment is sufficiently accurate to measure the ratio of $^{14}C/^{12}C$ and makes a distinction between fossil and natural compounds possible.

Although this method has made it easier to detect adulteration with synthetics, it cannot reveal adulteration involving compounds derived from cheap natural linalool or pinene. Refinements in the analysis of carbon isotopes exploit differences in the photosynthetic pathway used by different groups of plants. The C_4 pathway (typical of many tropical grasses) and C_3 pathway (typical of temperate grasses and most dicotyledons) of photosynthesis fix different proportions of ^{13}C and ^{12}C. C_4 plants are richer in ^{13}C than C_3 plants. The measurement of nuclear magnetic resonance (NMR) has been refined to such extent that it can identify whether a compound originates from a C_3 or C_4 plant.

The newest way to characterize chemical compounds is a method based on deuterium nuclear magnetic resonance spectroscopy. A small proportion of hydrogen in nature occurs as ^2H or deuterium. Nuclear magnetic resonance (NMR) spectroscopy enables the magnetic resonance of individual bonds between atoms in a molecule to be studied. It appears that the ^2H is very unevenly distributed over the various bonds in a molecule. As the internal distribution varies with the origin of the molecule, this method can distinguish if e.g. anethol is prepared from star anise, estragol or petroleum.

Physico-chemical methods of analysis of natural aroma products

The features characterizing (and complicating) the analysis of natural aroma materials are:

- A large number of components. Essential oils may contain hundreds of constituents.
- Large structural diversity. Several thousands of monoterpenes, sesquiterpenes and related phenylpropanoids are known, not to mention various unrelated compounds.
- The presence of many relevant components in small quantities. Often, 1–2%

of a natural product contain several hundreds of compounds, which may belong to many different groups.
- The possible presence of relevant individual compounds in extremely small quantities. The effective threshold concentration in water at which β-ionone becomes detectable is 0.007 ppb or 7.10^{-12}g per g water.

Rapid advances in chromatographic and spectroscopic analysis methods have revolutionized the knowledge of essential oils. However, in many cases this knowledge is still inadequate, as the human sense of smell is even more sensitive.

Probably the oldest techniques to separate components from a mixture are the chemical ones. The extraction of essential oils with acidic or alkaline aqueous solutions allows respectively the basic complexes and the acids and phenols to be isolated. Carbonyl compounds can be isolated by transformation into water-soluble hydrazonium salts. Esterification of alcohols is another option. However, chemical separation methods have several drawbacks. They require relatively large amounts of product, they may cause formation of artefacts and they can only separate compounds on the basis of their chemical functionality.

Physical separation methods exploit differences in physical properties of the components of a mixture: density, vapour pressure and solubility (see e.g. the Table on standard physical properties of some essential oils). One commonly used method of separation is fractional distillation. Recent developments allow very small quantities of product to be separated into large numbers of components. Distillation works best with components of low molecular weight and high vapour pressure. Heavy components require higher temperatures, which bring a risk of thermally-induced modification.

The commonest technique for separating compounds of a mixture when analysing essential oils is capillary gas chromatography. It entails vaporizing a minute sample of the product and transporting the vapour through a long and fine tube by means of a non-reactive gas, such as nitrogen, under conditions of a controlled increase in temperature. The tube or capillary chromatography column is made of an inert material such as silica and is coated with a thin film of a special absorbent in which the components of the mixture will dissolve. Separation of the components depends on differences in their solubility in the absorbent, which result in differences in the speed with which they pass through the column. A detector situated at the end of the column records the characteristics of each component when it leaves the column. The results are represented in a chromatogram from which components can be qualitatively and quantitatively identified.

Methods of analysis

Capillary gas chromatography is usually coupled with mass spectrometry and infrared spectrometry. The separated components of the mixture enter the spectrometer one by one, so that each of them can be analysed separately.

In gas-phase infrared spectrometry a beam of infrared light is directed at the vapourized sample and the absorption of the light is measured. The degree of absorption depends on the nature of the compound analysed and the wavelength of the light. The analysis results in an absorption spectrum that is unique to the compound tested. The identity of the compound is established by comparison with spectra of reference compounds.

In the mass spectrometer the compound to be analysed is bombarded with high-energy electrons. This results in a partial break-up of the molecules and the ionization of the whole molecules and the fragments. The mass and electric charge of the resulting ions are recorded and the identity of the original molecule can be established by comparing the information with reference data stored in a computer. If the identity of the compound cannot be established directly from the reference data, it can be inferred by piecing together the various fragments.

More detailed information on compounds is obtained by NMR spectroscopy. Nuclear magnetic resonance is the interference between an external magnetic field and the magnetic field generated by the nucleus of certain elements. The interference is influenced by position of the atom in a molecule. In e.g. ethanol, 3 differently bonded H atoms occur, each having a characteristic magnetic resonance. In NMR spectroscopy the resonance spectrum of the compound is recorded. In this spectrum all different H bonds are represented by specific peaks. To identify the compound tested, this pattern of peaks can be compared with reference data. If no matching reference data are available, the information combined with the results of mass spectrometer analysis can be used to infer the chemical nature of the compound.

1.4.5 Quality standards

Systems of quality standards have been developed to facilitate marketing and to guarantee the safety and quality of products. Such standards regulate not only the quality of individual products but also methods of analysis and quality management systems. The most important systems of standards for essential oils are those of the International Organization for Standardization (ISO), Geneva, Switzerland, the Essential Oil Association of the United States (EOA), and the International Fragrance Association (IFRA), Geneva, Switzerland.

The ISO issues 3 types of standards. The first type (ISO 9000) sets quality requirements for management and systems. The second type defines protocols and methods of analysis to be used in the establishement of particular parameters: for example, ISO 356 deals with the preparation of samples, ISO 279 with the determination of relative density, ISO 280 with the determination of the refractive index, ISO 592 with the determination of optical rotation and ISO 875 with the miscibility in ethanol. The third type of standard defines the limits for several characteristics an essential oil must comply with. Traditionally, these have been physical determinations, such as density, optical rotation, refractive index, miscibility with aqueous alcohol, and chemical determinations of groups of components of major interest. Older ISO standards indicated acceptable ranges for alcohol, carbonyl, acid and ester number. The latest ISO standards incorporate a chromatographic profile and concentration ranges for the most characteristic components. However, the variety of methods and protocols of analysis that are used makes it difficult to compare published profiles with the standards. A tabulated overview of ISO standards for physical characteristics of essential oils from plants dealt with in this volume is presented. When no ISO standard was available, the information was supplemented with standards from the EOA.

The Research Institute for Fragrance Materials (RIFM) of the IFRA publishes

comprehensive papers on fragrance compounds. They present many biological data, such as metabolism in mammals, toxicity, carcinogenicity, sensitization and pharmacology.
The Food and Drug Administration of the United States (FDA) and the Flavor and Extracts Manufacturers' Association (FEMA) deal specifically with the safety of products, including the essential oils used in foods. Products it deems safe are issued with a 'GRAS' or 'generally recognized as safe' statement, which may specify restrictions in relation to their use in certain products.

1.4.6 Adulterations

Substitutes for natural essential oils are synthetic compositions of aroma chemicals that mimic the character of the oil in question. Adulteration is the fraudulous modification of a product. Adulteration of natural essential oils covers a range of actions: standardization, reinforcement, liquidization, reconstitution, and commercialization.
Standardization involves improving the quality of a product to meet the standard requirements. One can standardize the content of characteristic substances by adding such products that have been isolated from another natural source or produced synthetically. Common examples are the addition of citral isolated from *Litsea cubeba* oil to lemon oil, and of 1,8-cineole from *Eucalyptus globulus* Labill. to rosemary oil.
Reinforcement (also called extension) is an extension of standardization. When the quality of an essential oil can be improved there is always the temptation to add exaggerated amounts of the characteristic compounds to improve the quality and to make a product with 'more olfactive value for money'.
In liquidization, the aim is to change not the olfactive quality of a product, but its appearance. Some absolutes may be semi-solid or liquid. If the liquid form is preferred, solvents can be added to the absolute. Various solvents are used for this purpose.
Reconstitution is the compounding of an aroma product using natural or synthetic compounds to obtain a product that is similar to the original natural oil. However, it is quite impossible to reconstitute complete natural oils, because they consist of hundreds of compounds, many of which are unknown. Reconstituted essential oils are used especially in functional perfumery. When a natural essential oil in a perfume is prohibitively expensive it can be replaced by a reconstituted oil. Rose oil, jasmine oil and orange flower oil are often reconstituted.
Commercialization of a product involves expanding its volume and lowering its quality, to make it more profitable. It may involve the use of reinforced, liquidized or reconstituted products. If properly declared, commercialization is an accepted practice. Some buyers cannot afford to pay the cost of a natural product and are willing to buy a commercialized product with similar though inferior characteristics. However, a buyer has the right to know what he or she is buying.

1.5 Classification of perfumes

The classification developed for perfumes differs somewhat from the classification of odours, but uses the same terminology. It is based on the assumption that each perfume has a basic, more or less overriding concept, within which variations are possible. Perfumes can be classified into two broad groups, feminine and masculine, but these overlap greatly. Feminine concepts are: floral, oriental and 'chypre'; masculine ones: 'fougère', oriental and 'chypre', whith citrus notes sometimes incorporated. The floral fragrance concept accounts for half of the international fragrance landscape. The concept is very broad and covers most of the spectrum of flower odours. The notes of the oriental concept are reminiscent of the legendary fragrances of the Orient, as typified by the sweet balms and resins of Arabia and precious spices of India and Indonesia. The term 'chypre' refers to a famous perfume named Chypre after the island of Cyprus, from which most of its fragrance materials originated. Bergamot, oakmoss and patchouli are typical notes in perfumes of this concept. The 'fougère' concept is based on the interplay of lavender, oakmoss and coumarin. Originally intended as a contribution to feminine perfumery, it became such an acknowledged masculine fragrance over time that it now plays virtually no role in feminine fragrances. When a single variation on a concept plays a dominant role it is sometimes used instead of the concept to describe a perfume. Table 3 gives an overview of the variations of the concepts and a few famous examples of each. Each perfume has a top note, a body or middle note and base note or dry-out. The top note is the odour of the most volatile components and is the first odour impression that a perfume gives. The top note gradually gives way to the body note, which represents the main sensory impression of a perfume. The dry-out remains for several to many hours after the application of a perfume. The three notes are described in the same terms as the variations. Perfume descriptions often also name the individual essential oils that can be recognized in the different stages of development of the odour of a perfume.

1.6 Production and international trade

Few comprehensive data have been published on the economics of essential oils. This reflects the great complexity of the global network of the production and trading of essential oil. The species involved are numerous (over 400), the economic significance of most individual oils is small, systematic compilation of data is rare and market knowledge is often jealously guarded e.g. by wholesale traders. Most import and export statistics tend to lump together several essential oils and even natural and synthetic materials. The blurred distinction between essential-oil plants and spices and, to a lesser extent, medicinal plants, further complicates the situation. The most recent comprehensive review of essential-oil production and marketing dates from 1993 (Lawrence, 1993). Only for a limited number of products are world market prices published regularly. An estimate of the production and value of the 20 most important essential oils is given in Table 4 (Lawrence, 1993). Over half of the world's exports comes from developing countries (Table 5). Among them, 4 countries predominate: China, Brazil, Indonesia and India. China and India show the greatest capacity to adapt to marketing changes and opportunities. All 4 countries are character-

Table 3. Perfume classification.

Concept	Variation	Examples
Feminine fragrances		
floral	green	Vent vert
	fruity	Lauren
	fresh	Diorissimo, Anaïs anaïs
	floral	Quelques fleurs, Giorgio
	aldehydic	Arpège, Madame Rochas
	sweet	l'Origan, Poison
oriental	amber	Shalimar, Samsara
	spicy	Youth dew, Opium
'chypre'	fruity	Chypre, Femme
	floral-animalic	Miss Dior, Cabochard
	floral	Coriandre
	fresh	Diorella
	green	Alliage
Masculine fragrances		
'fougère'	lavender	Silvestre, Cool water
	fresh	Drakkar noir, Jazz
	woody-amber	Paco Rabanne, Zino Davidoff
oriental	spicy	Old spice, Patou pour homme
	amber	Habit rouge
'chypre'	woody	Vétiver, Macassar
	leathery	Aramis
	fresh	Armani, Fahrenheit
	citrus	Eau sauvage

Source: Glöss, 1995.

ized by large and strong local markets for the essential oils produced, which dampens fluctuations in world demand and prices. They all have a strong position for a limited number of traditional products and have made long-term investments in research, training and supporting services.

1.7 Botany

1.7.1 Taxonomy

Many constituents of essential oils are derived from the isoprene molecule, which also plays a role in the synthesis of important biological compounds such as chlorophylls, gibberellins, carotenoids and steroids. It is not surprising therefore that aroma compounds are found throughout the plant kingdom and to a lesser extent in the animal kingdom. There are 108 families of higher plants known that yield over 2000 essential oils (Gildemeister & Hoffmann, 1956–1966). Many families are represented by one species only, but of the *Myrtaceae*, 330 essential oils derived from over 300 species and varieties are mentioned, including 213 essential oils from *Eucalyptus* (sensu lato). Economically, the most important families yielding essential oils are: *Gramineae* (*Cymbo-*

Table 4. Production and value of the 20 most important essential oils.

Essential oil	Species	Production (t)	Value 10⁶ US$
orange oil	*Citrus sinensis* (L.) Osbeck	26 000	58.5
cornmint oil	*Mentha arvensis* L. var. *piperascens* Malinv. ex Holmes	4 300	43.4
eucalyptus oil cineole type	*Eucalyptus globulus* Labill., *E. polybractea* R.T. Baker and other spp.	3 728	29.8
citronella oil	*Cymbopogon winterianus* Jowitt and *C. nardus* (L.) Rendle	2 830	10.8
peppermint oil	*Mentha* ×*piperita* L.	2 367	28.4
lemon oil	*Citrus limon* (L.) Burm.f.	2 158	21.6
eucalyptus oil citronellal type	*Corymbia citriodora* (Hook.) K.D. Hill & L.A.S. Johnson	2 092	7.3
clove leaf oil	*Syzygium aromaticum* (L.) Merrill & Perry	1 915	7.7
cedarwood oil (United States)	*Juniperus virginiana* L. and *J. ashei* Buchholz	1 640	9.8
litsea cubeba oil	*Litsea cubeba* (Lour.) Persoon	1 005	17.1
sassafras oil (Brazil)	*Ocotea odorifera* (Vell.) Rohwer (syn. *O. pretiosa* (Nees.) Mez.)	1 000	4.0
lime oil distilled (Brazil)	*Citrus aurantifolia* (Christm. & Panzer) Swingle	973	7.3
native spearmint oil	*Mentha spicata* L.	851	17.0
cedarwood oil (China)	*Chamaecyparis funebris* (Endl.) Franco	800	3.2
lavandin oil	*Lavandula* ×*intermedia* Emeric ex Loisel.	768	6.1
sassafras oil (China)	*Cinnamomum micranthum* (Hayata) Hayata	750	3.0
camphor oil	*Cinnamomum camphora* (L.) J.S. Presl	725	3.6
coriander oil	*Coriandrum sativum* L.	710	49.7
grapefruit oil	*Citrus* ×*paradisi* Macf.	694	13.9
patchouli oil	*Pogostemon cablin* (Blanco) Benth.	563	6.8

Source: Lawrence, 1993.

pogon spp., *Vetiveria* spp.), *Labiatae* (*Mentha* spp.), *Lauraceae* (*Litsea* spp.), *Myrtaceae* (*Corymbia* spp.), *Oleaceae* (*Jasminum* spp.), *Pinaceae* (*Cedrus* spp., *Picea* spp., *Pinus* spp.), *Rosaceae* (*Rosa* spp.), *Rutaceae* (*Citrus* spp.) and *Santalaceae* (*Santalum* spp.), while many spices that also yield essential oil are *Umbelliferae*. A few cryptogams yield essential oil; the most important ones are the lichen *Evernia prunastri* (L.) Ach. and the seaweed *Fucus vesicilosus* L. One family famous for its scented flowers, but hardly mentioned here, is the *Orchi-*

Table 5. Principal essential-oil exporting countries.

Country	Value (10^3 US$)	Quantity (t)	Proportional value (%)
China	141 967	14 693	18.6
European Community	124 811	9 656	16.3
United States	122 833	8 435	16.1
Hong Kong	47 250	6 869	6.2
Brazil	36 389		4.8
Indonesia	33 354	2 450	4.4
India	24 643	1 156	3.2
Switzerland	16 850	459	2.2
Argentina	15 743	1 503	2.1
Paraguay	11 478	1 130	1.5
Singapore	10 993	859	1.5
Thailand	10 818	778	1.4
Haiti	9 776	228	1.3
Japan	9 526	582	1.2
Turkey	8 891	15	1.1
Morocco	8 731	542	1.1
Former USSR	7 943	203	1.0
Mexico	7 896	1 493	1.0
Canada	6 893		0.9
Egypt	6 810	70	0.9

Note: Re-exports are included in the data. Data from countries with incomplete export statistics are partly based on statistics from importing countries. Due to discrepancies between import and export statistics, the total value of imports exceeds the value of exports by about 25%.
Source: Hay & Waterman, 1993.

daceae. Modern analytical equipment is sufficiently sensitive to analyse orchid odour, but the amounts present in the flowers is too small to extract the oil commercially. Perfumes with an odour approaching that of orchid flowers can be composed using natural or synthetic products and may soon be important in perfumery. However, it is still impossible to compose a perfume that captures the true odour in all its depth and complexity.

The animal kingdom contributes only a few, but nonetheless famous, fragrance materials, most notably musk from the musk deer, ambergris from the sperm whale and civet from the civet cat.

1.7.2 Morphology

Essential oils may be found in any part of a plant and are commercially extracted from roots, wood, bark, leaves, flowers, fruits and seeds. To some extent this reflects the many functions of the essential oil in the plant: in flowers the fragrance may attract insect pollinators, in fruits animals that distribute the seed, while in leaves the essential oil may function as insect repellant and in wood as preservative.

Aroma compounds are sometimes toxic materials formed or stored in special organs in plants. The variability of these organs reflects the varied taxonomy of essential oil plants; only a few examples of the many structures found can be given here. Oil glands may be simple or compound hairs on the leaves, as in *Pelargonium* and several *Labiatae*, where the gland consists of a multicellular hair with the oil concentrated in the enlarged apical cell or in the space between the cell-wall and the outer cuticula. *Pogostemon* Desf. has 2 types of oil glands: the common epidermal hair glands and mesophyll glands. The mesophyll glands are complex structures located in the palisade tissue and consist of a large secretory cell located near a small vascular bundle. The secretory cell has very dense cytoplasm and a large nucleus and is surrounded by a cuticula. The essential oil produced is contained in the space between the cell wall and the cuticula. In the *Rutaceae* and *Myrtaceae* the essential oil is concentrated in large subepidermal glands arising from a specialized mother cell. The mother cell divides into daughter cells that separate from one another and disintegrate to leave a central cavity. The cells surrounding the cavity produce essential oil and the cavity enlarges by the breakdown of the walls of the surrounding cells. In *Santalum* spp. the compounds that are distilled as essential oil are deposited in the xylem as part of the formation of the heartwood. The formation of fragrant wood is much more complex in *Aquilaria* spp., where it is only found in old, diseased trees. It is assumed that trees weakened by fungal attack are infected by a secondary fungal parasite that is involved in the formation and deposition of the essential compounds.

1.8 Ecology

Few general statements can be made about the ecological requirements of essential-oil plants. Some species are grown in widely differing habitats. *Citrus bergamia* is grown in the hot and dry subtropical region of Calabria (Italy) but also in more humid, tropical parts of Guinea and Ivory Coast. *Polianthes tuberosa*, originally from Mexico, was formerly widely grown in southern France and is now cultivated mainly in Karnataka (India). *Pelargonium* spp. originating from South Africa were introduced into France, where natural hybrids developed that are now cultivated from temperate England to equatorial Kenya. Although a location should meet the basic ecological requirements of the essential-oil crops grown, it seems much more important that very high standards of cultivation and processing are maintained and that they are accompanied by a well organized trading network. This may explain the former role of Grasse (France), the very large production of several essential oils in the small islands of Nosy Bé and Mauritius near Madagascar and the recent developments in Hainan (China). However, ecology plays an important, but subtle role in the quality of essential oils. In Bulgaria, rose oils can be distinguished, like wine, by the year in which they were produced. Many oils are therefore traded with their origin attached to their name: vetiver oil Bourbon from Mauritius or otto of roses Turkey.

In only a few cases can differences in composition of essential oil be attributed unequivocally to ecological factors, e.g. the effect of temperature on the quality of geranium oil.

1.9 Agronomy

Crop husbandry measures in essential-oil crops differ little from those of other annual and perennial crops. Weed control needs special attention in crops that are harvested in bulk as weeds may reduce the quality of the essential oil if they are distilled with the crop. The use of herbicides and chemicals for disease and pest control often needs special care, as pesticide residues may also affect the quality of the oil.

The harvesting of most essential-oil crops too is similar to harvesting comparable crops. *Cymbopogon* spp. are harvested in bulk and require little special care. The wood of tree crops such as *Cinnamomum camphora* is chipped before distillation in a way similar to chipping wood for pulping. Crops grown for their flowers are a special case. Picking the flowers of crops such as *Rosa* and *Jasminum* requires an enormous labour input. It takes about 2.5 hours to harvest 1 kg of *Jasminum* flowers. Moreover, the flowers have to be picked early in the morning before temperatures become too high. To obtain 1 kg concrete or 0.5 kg absolute, 1000 kg of flowers are required. This accounts for the very high cost of some aroma materials and the gradual shift of production to low-income countries. Production of crops such as *Pelargonium* first moved to Mauritius, but when wages there increased, China became the main country of production. The production of many crops has followed this trend; only the very labour-intensive crop *Rosa* is still hardly grown outside its traditional areas of production: Bulgaria, France, India, Morocco and Turkey. Established trade lines and guaranteed quality apparently compensate for increasing costs.

1.10 Genetic resources and breeding

The essential-oil industry is relatively small and comprises a large number of crops. In the market for high quality essential oils used in luxury perfumery, suppliers try to meet the demands of buyers for products of well-established qualifications. In such a market it is difficult to introduce a new variety with almost unavoidably somewhat different characteristics. In the production of lavender oil, specifications have been laid down for the oil of several clones. Even for lavandin oil, which is a less exclusive product than lavender oil, there are detailed specifications for the oil from the main cultivars. The small size of the market for individual essential-oil crops also hampers the establishment of breeding programmes and gene banks. At the same time, however, the perfume industry is a creative one, always searching for new fragrances and experimenting to compound new attractive products. This would suggest that there is potential for introducing new products, provided that a stable supply of a high and constant quality can be guaranteed.

The situation is different for crops yielding essential oils used mainly in cosmetics and functional perfumery. The oils are selected more for their main aroma components than for the delicacy of their fragrance, on the basis of a large number of compounds and on the balance between them. For *Cymbopogon* spp., which yield essential oils used primarily for their main components, there are breeding programmes and a considerable number of improved cultivars have been released e.g. in India. Programmes to select superior trees have also been established, e.g. in Australia and Brazil, for *Corymbia citriodora*, which is grown mainly for its citronellal. Most breeding work is conducted in India, at the Central Institute of Medicinal and Aromatic Plants, Lucknow and by the regional institutes associated with it.

1.11 Prospects

1.11.1 Economic trends

The current revival of interest in 'natural' i.e. animal-based or plant-based materials applies strongly to aromatherapy and to flavour and fragrance products. Whereas the use of essential oils in general medicine is likely to remain limited to cough syrups and antiseptic preparations, aromatherapy has found a niche that is increasing in importance. Its objective of invigorating a person through the use of natural aroma materials combined with massages and baths appeals to a growing group of enthusiasts. Consequently, it represents an expanding market for essential oils.

In the food industry, natural products are enjoying a strong consumer preference, while the use of synthetic compounds is regulated by ever stricter laws and regulations. A huge firm such as Nestlé reflects this interest, using as flavour products: 75% naturals, 12.5% enhanced naturals and 12.5% nature-identical and artificial products. The growth of the market for exotic foods also contributes to a steadily increasing demand. At the same time, the growing demand for ready-made, i.e. industrially prepared food increases the use of essential oils, as this use can be controlled more accurately than that of fresh plant materials.

The underlying basis for the role of phytochemicals in perfumery is the ability of plants to synthesize molecules, many of which have complex structures beyond the dreams or economics of the organic chemist. Plants further compound large numbers of fragrance materials into a single essential oil, giving its odour a richness that cannot be copied by a perfumer using synthetic compounds.

The rapid developments in the analysis of essential oils, especially the combined chemical and olfactive characterization of compounds present in trace amounts only, will encourage increased application of synthetic compounds in perfumery. Although the use of synthetic products in industrial and functional perfumery is likely to grow, there is little doubt that essential oils will continue to play a central role in luxury perfumery and cosmetics. The contrasting pattern in production between lavender oil and vetiver oil exemplifies these trends. The production of lavender oil, which is strongly supported by research, is relatively stable in spite of competition from existing synthetics, while the production of vetiver oil is declining. Although vetiver oil seems to be protected by a lack of synthetic alternatives, irregularities in production and quality have depressed world demand and production.

1.11.2 Research needs

The production of essential-oil crops can expand along 3 routes. The first is for such crops to follow market demand in areas where their production is already well established. To cope with increasing competition in inceasingly open markets and higher wages, productivity and product quality control will have to be improved constantly. Research and extension should support these developments.

The second option is for new essential-oil crops to be introduced into regions traditionally producing essential oils. This requires intensive economic research and agronomic testing. South-eastern China, Morocco, Argentina and Brazil are examples of areas where new crops have been introduced successfully. The most challenging option is to establish a new essential-oil industry. This can meet with lasting success, as demonstrated by the varied production in the Indian Ocean islands of the Comoros, Mauritius and Madagascar and the bergamot production in West Africa. The history of production of geranium oil in East Africa, however, shows that disruptions in supply and quality control can cause irrevocable havoc in an industry.

The development of new uses for essential oils forms a special field of research. The use of phytochemicals including essential oils for the control of microorganisms in agriculture is gaining importance. The essential oils from *Mentha* × *piperita* L. and several *Cymbopogon* spp. have been tested for their fungicidal effect against *Helminthosporium oryzae*, a devastating leaf spot disease in rice. And on the basis of the traditional use of aromatic plants, essential oils are also being tested to control insects in 3 broad areas: as antifeedants, juvenile hormones and insecticides.

2 Alphabetical treatment of species

Abelmoschus moschatus Medikus

Malvenfam.: 46 (1787).
MALVACEAE
$2n = 72$

Synonyms *Hibiscus abelmoschus* L. (1753).

Vernacular names Musk mallow, ambrette, mushkdana (En). Ambrette, ketmie musquée (Fr). Indonesia: gandapura, kasturi (general), kakapasan (Sundanese). Malaysia: kapas hantu, kapas hutan, gandapura. Philippines: dalupang, kastuli, kastiokastiokan (Tagalog). Thailand: chamot-ton, som-chaba (Bangkok), mahakadaeng (northern). Vietnam: c[aa]y b[oo]ng v[af]ng, b[us]p v[af]ng.

Origin and geographic distribution *A. moschatus* occurs from India to southern China including Hainan and Taiwan and through South-East Asia to northern Australia and the Pacific. In Malesia it is common in the more humid areas, rare in the Lesser Sunda Islands and southern Papua New Guinea, lacking in the south-eastern Moluccas. It is cultivated commercially in Java, India (mainly in the Deccan and Carnatic), Madagascar and in parts of Central and South America. On a small scale it is cultivated and occasionally occurs as a weed throughout the tropics and in warm temperate areas.

Uses *A. moschatus* is the source of ambrette seed oil used in luxury perfumery, cosmetic products and as an additive in the preparation of some kinds of chewing tobacco, baked products, sweets, alcoholic (e.g. vermouth and bitters) and non-alcoholic drinks. Arabs sometimes flavour their coffee with the seed and in India and Malaysia pounded seeds are used to perfume hair, while seeds are also placed between clothes to keep away insects. Seeds are burned as incense and used in making incense sticks (agarbattis). Tender leaves, shoots and pods are occasionally eaten as vegetable.

A. moschatus has many applications in traditional medicine. In the Philippines a decoction of the roots and leaves is taken as an emollient remedy for gonorrhoea and rheumatism, while in Burma (Myanmar) and the Philippines the seed is said to have stomachic, tonic, diuretic, antihysteric, stimulating and antispasmodic properties. In Indonesia pulverized seeds mixed with powder provide a useful remedy to treat prickly heat. In Indo-China the root is said to be effective in the treatment of blennorrhagia and leucorrhoea, the leaves and flowers are rubbed on scabies and applied as poultice to swellings. In traditional Vietnamese medicine the plant is used as an antivenom and a diuretic. It is also said to be an aphrodisiac. The tuberous roots of *A. moschatus* subsp. *tuberosus* (Span.) Borss. are said to be sought after by the Chinese as a substitute for ginseng.

The leaves are sometimes used by Malay people as wrappers for parcels. Fibre from the stem is a substitute for jute, but offers no advantages over the latter. The mucilage from the roots is used in China for sizing paper. *A. moschatus* is sometimes grown as an ornamental.

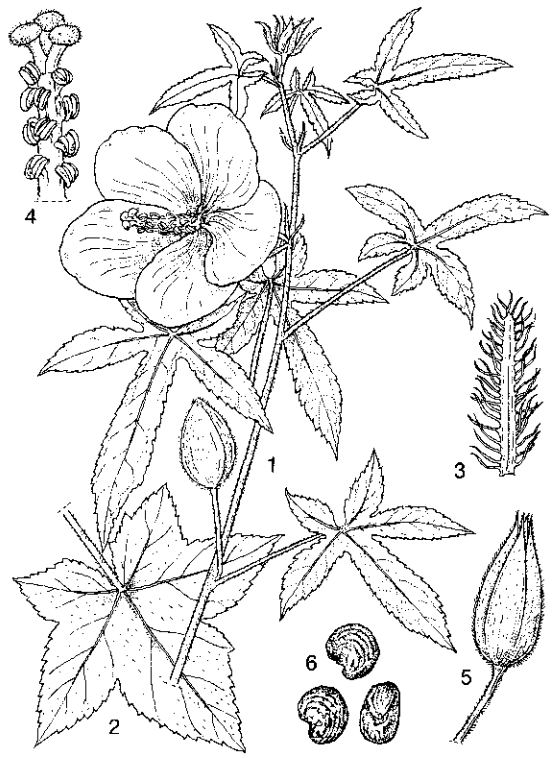
Production and international trade Less than 1000 kg ambrette seed oil are produced annually. The main producers are India, Colombia, Ecuador and Martinique. Ambrette seed oil is traded in small quantities only and rarely mentioned separately in trade statistics. The world market price is about US$ 5000/kg (1998).

Properties The seed of *A. moschatus* contains per 100 g: 13–15 g fatty oil and 0.2–0.6% essential oil. The main constituents of the fatty oil are: palmitic acid (20%), oleic acid (20–25%), linoleic acid (50–57%), stearic acid (2.5–4%) and smaller amounts of myristic acid and palmitoleic acid. When ambrette seed is crushed before steam distillation, the odourless, palmitic acid is distilled over together with the aromatic components yielding a crude oil of paste-like consistency. The aromatic components are concentrated in the outer seed coat and distillation of whole seed gives a liquid essential oil, containing only small amounts of fatty oil, but also a lower yield of essential oil. This ambrette seed oil should be allowed to age for several months before being used in aroma or flavour materials. By ageing, the original fatty notes become subdued and a rich sweet floral-musky aroma with distinctly wine-like or brandy-like notes develops, with a uniquely rich bouquet known for the exalting effect it imparts to perfumes. The odour has notes also found in a great variety of products, e.g. cypress oil, Bulgarian rose oil, sage clary oil and cognac oil; there are also some notes with a similarity to the aroma of higher dodecyl esters. The aroma is strong and long lasting and the recommended concentration in a final product is about 1–3 mg/kg, while the minimum perceptible concentration is 0.1–0.4 mg/kg (0.1–0.4 ppm). The essential oil is classified by the Food and Drugs Administration of the United States (FDA) as 'generally recognized as safe' (GRAS No 2051). The chemical characteristics of the essential oil are only incompletely known and are affected by the method and conditions of extraction. The characteristic musk-like odour is due mainly to ambrettolide (Z-hexadec-7-en-16-olide) and Z-tetradec-5-en-14-olide, both macro-

cyclic lactones. Other major components are farnesol and farnesyl esters and other acyclic aliphatic esters and terpenes. The composition of the volatile fraction of the oleoresin obtained by solvent-extraction of the seed is similar to the composition of the steam-distilled essential oil. An ambrette seed oil from Vietnam was characterized by (E)-2,3-dihydrofarnesyl acetate (32–67%), (E, E)-farnesyl acetate (15–36%), ambrettolide (3–6%) and (Z,E)-farnesyl acetate (1–5%). See also: Composition of essential-oil samples and the Table on standard physical properties.
The weight of 1000 seeds is about 13 g.

Adulterations and substitutes Ambrette seed oil was originally a substitute for deer musk, but became an essential oil in its own right because of its subtly different, flowery fragrance. The characteristic constituent of ambrette seed oil, ambrettolide, is made synthetically. Musk ambrette, a synthetic nitro-musk compound is used as a fragrance and fixative material. It is olfactively different from ambrette seed oil.

Description A variable, annual or biennial, erect herb or undershrub, 0.5–3.5 m tall, hispid, often woody at base, with taproot or tuberous root; stem usually solid, sometimes hollow; stem apices and petioles with many obliquely downwardly directed long sharp bristles, rarely sparsely hairy or glabrous. Leaves alternate, extremely variable in shape and size; petiole 6–30 cm long; stipules linear-filiform, simply hairy; lower leaves orbicular to transversely elliptical in outline, 6–22 cm × 8–24 cm, base cordate, angular or 3–7-palmately lobed or parted; higher leaves usually narrower and often hastate or sagittate, lobes spreading, oblong-lanceolate, coarsely serrate-dentate, rarely entire, both surfaces hispid with simple hairs and usually also minute stellate hairs, rarely glabrous. Flowers axillary, solitary; pedicel 2–19 cm long, somewhat accrescent; epicalyx segments (4–)7–10(–16), free, persistent, linear-lanceolate or oblong, 0.75–2.5 cm long, not enveloping the entire fruit as a lattice and much shorter, usually acute, simply hairy; calyx spathaceous, apex 5-toothed, splitting on one side during expansion of the corolla, adnate to and falling with the corolla, outside stellate-tomentose, inside simply sericeous; petals 5, obovate, 3.5–10 cm × 2.5–5.5 cm, yellow with crimson centre or white to red, with scattered gland-hairs or glabrous, apex rounded, base fleshy and ciliate with simple hairs; staminal column much shorter than the petals, antheriferous throughout, usually yellow, but dark purple at base, glabrous; ovary ovoid, 5-celled, hirsute; style 1, distally 5-branched but branches sometimes united to various degree, hairy; stigmas discoid. Fruit a loculicidally dehiscent, many seeded, ovoid or globose capsule, 2–8 cm long, occasionally fusiform, acuminate with a short rostrum, somewhat angular, usually hispid with simple stiff hairs, often also with short simple hairs and minute stellate hairs, rarely glabrous, black or dark brown; valves chartaceous or coriaceous, inside smooth and shining. Seed reniform, 3–4.5 mm long, concentrically ribbed, somewhat warty, mostly glabrous, sometimes ferrugineously stellate-tomentose, black-brown, often smelling of musk.



Abelmoschus moschatus Medikus – 1, flowering branch; 2, lower leaf; 3, segment of epicalyx; 4, part of staminal column with anthers and stigmas; 5, capsule; 6, seeds.

Growth and development In India the first flowers of *A. moschatus* are formed in the axil of the 3rd to 8th leaf depending on the cultivar. The first buds are formed 25–39 days after germination. Flower buds take 22–25 days to reach full bloom and flowering continues for 45–80 days. Anthesis occurs between 9 a.m. and 11 a.m. and the stigma is receptive on the day of anthesis. The fruit takes about 25 days from setting to maturity.

Other botanical information *A. moschatus* is a very variable species with many synonyms and subclassifications. At present 3 subspecies are distinguished:
- subsp. *biakensis* (Hochr.) Borss. A stout herb or undershrub, up to about 2 m tall, minutely stellate-hairy, with a long slender taproot; stem usually hollow; leaves large, orbicular, 10–19 cm in diameter, palmatilobed; petiole 6–13 cm long; pedicel very long and stout, after flowering up to 19 cm × 3–4 mm; epicalyx segments 8, lanceolate, 15–20 mm × 3–4 mm, in fruit appressed; corolla white or yellow with dark purple centre; capsule 5–8 cm long, with coriaceous valves; seed subglabrous. Distributed in New Guinea, possibly also cultivated as a vegetable.
- subsp. *moschatus*. A stout herb or undershrub, up to about 1.5 m tall, with a long, slender taproot; stem usually retrorsely hispid; pedicel 3–8 cm long; epicalyx segments 6–10, 8–20 mm × 1–2.5 mm, in fruit appressed; corolla yellow with dark purple centre; capsule 5–8 cm long, thinly hispid, with chartaceous valves; seed subglabrous. In this subspecies 2 varieties can be distinguished:
  - var. *betulifolius* (Mast.) Hochr. Stem mostly glabrous, spotted red, hollow; epicalyx segments 6–8, lanceolate, 17–25 mm × 2.5–5 mm. Distributed in Indo-China, in Malesia rare.
  - var. *moschatus*. Stem always hispid, mostly evenly tinged red, rarely hollow; epicalyx segments 7–10, linear, 8–15 mm × 1–2 mm. Distribution as given for the species.
- subsp. *tuberosus* (Span.) Borss. An erect or decumbent herb up to 75 cm tall with a short, tuberous, turgid taproot; stem usually patently hairy, sometimes prickly; epicalyx segments 9–10, in fruit spreading or reflexed, never appressed; corolla usually white or pink, sometimes yellow; capsule 2–5 cm long, densely hispid; seed ferrugineously tomentose. Distributed in Indo-China, Hainan, Malesia and northern Australia.

A. moschatus subsp. *moschatus* is tetraploid ($2n$ = 72); subsp. *tuberosus* is diploid ($2n$ = 36).

Ecology *A. moschatus* can grow in a variety of places, e.g. roadsides, brushwood, fallow land, and on the bunds of rice fields. In the tropics it occurs up to 1650 m altitude in Indonesia, while in India it is cultivated up to 1000 m. *A. moschatus* requires a humid tropical or subtropical climate, although heavy and continuous rain affects crop growth negatively. The optimum temperature for vegetative growth is about 20–28°C, but it can tolerate temperatures up to 45°C. Frost is not tolerated. It is daylength sensitive, short days promoting early flowering. Flowering is also stimulated by low night temperatures. During flowering and fruiting dry weather is preferred. *A. moschatus* thrives in fertile loamy or sandy-loamy soil. Growth is often poor on clay and sandy soils and on saline or strongly alkaline soils. Waterlogging is not tolerated. Subsp. *biakensis* grows near beaches, subsp. *tuberosus* prefers locations with an annual dry period and where the vegetation is periodically burnt.

Propagation and planting *A. moschatus* is propagated by seed. It requires a fine but compact seedbed for uniform germination. In India about 5 kg/ha of seed are used for sowing in rows spaced 75–90 cm apart. When the seed is dibbled at a spacing of 90 cm × 90 cm, 1–1.5 kg/ha is needed. Soaking the seed in water overnight accelerates germination. Seed is sown 1–2 cm deep. Under favourable conditions, germination starts 4–15 days after sowing and is complete after 15–30 days. The optimum temperature for germination is about 30°C. The germination rate of good commercial seed is about 85%. In row planting, thinning is required; in India it is done to about 60 cm, in China to 45–50 cm between plants.

Husbandry *A. moschatus* needs to be weeded 2–3 times during early growth. Later, the superficial root system may be damaged by hoeing. In northern India where lush vegetative growth often leads to poor fruit set, pruning 50–60 days after transplanting tended to increase seed yield by about 40%. Earlier pruning was not beneficial. In a fertilizer trial in India on a sandy loam poor in P and rich in K, seed yield increased from 0.5 to 1.2 t/ha in response to an application of 120 kg N/ha, while a yield of 1.5 t/ha was obtained with 120 kg N/ha in combination with 35 kg P/ha.

Diseases and pests *A. moschatus* suffers from several diseases, the most important being Hibiscus mosaic virus (HMV), anthracnose and leaf spot. Plants infected with HMV should be uprooted and destroyed as there is no other effective control. Anthracnose, caused by *Colletotrichum hibisci*, affects all plant parts and may start in the seedling stage. Seed treatment and spraying with fungicides, e.g. Bordeaux mixture, can control the disease. *Alternaria* leaf spot and *Phytophthora* leaf blight can cause damage, the latter especially under humid conditions. Seed treatment can reduce losses. In India, spotted bollworm (*Earias insulana*) attacks the crop during vegetative growth and the fruiting stage. Infested shoots turn brown above the point of infestation, bend down and die. Fruits are also affected. Preventive spraying with thiodan at 10–15 day intervals from the seedling stage until harvesting effectively controls the pest, but is rarely practised by small farmers. Pink bollworm (*Pectinophora gossipialla*) causes some damage to pods and seeds in northern India. A cotton semilooper (*Anomis flava*) is observed in India during the rainy season, the intensity of attack decreases as temperatures become lower, and the pest disappears in mid-November.

Harvesting In India fruit sets continuously from October to April. As mature pods open and shatter their seed, several picking rounds are needed. Harvesting starts when most pods begin to turn from green to brown and just start to open. Pods are picked when three-quarters of their body has turned blackish-brown; the seed is removed manually. Picking is an arduous task as the plants, including the pods, possess hairs that cause itching. In India harvesting has often stopped by the end of February, as later harvesting rounds yield too little to be economical.

Yield Average seed yield obtained in India is 0.8–1 t/ha.

Handling after harvest After drying in the shade, the pods are mostly threshed by being beaten with sticks. The husk is then removed by winnowing.

Steam distillation of whole seed yields ambrette seed oil, while distillation of ground seed and hydrocarbon extraction of ground seed produces ambrette seed concrete, largely consisting of palmitic and myristic acids, which are unstable and odourless. Ambrette seed absolute is prepared from the seed concrete either by neutralization and subsequent elimination of fatty acids or by steam distillation of the concrete followed by washing with alcohol.

Genetic resources The main centre of diversity for *Abelmoschus* DC. is India where *A. esculentus* (L.) Moench, *A. manihot* (L.) Medikus, *A. moschatus* and 7 related wild species occur. An *Abelmoschus* germplasm collection is kept in Thailand with 78 accessions, 30 of which are of *A. moschatus*, mostly of subsp. *tuberosus*. In China, the National Genebank holds 20 accessions of okra and several related species including *A. moschatus*; the Genebank of the Beijing Academy of Agricultural Sciences holds 10 accessions. Germplasm of *Abelmoschus*, including *A. moschatus*, has also been collected in Nepal.

Breeding *A. moschatus* is autogamous and methods of manual emasculation have been developed for breeding work. However, very little breeding work has been done. *A. moschatus* is highly resistant to the cotton jassid *Empoasca biguttula* which attacks *Abelmoschus manihot* and *A. esculentus*. Although *A. moschatus* is reproductively incompatible with the other 2 cultivated *Abelmoschus* species, tissue and protoplast fusion techniques may be useful for transferring the resistance.

Prospects As musk from the musk deer becomes increasingly rare and as the safety of synthetic nitro-musk remains uncertain, ambrette seed oil remains a valuable source of musk-like fragrances. Such fragrances remain in high demand in perfumes and skin-care products and demand for *A. moschatus* is therefore likely to remain strong.

Literature |1| Charrier, A., 1984. Genetic resources of the genus Abelmoschus Med. (okra). International Board for Plant Genetic Resources, Rome, Italy. 61 pp. |2| Cravo, L., Périnau, F., Gaset, A. & Bessiere, J.M., 1992. Study of the chemical composition of the essential oil, oleoresin and its volatile product obtained from ambrette (Abelmoschus moschatus Moench) seeds. Flavour and Fragrance Journal 7: 65–67. |3| Duhan, S.P.S. & Singh, D.V., 1992. Cultivation and utilization of mushkdana. Current Research on Medicinal and Aromatic Plants 14: 181–191. |4| Dung, N.X., Khien, P.V., Nhuan, D.D., Hoi, T.M., Ban, N.K., Leclercq, P.A., Muselli, A., Bighelli, A. & Casanova, J., 1998. The seed oil of Hibiscus abelmoschus L. (Malvaceae) growing in Vietnam: a valuable source of fixative fragrance components. Journal of Essential Oil Research 10: in press. |5| Hamon, S., Charrier, A., Koechin, J. & van Sloten, D.H., 1991. Les apports potentiels à l'amélioration génétique des gombos (Abelmoschus spp.) par l'étude de leurs ressources génétiques [Potential improvement of okra (Abelmoschus spp.) through the study of its genetic resources]. Plant Genetic Resources Newsletter 86: 9–15. |6| Nee, T.Y., Cartt, S. & Pallard, M.R., 1986. Seedcoat components of Hibiscus abelmoschus. Phytochemistry 25: 2157–2161. |7| Perry, L.M., 1980. Medicinal plants of East and Southeast Asia. Attributed properties and uses. MIT Press, Cambridge, United States. p. 252. |8| Singh, V.P. & Duhan, S.P.S., 1981. Note on the response of ambrette (Abelmoschus moschatus Medic.) to graded doses of nitrogen and phosphorus. Indian Journal of Agricultural Science 51: 356. |9| Srivastava, U.C., 1995. Ambrette seed. In: Chadha, K.L. & Rajendra Gupta (Editors): Advances in Horticulture. Vol. 11: Medicinal and aromatic plants. Malhotra Publishing House, New Delhi, India. pp. 887–897. |10| van Borssum Waalkes, J., 1966. Malesian Malvaceae revised. Blumea 14: 1–251, in particular pp. 90–95.

Sri Hajati Widodo

Acacia farnesiana (L.) Willd.

Sp. pl. ed. 4, 4: 1083 (1806).

LEGUMINOSAE

$2n = 26, 52, 104$; polyploidy is common

Synonyms *Mimosa farnesiana* L. (1753), *Vachellia farnesiana* (L.) Wight & Arnott (1834), *Acacia smallii* Isely (1969).

Vernacular names Cassie flower, sponge tree, mimosa bush (Australia) (En). Sweet acacia, popinac (Hawaii) (Am). Cassier, cassier de Farnèse, cassier ancienne (Fr). Indonesia: kembang jepun (Javanese), bunga bandara (Sumatra), sari konta (Balinese). Malaysia: pokok laksana (Peninsular Malaysia). Philippines: aroma, kandaroma (Iloko), kambang (Sulu). Burma (Myanmar): nan-lon-kyaing. Cambodia: sâmbu:ë mi:ëhs. Laos: kan 'thin 'na:m (Vientiane), kho:n^2 ko:ng dê:ng, kho:n^2 ko:ng 'na:m (Luang Prabang). Thailand: krathin-thet, krathin-hom (central), khamtai (northern). Vietnam: c[aa]y keo ta, keo th[ow]m, keo thi[ees]u (Ho Chi Minh City).

Origin and geographic distribution *A. farnesiana* originated in the northern part of tropical America, where its closest relatives can also be found. It is the most widely distributed *Acacia* species, introduced to all tropical and subtropical regions of the world for its fragrant flowers and has become widely naturalized and sometimes weedy, e.g. in the southern United States and Australia. In Malesia it was first introduced to the Philippines from Mexico by the Spaniards. It is now recorded throughout South-East Asia. It was first cultivated in Europe in the Hortus Farnesianus in Italy in 1611 and has become an important crop in southern France.

Uses The volatile components of cassie flowers can be extracted by the enfleurage method to yield cassie pomade, but this method is now rarely used. On solvent extraction the flowers yield cassie concrete, which is mostly processed further into cassie absolute. The absolute is used in luxury perfumes to which it lends a unique warmth and woody-floral note. Cassie absolute from concrete is occasionally used in flavours. In very low concentration it imparts a delightful naturalness and body to raspberry flavours.

Cassie absolute can also be prepared from cassie pomade. It is an extremely scarce perfume material that differs in character from cassie absolute from concrete and is not a substitute for the latter. In India a local type of pomade, attar of cassie, is made from cassie flowers.

Flowering branches are sold as cut flowers and are known in commerce as cassie flowers. The seed is occasionally used as a food, e.g. by Aboriginal peoples in Australia, who eat them after roasting. Sprouted seeds are a popular vegetable. The pods, which contain a sweet pulp surrounding the seeds, and the leaves are browsed by livestock in many countries, but the flavour of beef from cattle that have browsed on *A. farnesiana* is said to be tainted. The flowers are highly attractive to bees.

In some parts of India, the bark and the pods are used for dying and tanning. The gum exuded by the stem is used as a substitute for gum arabic and is considered superior for certain purposes.

The tree is planted worldwide as an ornamental, more extensively in e.g. Egypt, Israel and dry regions of Java. In countries such as India and Iraq and in the Mediterranean it is planted extensively for hedges and wind-breaks. The wood can be used like the wood of *Acacia nilotica* (L.) Willd. ex Del. in ship building, for carts, farm implements, posts, tool handles and for furniture, as the grain has an attractive appearance. In India twigs are used as toothbrushes. The wood is an excellent fuel, widely used in the Americas.

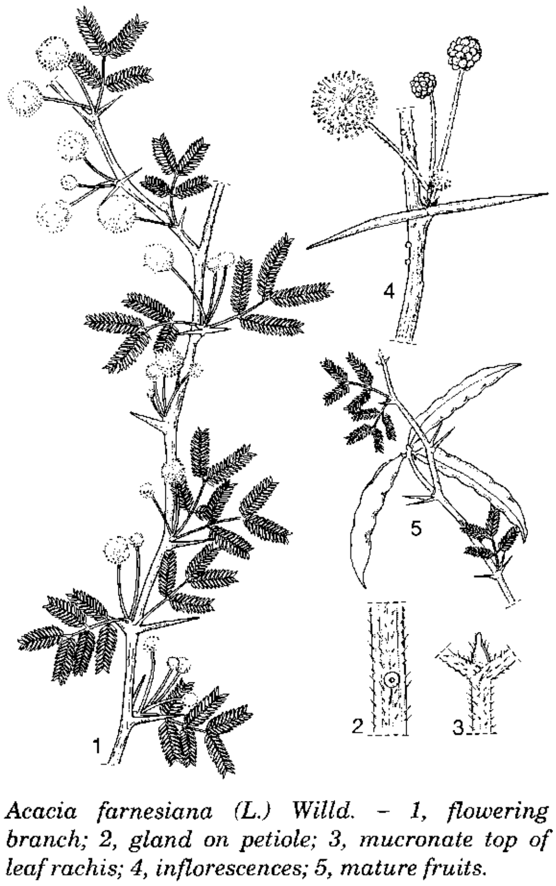
A. farnesiana has a great number of uses in traditional medicine. The bark has medicinal properties and is employed to treat cough and as an astringent e.g. to treat bleeding gums. In Java cassie flower is used as an emetic and by women after childbirth. In the Philippines it is applied in decoction to treat prolapsed rectum and as an injection for leucorrhoea. A lotion and a poultice of the tender leaves is applied to ulcers and sores previously washed with the decoction. Roots are chewed for sore throat and in decoction they are employed as a remedy for tuberculosis. The tender leaves are bruised with a little water and swallowed against gonorrhoea and affections of the bladder. The flowers are employed in Martinique as a stimulant and antispasmodic. An ointment made from the flowers is used in Mexico as a remedy for headache and their infusion for dyspepsia. The green fruit is very astringent and in decoction it is employed against dysentery and inflammation of the skin and mucous membranes. The pulp of the pods is used in France as a purgative.

Production and international trade Industrial production of cassie flower for perfume started near Cannes in south-eastern France and is still concentrated in that area, with smaller numbers of trees along the neighbouring Italian coast and in Northern Africa. Cassie pomade (attar of cassie) is produced in India but for the local market only. Cassie absolute from concrete is produced in very limited quantities; annual production is in the order of 100 kg only. The absolute is expensive; the world market price is several thousand US$ per kg (1998).

Properties Cassie concrete is a solid waxy, dark yellow or brown mass. On alcoholic extraction it yields 30–35% cassie absolute from concrete. This absolute is a dark yellow to pale brown viscous liquid, clear at about 20°C, but forming waxy flakes when colder. Its odour has a herbaceous-flowery top note, an extremely warm, powdery-spicy, but at the same time floral body and a deep and very tenacious cinnamic-balsamic dry-out. It combines well with a wide range of aroma materials.
As a flavour material it adds naturalness and body to raspberry flavours when used at a concentration only slightly above the minimum perceptible level (0.04–0.08 mg per 100 g). The Food and Drugs Administration of the United States (FDA) classified the absolute as 'generally recognized as safe' (GRAS No 2260).
On alcoholic extraction, cassie pomade (prepared by extracting the flowers by macerating them in fatty oil or heated fat) yields cassie absolute from pomade. Cassie absolute from pomade is a dark green or olive green, very viscous liquid. Its olfactive properties differ from those of cassie absolute from concrete: it has a fresher top note and a much lighter body note, but lacks the tenacity of the absolute from concrete.
The main volatile components of the absolute from concrete are methyl salicylate, anisaldehyde, geraniol (and derivatives) and benzaldehyde. The characteristic fragrance of cassie absolute is attributed to 3 minor components: 3-methyldec-3-en-1-ol, 3-methyldec-4-en-1-ol and 3-methyldec-4-enoic acid. See also: Composition of essential-oil samples.
The fodder quality of the leaves has been analysed in Hawaii, and that of the pods in Australia. Leaves contain per 100 g dry matter: crude protein 17 g, crude fibre 18 g, ether extract 2 g, N-free extract 57 g, and ash 5 g. Pods contain per 100 g dry matter: crude protein 17 g, crude fibre 19 g, ether extract 1.5 g, N-free extract 58 g, ash 4 g, Ca 0.6 g, and P 0.2 g.
The wood is brownish-yellow and has a distinctive, somewhat unpleasant smell. It is heavy (specific gravity 0.8), hard and close-grained and has good durability. The bark has a high content of tannin (30–40%).
The weight of 1000 seeds is 67–90 g.

Adulterations and substitutes Cassie absolute is adulterated with mimosa absolute extracted from the flowers of *Acacia dealbata* Link and isoeugenol and can be contaminated with extracts of carob tree flowers (*Ceratonia siliqua* L.). Several synthetic cassie base materials have been developed.

Description Branched shrub or rarely a small tree up to 4(–10) m tall; bark rough, light brown. Branchlets terete, greyish-brown to purplish-grey, glabrous, with prominent lenticels. Leaves, lateral shoots and peduncles often arising from short spurs on older wood. Leaves alternate, bipinnately compound; stipules spinescent, straight, up to 5 cm long, whitish-grey; petiole 0.5–1.3 cm long, with a circular, sessile, often raised gland present



Acacia farnesiana (L.) Willd. – 1, flowering branch; 2, gland on petiole; 3, mucronate top of leaf rachis; 4, inflorescences; 5, mature fruits.

in the distal half; rachis 4–6 cm long, mucronate at the top, sometimes with a gland near the apical pinnae; petiole and rachis pubescent to tomentose; pinnae in 2–8 pairs, 1.5–3 cm long, eglandular; leaflets in 10–21 pairs per pinna, opposite, sessile, linear-oblong, 2–8 mm × 0.8–1.8 mm, base truncate, apex asymmetrically acute, mucronate, both surfaces glabrous, main vein excentric, lateral veins raised and prominent below. Inflorescence composed of pedunculate globose glomerules of 50–60 flowers, aggregated in groups of 1–7 in the upper leaf-axils; peduncle 0.8–3.5 cm long, with a ring of bracts (involucel) at the summit, hidden by the flowers; flowers sessile, pentamerous, golden-yellow, fragrant; calyx 1–1.3 mm in diameter, tube glabrous, teeth 5, triangular, acute, 0.2 mm long, glabrous except for the exterior of the apex; corolla 2.3–2.5 mm long, tube glabrous, lobes 5, elliptical, about 0.5 mm long, acute, scarcely puberulous at the apex; stamens numerous, 4–5.5 mm long, anthers glandless; ovary subsessile, about 1.5 mm long, densely puberulous. Fruit a mostly slightly curved (sometimes straight), cylindrical pod, 4–7.5 cm × 1–2 cm, turgid, dark brown to black, rigidly chartaceous, glabrous, indehiscent, not bullate over the seeds, veins obliquely longitudinal, with some prominulous anastomoses. Seeds in 2 rows, placed obliquely transverse in the pod, embedded in a sweet pulp, ellipsoidal, 7–8 mm × 4–5.5 mm, slightly flattened, olive-brown to olive-green also light brown to dark brown or black; areole elliptical, 6.5–7 mm × 4 mm, open towards the hilum.

Growth and development *A. farnesiana* grows readily from seed and can colonize disturbed areas. Flowering starts about 3 years after planting and plants reach full production at 5–6 years of age. In Malesia, flowering occurs throughout the year, in Central America from November to April, while pods ripen from March to May. In France flowering takes place during September–October, while cv. Semperflorens flowers in April–May too. *A. farnesiana* coppices well. It fixes atmospheric nitrogen.

Other botanical information The variability of *A. farnesiana* is great. Two varieties are distinguished based on leaf and pod characters: var. *farnesiana* and var. *guanacastensis* Clarke, Seigler & Ebinger. The latter is found from Mexico to Costa Rica. It is distinguished from the typical variety by its longer (7–15 cm), puberulent fruits with uniseriate seeds, larger leaves with 4–9 pairs of pinnae and 21–28 pairs of leaflets, pilose petiole and abaxially pubescent rachis and leaflets.

Several cultivars have been developed in France. Cv. Cavenia, grown in southern France is well known for its tolerance of drought and frost, but its oil is of secondary quality. Cv. Semperflorens is renowned for its vigour and tallness, and requires more care, nutrients and irrigation, but produces 2 harvests of flowers per year.

Ecology *A. farnesiana* is mostly found as a dominant component of secondary vegetation in dry places, but tolerates a wide range of annual rainfall (up to 4000 mm) and prefers a long dry season. Annual rainfall in its habitat in Australia ranges from 150–700 mm. It requires a mean annual temperature of 15–28°C and occurs from sea-level up to 1500 m altitude. Its natural distribution in Malesia is up to 400 m altitude, while in cultivation it grows up to 1200 m. Frost is tolerated to a minimum of −5°C. It is found scattered or in pure, open stands in plains, savanna grasslands, tidal flats, sandy river beds, brushwood, and waste ground, on heavy soils including black clays, loamy or sandy soils with a pH of 5–8(–10). In France, however, *A. farnesiana* may grow and flower poorly on alkaline soils. It tolerates saline conditions and fire.

Propagation and planting Propagation of *A. farnesiana* is by seed or cuttings. Seed can be stored for long periods without loss of viability because of the hard seed-coat. Good germination is obtained by mechanical scarification. Hot water treatment of seed is recommended in France, but elsewhere has been reported to give disappointing results. In France, seedbeds are prepared on light, fertile soil in spring. Seeds are spaced at 20 cm and covered with about 5 cm soil. Germination takes place after about 1 month. Cuttings are used occasionally.

In France, transplanting is done after 1 year in fields ploughed to a depth of 50–70 cm and well manured. Plants are spaced at 2.5–5 m in open fields. Where low temperatures occur, planting may be done along the walls of buildings or terraces. At planting the main root is cut back and the stem is pruned to about 50 cm. The lower branches are also removed, leaving only a few branches near the top.

Husbandry Regular weeding is needed after planting. In France all shoots except the main limbs are removed during the first summer after planting. The plants are earthed up at the end of autumn. The next spring, the main limbs are cut back to about 15 cm and all new branches are removed. Plants are subsequently trained to form a vase of 3–4 branches to facilitate harvesting. Later, *A. farnesiana* requires little care, except soil tillage and earthing-up after harvesting. Fertilizer is applied sparingly, mostly once in 4 years. Annual pruning is done in March–April, taking care not to disturb the soil around the base of the stem. All branches that bore flowers the preceding year are cut back to 10–15 cm. Later, when new shoots are about 10 cm long, all but the most vigorous ones are removed, especially at the end of branches. In mid-summer when branches are 30–40 cm long they are topped to promote flowering.

In Texas *A. farnesiana* is sometimes managed to form 30% of the vegetation cover in rangeland, as it improves the quality and quantity of winter grass production. More often, however, it is considered a weed. It can be controlled by various herbicides.

Diseases and pests *Oncideres pustulata* causes some damage in Texas by girdling branches, but otherwise no serious diseases or pests of *A. farnesiana* have been reported.

Harvesting *A. farnesiana* comes into full production in France 5–6 years after planting. Trestles are used when picking the flowers, as the branches are rather brittle and are easily damaged. Flowers are picked 1–3 times per week depending on the location and the temperature and only when they are dry.

Yield Young trees yield annually 0.5–1 kg flowers. Well managed, large, selected trees may yield 6–10 kg per year. Annual yields of up to 1500 kg/ha have been reported.

Handling after harvest Formerly, the essential oil of cassie flowers was extracted by macerating the flowers in oil or by the enfleurage method. Both methods involved leaving the flowers in contact with the oil or fat for several hours and replacing them with fresh ones until the oil or fat was saturated with the volatile compounds. The oil was then strained to form cassie pomade. This method is now only very rarely used. Cassie flowers are now mostly extracted with a volatile solvent to yield cassie concrete. The concrete is later mixed with alcohol and distilled to produce cassie absolute; 1 kg of flowers yields 1–4 g absolute. Direct distillation of the flowers yields inferior products.

Genetic resources and breeding Only very small collections of germplasm of *A. farnesiana* exist: e.g. the National Germplasm Repository in Miami (United States) holds 10 accessions. No breeding programmes are known.

Prospects As production costs of cassie absolute in France are high and because of the very wide ecological adaptability of *A. farnesiana*, it seems warranted to investigate the possibility of cultivating it for the perfume industry in other countries, including South-East Asia.

Literature |1| Clarke, H.D., Seigler, D.S. & Ebinger, J.E., 1989. Acacia farnesiana (Fabaceae: Mimosoideae) and related species from Mexico, the southwestern U.S., and the Caribbean. Systematic Botany 14: 549–564. |**2**| Duke, J.A., 1981. Handbook of legumes of world economic importance. Plenum Press, New York, United States. pp. 5–7. |**3**| El-Gamassy, A.M. & Rofaeel, I.S., 1975. The effect of tree age and time of day for collecting the flowers on the flower yield, content and composition of cassie (Acacia farnesiana) essential oils. Egyptian Journal of Horticulture 2: 39–52. |4| El-Gamassy, A.M. & Rofaeel, I.S., 1975. The effect of some procedural aspects in the extraction of cassie essential oils on their yield, contents and properties. Egyptian Journal of Horticulture 2: 53–65. |**5**| Flath, R.A., Mon, T.R., Lorenz, G., Whitten, C.J. & Mackley, J.W., 1983. Volatile compounds of Acacia sp. blossoms. Journal of Agricultural and Food Chemistry 31: 1167–1170. |**6**| Nielsen, I.C., 1992. Mimosaceae (Leguminosae – Mimosoideae). Acacia. In: de Wilde, W.J.J.O., Nooteboom, H.P. & Kalkman, C. (Editors): Flora Malesiana, Series 1, Vol. 11. Foundation Flora Malesiana, Leiden, the Netherlands. pp. 34–64. |**7**| Quisumbing, E., 1951. Medicinal plants of the Philippines. Bureau of Printing, Manila, the Philippines. pp. 362–364. |**8**| Rolet, A., 1918. Le cassier. In: Plantes à parfums et plantes aromatiques [Perfume plants and aromatic plants]. J.B. Baillière, Paris, France. pp. 263–273. |**9**| Stewart, J.L., Dunsdon, A.J., Hellin, J.J. & Hughes, C.E., 1992. Wood biomass estimation of Central American dry zone species. Tropical Forestry Papers No 26. Oxford Forestry Institute, Department of Plant Sciences, University of Oxford, Oxford, United Kingdom. pp. 6–9.

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Alpinia Roxburgh

Asiat. Res. 11: 350 (1810).

ZINGIBERACEAE

A. malaccensis: $2n = 48$; *A. zerumbet*: $2n = 42$

Major species and synonyms

- *Alpinia galanga* (L.) Willd. See Prosea No 13: Spices.
- *Alpinia malaccensis* (Burm.f.) Roscoe, Trans. Linn. Soc. 8: 345 (1808), synonyms: *Maranta malaccensis* Burm.f. (1768), *Languas malaccen-*

sis Merrill (1921), *Catimbium malaccense* (Burm.f.) Holttum (1950).
- *Alpinia zerumbet* (Pers.) Burtt & Smith, Notes Royal Bot. Gard. Edinburgh 31: 204 (1972), synonyms: *Zerumbet speciosum* Wendl. (1798), *Costus zerumbet* Pers. (1805), *Alpinia speciosa* (Wendl.) K. Schum. (1904), *Catimbium speciosum* (Wendl.) Holttum (1950).

Vernacular names
- *A. malaccensis*: Indonesia: laja gowah (Sundanese), langkuas malaka (Moluccas), susuk (Lampung, Sumatra). Malaysia: puar, bangle. Philippines: taglak babae. Thailand: kha paa.
- *A. zerumbet*: Shell ginger, shell flower, light galangal (En). Atoumau (Martinique)(Fr). Indonesia: galoba merah, goloba koi, langkuas laki-laki (Moluccas). Philippines: langkuas na pula. Vietnam: cay ri[eef] [aas]m, cay g[uwf]ng [aas]m.

Origin and geographic distribution *Alpinia* occurs throughout South and South-East Asia from India to Japan, the Philippines, New Guinea and Australia, extending into the Pacific. The origin of *A. malaccensis* is unknown; it is widespread from the moister parts of the Himalayas, the western Ghats and the hills of Bengal and Chittagong in India to Malaysia, Indonesia and the Philippines. It is cultivated in north-eastern India, Java (Indonesia) and Guandong (China). *A. zerumbet* is considered native to north-eastern India, Burma (Myanmar), Indo-China, China and Japan. It is cultivated throughout South-East Asia and in many other tropical and subtropical countries.

Uses Many species of *Alpinia* are cultivated as garden plants and as pot plants for their attractive, often variegated leaves and striking inflorescences. *A. galanga* is an important spice and yields an essential oil marketed as galangal oil.
All parts of *A. malaccensis* are fragrant, and its leaves and rhizomes contain different essential oils. The essential oil from the leaves is marketed as 'Essence of Amali' and is used in perfumery. In the Moluccas, women once perfumed their clothing and hair with the pounded skin of the fruit. The rhizome of *A. malaccensis* is occasionally used as a spice, while it is eaten as a vegetable in north-eastern India. The rhizomes were chewed in the Moluccas together with betel nut (*Areca catechu* L.) to make the voice strong and clear. The pounded rhizome is applied to cure wounds, but it was also an ingredient in a kind of poison. The ripe and unripe fruits are well known in traditional medicine to control vomiting.
In Ambon the leaves of *A. zerumbet* were used as wrappers for cooked rice to impart a fine smell. The pith of the young stem was commonly eaten in parts of Malaysia. In eastern Asia the leaf sheaths are a source of fibre for rope, while paper is made from the whole plant. The paper is strong, transparent and of good quality. However, both rope and fibre are of local importance only and mainly used in times of scarcity. In the Philippines a decoction of the leaves is used as a bath against fevers. In China, the seed is used to clear away cold, invigorate the spleen and warm the stomach. Components from the seed have shown anti-stomach-ulcer properties. The rhizome has antibacterial properties and stimulates digestion. It is indicated in the treatment of dyspepsia, flatulence, vomiting, gastralgia, colic, diarrhoea and malaria.

Production and international trade The essential oils of both the *Alpinia* species described here are traded in small quantities only and no statistics are available on production or trade.

Properties Steam distillation of the leaves of *A. malaccensis* yields 0.1–0.2% of an essential oil called 'Essence of Amali', consisting mainly of methyl cinnamate (75%), while the rhizomes yield 0.2–0.3% of a similar essential oil that is, however, less rich in associated pinenes and therefore has a slightly different scent. Seed of *A. malaccensis* from Guandong (China) contains 0.03% of an essential oil containing 1,8-cineole, citronellol, 4-phenyl-3-buten-2-one, decanoic acid, geranyl acetate, nerolidol, lauric acid, α-farnesol, β-farnesol, myristic acid, and palmitic acid.
A. zerumbet is aromatic in all its parts; fresh leaves contain 0.1–0.2% essential oil. It is impossible to present a general outline of the composition of the essential oil, because analyses show marked quantitative and qualitative differences. Possible reasons for this are differences in the genetic make-up of the sample plants used, in environmental conditions and in extraction methods. Analysis of leaf oils from Amazonia (Brazil), Egypt and Martinique indicated as main components: terpinen-4-ol, 1,8-cineole, γ-terpinene, sabinene, para-cymene, α-thujene, α-terpinene and β-pinene, while the main components of an oil from Japan were camphor, camphene and cynnamyl acetate. The essential oil distilled from the rhizome in Egypt was rich in terpinen-4-ol, 1,8-cineole, sabinene, γ-terpinene and fenchyl acetate. A comparable oil distilled in Martinique consisted mainly of terpinen-4-ol (nearly 50%) and α-terpineol, while all other components occurred in very small quantities only.

Seed of *A. zerumbet* contains 0.3–0.5% essential oil. Chemical analysis of a seed oil from Guangzhou (China) indicated the following main components: para-cymene, 1,8-cineole and torreyol. Several compounds with in vitro antihistamine and spasmolytic activity have been isolated from the rhizomes of *A. zerumbet*, including the following sesquiterpenes: β-eudesmol, nerolidol, racemic humulene epoxides and 4-α-hydroxy-dihydroagarofuran. The activity of the essential oil against stomach-ache, vomiting and dyspepsia has been attributed to the compounds dihydro-5,6-dehydrokawain and 5,6-dehydrokawain. Dihydro-5.6-dehydrokawain also inhibits plant growth. See also: Composition of essential-oil samples.

Description Perennial, erect herbs, with numerous leafy stems usually 2–4 m tall and creeping, fleshy rhizomes. Leaves numerous, distichous, usually petiolate, often sheathing; ligule well-developed; blade lanceolate to ovate, finely pinnately veined. Inflorescence usually terminal on leafy stem, spicate, paniculate or racemose, when young usually protected by spathe-like sterile bracts; fertile bracts subtending a cincinnus of 2–many flowers; bracteoles present or absent, sometimes tubular; calyx tubular, splitting unilaterally when flower expands; corolla tubular, tube usually not longer than the calyx, 3-lobed, lobes unequal, dorsal one largest; staminodes usually 3, labellum (anterior staminode) usually large and showy, 2 lateral staminodes small or absent; fertile stamen one, subsessile or with well-developed filament, anther sometimes with prolonged connective; pistil with a 3-locular ovary surrounded by massive glands, stigma expanded with a narrow, hairy orifice. Fruit a many-seeded, dehiscent capsule, crowned by calyx remnants. Seed angular, arillate.

- *A. malaccensis*. Robust herb, leafy stem 2–4 m tall, strongly aromatic when bruised. Leaf with densely short hairy sheath near the blade; ligule entire, up to 1 cm long, coriaceous, hairy; petiole rounded, 3–7 cm long, furrowed; blade narrowly lanceolate, 40–90 cm × 7(–20) cm, acuminate, usually densely pubescent below or pubescent on margins and midrib. Inflorescence erect or slightly curved, about 35 cm long, with 30 or more cincinni of usually 2 flowers each, main axis pubescent; bracts absent; bracteoles open to base, 1.5–2 cm long, folding round the bud and deciduous as the flower opens, white; cincinni of 2 very shortly pedicellate flowers or reduced to a single flower, stalk 0.5–1.5 cm long; calyx 2 cm long, shortly 3-lobed and deeply split unilaterally, white, pubescent; corolla white, tube up to 1 cm long, lobes ciliate, lateral lobes 3 cm × 1 cm, dorsal lobe up to 4 cm × 2.5 cm; labellum broadly ovate, 3–5 cm long and at widest part 3 cm across, sides incurved, narrowing to an emarginate apex, at the base with 2 papillose fleshy swellings, yellow-orange with scarlet lines; lateral staminodes subulate, up to 5 mm long; filament about 1 cm long, anther connective not prolonged into a crest; ovary 5 mm long, pubescent; epigynous glands 5, free, 5 mm long. Capsule globose, up to 3 cm in diameter, shortly pubescent, red. Seed 3–4-angular, about 5 mm long.
- *A. zerumbet*. In general much like *A. malaccensis*; main differences are: leafy stem up to 2 m tall; petiole up to 2.5 cm long; inflorescence decurved or drooping, up to 20 cm long, bearing 25 or more cincinni of 2 flowers each, but the flowers are larger; bracteoles white with pink apex; labellum entire or shallowly lobed; fruit orange.

Alpinia zerumbet (Pers.) Burtt & Smith – 1, habit; 2, inflorescence; 3, bracteole; 4, cincinnus with 2 flowers (one bracteole removed); 5, corolla tube dissected showing stamen, staminodes, epigynous glands and stigma.

Growth and development A large clump of up to 1 m in diameter may develop within a year after vegetative propagation from a portion of rhizome. In Java *A. malaccensis* flowers throughout the year.

Other botanical information There have been several attempts at a subgeneric classification of the large genus *Alpinia* (about 230 species). The most recent classification, based mainly on the character of the labellum (petaloid or non-petaloid), divides the genus into 2 subgenera: subgenus *Alpinia* occurring throughout the area of distribution of the genus but with a centre of diversity in continental Asia, and subgenus *Dieramalpinia* (K. Schum.) K. Schum. absent from continental Asia and with a centre of diversity in New Guinea and the Moluccas. In subgenus *Alpinia* the labellum is usually concave with incurved margins, commonly striped or spotted, the margins extending into a petaloid area with divergent venation. In subgenus *Dieramalpinia* the labellum is held erect and almost always closely pressed against the stamen, usually not striped or spotted, lateral margins not well developed, the apex only occasionally expanding into a small petaloid area. The *Alpinia* species discussed here belong to subgenus *Alpinia* section *Alpinia* subsection *Catimbium* (Horan.) R.M. Smith. The subsection is distributed from eastern India and Sri Lanka to eastern China and Taiwan and through South-East Asia to New Guinea. It does not occur naturally in Sumatra, Java and the Lesser Sunda Islands.

A. malaccensis var. *nobilis* (Ridley) I.M. Turner occurs from Java and Peninsular Malaysia to Indo-China and north-eastern India. It is characterized by its large flowers and large, hairy leaves. *A. latilabris* Ridley is another species in subsection *Catimbium* occurring in Borneo, Peninsular Malaysia and Indo-China, which also contains an essential oil in all parts. *A. officinarum* Hance is grown in Hainan and the adjacent coast of mainland China; its rhizome is the source of true galangal oil used in flavour and perfume compositions to which it imparts unique, warm, spicy notes. *A. galanga* was formerly used as a source of essential oil, but is now only used as a spice. The latter 2 species belong to subsection *Alpinia*.

Ecology *A. malaccensis* and *A. zerumbet* occur mainly in secondary vegetation, bamboo and teak forest, brushwood and ravines; they prefer shady conditions. Both grow only rarely in primary forest. In Java, *A. malaccensis* is grown from sea-level up to 1500 m altitude; in the Western Ghats in India up to 1000 m. In Malaysia it probably escaped from cultivation in Melaka and is now found wild in swampy areas in Pahang and Selangor. For optimal growth it requires a temperature of 27–30°C during daytime and 17–18°C at night, filtered or diffuse sunlight and adequate watering.

Agronomy *A. malaccensis* is mainly a smallholder crop, usually planted along the border of gardens. Long top-ends of rhizomes are used for propagation and should be planted in well tilled soil. When grown in rows, plants are spaced at 1 m. Weeding and subsequent earthing-up of the rhizomes are carried out every month until 6 months after planting. The rhizomes are harvested after 8 months. Whole plants are pulled up, the shoots cut off and the rhizomes washed and cleaned. One 8-month-old plant yields about 1 kg rhizomes and 35 kg leaves. The rhizomes and leaves are marketed fresh or dried.

A. zerumbet is produced commercially in the United States and Europe as an ornamental and can be propagated by tissue culture.

Genetic resources and breeding No substantial germplasm collections of *A. malaccensis* and *A. zerumbet* are known to exist.

Prospects In South-East Asia *A. malaccensis* and *A. zerumbet* are used to a very limited extent only for their essential oil and as medicinal plants. Since knowledge of their chemical composition, ecological requirements and cultivation is still very limited, their future use and importance are hard to predict. They are likely to remain of some importance as ornamentals.

Literature |1| Burtt, B.L. & Smith, R.M., 1972. Key species in the taxonomic history of Zingiberaceae. Notes from the Royal Botanic Garden Edinburgh 31: 177–227. |2| Darwis, S.N., Madjo Indo, A.B.D. & Hasiyah, S., 1991. Tumbuhan obat famili Zingiberaceae [Medicinal plants of the family Zingiberaceae]. Pusat Penelitian dan Pengembangan Tanaman Industri, Bogor, Indonesia. pp. 19–20. |3| Dung, N.X., Chinh, T.D., Rang, D.D. & Leclercq, P.A., 1994. Volatile constituents of the seed and fruit skin oils of Catimbium latilabre (Ridl.) Holtt. from Vietnam. Journal of Essential Oil Research 6: 541–543. |4| Fujita, T., Nishimura, H., Kaburagi, K. & Mizutani, J., 1994. Plant growth inhibiting alpha-pyrones from Alpinia speciosa. Phytochemistry 36: 23–27. |5| Holttum, R.E., 1971. The Zingiberaceae of the Malay Peninsula. The Gardens' Bulletin Singapore 13: 1–248, particularly pp. 149–156. |6| Hsu, S.Y., Lin, M.H., Lin, L.C. & Chou, C.J., 1994. Toxicologic studies of dihydro-5,6-dehydrokawain and 5,6-dehydrokawain. Planta Medica 60: 88–90. [7] Itokawa, H., Morita, M. & Mitashi, S., 1981. Phenolic compounds from the rhizomes of Alpinia speciosa. Phytochemistry 20: 2503–2306. [8] Prudent, D., Périneau, F., Bessière, J.M. & Michel, G., 1993. Chemical analysis, bacteriostatic and fungistatic properties of the essential oil of the Atoumau from Martinique (Alpinia speciosa K. Schum.). Journal of Essential Oil Research 5: 255–264. [9] Smith, R.M., 1990. Alpinia (Zingiberaceae): a proposed new infrageneric classification. Edinburgh Journal of Botany 47: 1–75. [10] Zhu, L.F., Li, Y.H., Li, B.L., Lu, B.Y. & Xia, N.H., 1993. Aromatic plants and essential constituents. South China Institute of Botany, Chinese Academy of Sciences. Hai Feng Publishing Company. Chinese National Node for APINMAP, China. p. 188.

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Aquilaria malaccensis Lamk

Encycl. méth. bot. 1: 49, t. 356 (1783).

THYMELAEACEAE

$2n = 16$

Synonyms *Aquilaria agallocha* Roxb. (1832), *Agallochum malaccense* (Lamk) Kuntze (1891), *Aquilariella malaccensis* (Lamk) v. Tieghem (1893).

Vernacular names Agar wood, Malayan aloeswood, Malayan eaglewood (En). Bois d'aigle, calambac, calambour (Fr). Indonesia: gaharu, ki karas (Sundanese), mengkaras (Sumatra). Malaysia: gaharu, tengkaras, karas. Burma (Myanmar): agar. Vietnam: tr[aaf]m h[uw][ow]ng.

Origin and geographic distribution *A. malaccensis* occurs from north-eastern India (Bengal, Assam) through Burma (Myanmar) (Tenasserim) to Peninsular Malaysia, Sumatra, Bangka, Borneo and the Philippines (Luzon).

Uses Agar wood is the rare and famous, resin-containing heartwood produced from old and diseased trees of several *Aquilaria* species of which *A. malaccensis*, *A. crassna* Pierre ex H. Lecomte from Indo-China and Thailand and *A. sinensis* (Lour.) Sprengel (synonym *A. grandiflora* Benth.) from southern China are most important. In trade a distinction between the wood from these species is rarely made. The fragrance produced by the burning agar wood has been highly valued for thousands of years, and its use as incense for ceremonial purposes in Buddhism, Confucianism and Hinduism is widespread throughout eastern and southern Asia. In Thailand it is put into funeral pyres, while in Japan, the incense is used in tea ceremonies. In the early 19th Century agar wood was part of the tribute paid by Vietnam to the imperial court in Beijing. Wood only partly saturated with resin but still fragrant, and occasionally also the wood remaining after distillation, is made into sticks called 'joss-sticks' or 'agarbattis' which are burnt as incense. Agar-wood oil is an essential oil obtained by water and steam distillation of agar wood. Agar-wood oil is used in luxury perfumery for application in e.g. oriental and woody-aldehydic bases, 'chypres' and 'fougères'. It produces interesting odour notes with clove oil, e.g. in carnation bases. The oil is so rare and expensive that it is only produced on request. Attars of agar wood are used more widely in the Middle East and India.

The silvery inner bark can be removed from the trunk in a single large sheet. It is highly valued for its strength and durability and is made into cloth and ropes. In Assam and Sumatra it is made into writing material, formerly only used for chronicles of important events and religious books.

In western, Chinese and Indian medicines the incense is used against cancer, especially of the thyroid gland. In China it is applied as a sedative against abdominal complaints, asthma, colics and diarrhoea, and as an aphrodisiac and carminative. The incense is also used as an insect repellent. Grated wood enters into various preparations used especially during and after childbirth, and to treat rheumatism, smallpox and abdominal pains. Decoctions of the wood are said to have anti-microbial properties, e.g. against *Mycobacterium tuberculosis* and *Shigella flexneri*.

The timber of undiseased trees, known as 'karas', is very light and is suitable for making boxes, light indoor construction and veneer.

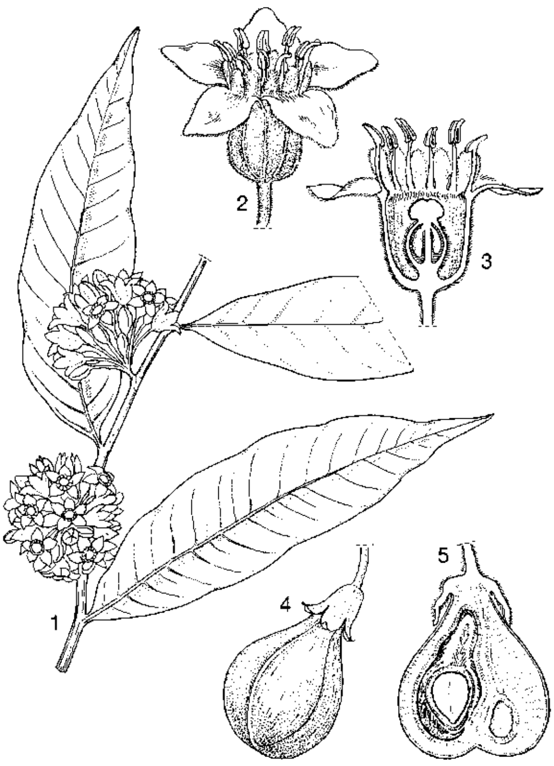
Production and international trade The retail price of agar wood varies between countries and depends on quality. The 1993 statistics from Saudi Arabia show that in Dubai the prices per kg varied from US$ 27 of low grade agar wood to close to US$ 10 000 for the highest grade. In the United Kingdom, commercial agar-wood oil retails UK£ 160 for 2.5 ml, while in Thailand, low grade agar wood could fetch a price per kg of US$ 1.20 and the finest grade US$ 2800. In Malaysia, the 1996 prices per kg range from US$ 5 for mixed grades to US$ 1000 for the top grade.

Malaysia is the leading supplier of agar wood to the Arabian Peninsula, with just over 25% of the market in 1991 with a trade value of US$ 2.25

million, followed closely by Singapore with US$ 2.1 million, while Indonesia, Thailand and India follow close behind. Trade with the United States fluctuates strongly; it imported over 66 000 kg in 1985, less than 28 000 kg in 1990 and 31 000 kg in 1994.

Properties Agar-wood oil is a yellow to dark amber, viscous liquid with a characteristic balsamic and woody odour. It has olfactively some resemblance with vetiverol or styrax and has a sweetness similar to that of sandalwood oil. Its odour is long-lasting and exhibits a good tenacity in applications. Few analyses of the volatile components of agar wood have been made. Analyses made in Switzerland reported agarofuranoids and sesquiterpenoids of the eudesmane, eremophilane, valencane and vetispirane type as the main components. An analysis from Japan of the essential oil obtained from agar wood identified as originating from *A. malaccensis* used diethyl ether extraction of the highest quality agar wood. This analysis indicated that oxygenated sesquiterpenes and chromone derivatives are the main components of the esential oil. The main components identified in the smoke obtained by heating the wood to about 200°C belonged to the same group of components. Analysis of a commercial sample from India, however, gave a rather different composition. See also: Composition of essential-oil samples.
A. malaccensis yields a soft, lightweight hardwood with a density of about 400 kg/m^3 air dry. The wood is creamy white to pale yellowish-brown or greyish-brown, heartwood and sapwood not clearly differentiated; the texture is rather coarse and the wood diffuse-porous. Growth rings are distinct or indistinct; vessels very small to medium-sized, solitary or in radial multiples of 2–5 or in clusters; parenchyma scanty paratracheal; rays very fine. Included phloem is always present in isolated, evenly distributed strands. The scented wood differs from the normal wood due mainly to deposition of an aromatic resin. The resin is concentrated in the included phloem strands. Because of the resin content the scented wood is relatively hard, brittle and heavy. Moreover, all samples of scented wood contain fungi with abundant septae in their hyphae. Most of the phloem strands in the scented wood are similar to those in normal wood, but a few are altered and have the appearance of an inter-xylarly vascular bundle with abaxial phloem, adaxial xylem and cambium in between the two ('abnormal tertiary tissue'). Formation of these tertiary tissues is associated with injury.
The weight of 1000 seeds is about 670 g.

Description Tree, up to 20(–40) m tall, with bole up to 60 cm in diameter, usually straight, sometimes fluted or with thick (10 cm) buttresses up to 2 m high; bark smooth, whitish; branchlets slender, pale brown, pubescent, glabrescent. Leaves simple, alternate; petiole 4–6 mm long; blade elliptical-oblong to oblong-lanceolate, 7.5–12 cm × 2.5–5.5 cm, chartaceous to subcoriaceous, glabrous, sometimes pubescent and glabrescent beneath, shiny on both surfaces, base acute, attenuate or obtuse, apex acuminate, acumen up to 2 cm long; veins in 12–16 pairs, rather irregular, often branched, elevated and distinct beneath, curving upward to the margin, plane or obscure above. Inflorescence a terminal, axillary or supra-axillary, sometimes internodal umbel, usually branched into 2–3 umbels, each with about 10 flowers; peduncle 5–15 mm long; pedicel slender, 3–6 mm long; flowers 5-merous, campanulate, 5–6 mm long, green or dirty-yellow, scattered puberulous outside; floral tube nearly glabrous inside,



Aquilaria malaccensis Lamk – 1, flowering branch; 2, flower; 3, longitudinal section through flower; 4, fruit; 5, longitudinal section through fruit.

distinctly 10-ribbed, persistent in fruit; calyx lobes 5, ovate-oblong, 2–3 mm long, almost as long as the tube, reflexed, densely puberulous within; petaloid appendages 10, inserted at the throat of the tube, oblong or slightly ovate-oblong, about 1 mm long, slightly incurved, densely pilose; stamens 10, free, emerging from the throat of the tube, filamentous, 1.2–2 mm long, episepalous ones longer than the others; anthers linear, obtuse; pistil included; ovary ovoid, 1–1.5 mm long, 2-celled, densely pubescent; style obscure, stigma capitate. Fruit a loculicidal capsule, obovoid or obovoid-cylindrical, 3–4 cm × 2.5 cm, usually compressed, pubescent, glabrescent, base cuneate, apex rounded; pericarp woody. Seed ovoid, 10 mm × 6 mm including a beak 4 mm long, densely red-haired, bearing from the base a twisted, tail-like, pubescent appendage as long as the seed. Seedling with epigeal germination.

Growth and development In a plantation in Malaysia, 67-year-old trees of *A. malaccensis* had reached an average height of 27 m and a diameter of 38 cm. Mature trees of about 80 years old in Assam (north-eastern India) may reach a height of 25–30 m and a diameter at breast height of 55–70 cm. In Arunachal Pradesh (north-western India) trees reached a height of nearly 5 m and a diameter of 30 cm 8 years after planting. Flowering and fruiting may start at an age of 7–9 years in north-western India where trees flower in March and bear fruit in June–July. Good seed years occur infrequently and a medium sized tree may then produce 1.5 kg seed.

Agar wood formation is a pathological process taking place in the stem or main branches where an injury has occurred. Fungi are involved in the process, but the process itself is not yet fully understood. Damage by boring insects is often associated with the infection. It is believed that the tree is first attacked by a pathogenic fungus, which causes it to weaken. Infection by a second fungus causes the formation of agar wood, but it is unclear whether it is a product of the fungus or the tree. The fungus implicated in the formation of agar wood in *A. malaccensis* is *Cytosphaera mangiferae*, while *Melanotus flavolives* is assumed to play a similar role in *A. sinensis*. *A. malaccensis* forms an association with endotrophic mycorrhizal fungi.

Other botanical information The 3 *Aquilaria* species considered as major sources of agar wood, *A. crassna* (from Indo-China), *A. malaccensis* (India, Malesia) and *A. sinensis* (China), are closely related. They can be distinguished by the length of their calyx lobes: 12–15 mm in *A. crassna*, 2–3 mm in *A. malaccensis* and 8 mm in *A. sinensis*. Other sources of agar wood in South-East Asia include some minor *Aquilaria* spp., *Enkleia malaccensis* Griffith, and the timbers *Gonystylus bancanus* (Miq.) Kurz and *G. macrophyllus* (Miq.) Airy Shaw.

A. agallocha is sometimes considered a species distinct from *A. malaccensis*; the former is then native to north-eastern India, the latter to Malesia.

Ecology *A. malaccensis* is commonly found in primary and secondary forest, mainly in plains but also on hillsides and ridges up to 750 m altitude. It always occurs scattered, in Peninsular Malaysia and north-eastern India at a density of about 2.5 trees/ha. In north-eastern India it occurs up to 1000 m altitude, but grows best in undulating terrain from 200–700 m, with an annual rainfall of 1500–6500 mm, a mean annual maximum temperature of 22–28°C and a mean annual minimum temperature of 14–21°C. In north-eastern India it is found in wet-evergreen and evergreen forest and more rarely in semi-evergreen forest. *A. malaccensis* prefers heavy soils developed from gneiss and other metamorphic rocks, but it also grows well on sandy loams developed from sandstone.

Propagation and planting To date, *A. malaccensis* is only propagated by seed. Fruit harvested for seed should be collected when mature but still green. The best time for harvesting in north-eastern India is the second week of June. A medium-sized tree produces about 2000 seeds per year, but seed production may fluctuate greatly between years. Fruits are dried in the shade for about 2 days. They then burst and release the seed. Seed should be sown immediately, as it remains viable for only about 1 month. In north-eastern India it is sown in nursery beds, about 5 mm deep in a mixture of soil, sand and manure and kept under light shade. Germination starts after 10–12 days and is normally complete after 1 month. Seed sown immediately after collection has about 65% germination, falling to 45% after 1 week and 5% after 3 weeks in storage. Application of insecticides is often required, as the seedlings are more heavily attacked. Seedlings are pricked out into polythene bags 40–45 days after germination when they are 3–5 cm tall, and are kept under shade. They are ready for transplanting when 30–35 cm tall and 10–12 months old. Transplanting bare-rooted seedlings has been tried successfully in Malaysia. In north-eastern India seedlings are planted out in May–June at a spacing of 2.5 m × 2.5 m, in Malaysia a spacing of 2 m × 6 m has been used in trial plantings. Plantations of *A. malaccensis* have been established mainly for experimental purposes to test methods for the induction of agar wood formation.

Husbandry After planting, *A. malaccensis* requires regular weeding, up to 4 weedings during the first year, gradually decreasing to 1 weeding in the 5th year. Thinning to the final stand is done in the 5th year. Through competition and mortality the density in a uniform stand in Malaysia decreased to 31 trees/ha in 67 years. In natural forests regeneration of *A. malaccensis* seems adequate to maintain the density of trees, if only old diseased trees are harvested. In that case harvesting is only economic if it is combined with the extraction of other non-wood forest products.

Diseases and pests Little information is available on diseases and pests of *A. malaccensis*.

Harvesting Although trees containing large amounts of agar wood often appear weakened and stag-headed, only experienced collectors can select trees exhibiting partial agar wood formation from natural stands of *A. malaccensis*. Because of their very high value, trees are often cut indiscriminately, and harvesting groups scour the forests of South-East Asia for *Aquilaria* trees using any means of transport available. The trunk of felled trees is cut into pieces and collectors then cut through the entire tree to locate the agar wood. Most attention is given to damaged parts and knots. The soft white wood of the tree was formerly often left to rot, which takes about 6 months. The agar wood that is not affected by this rotting process is collected later. This led to the belief that agar wood is formed in the ground after felling the tree.

Handling after harvest For processing, pieces of agar wood are chopped into small chips and soaked in water. After proper maceration these are fed into a still for water and steam distillation. Solvent extraction is also used. The remains after distillation and wood only partially converted to agar wood are ground to sawdust. This is mixed with an adhesive substance to form a paste with which long thin sticks are covered to form incense sticks.

Genetic resources and breeding No germplasm collections or breeding programmes of *A. malaccensis* are known to exist. It is listed as an endangered species by CITES.

Prospects The extremely high prices paid for high quality agar wood and for the essential oil and the indiscriminate felling of diseased and healthy trees threaten natural stands of *Aquilaria* including *A. malaccensis* to extinction. Research into possibilities of artificial induction and stimulation of agar wood formation is therefore urgently required and may offer high economic returns, especially as trials indicate that management of plantations presents no great difficulties. Unless such methods are developed, *A. malaccensis* may soon be extinct.

Literature |**1**| Beniwal, B.S., 1989. Silvical characteristics of Aquilaria agallocha Roxb. Indian Forester 115: 17–21. |**2**| Gianno, R., 1986. The exploitation of resinous products in a lowland Malayan forest. Wallaceana 43: 3–6. |**3**| Hou, D., 1960. Thymelaeaceae, Aquilaria. In: van Steenis, C.G.G.J. (Editor): Flora Malesiana, Series 1, Volume 6. Wolters-Noordhoff, Groningen, the Netherlands. pp. 6–15. |**4**| Ishihara, M., Tsuneya, T. & Uneyama, K., 1993. Components of the volatile concentrate of agarwood. Journal of Essential Oil Research 5: 283–289. |**5**| Ishihara, M., Tsuneya, T. & Uneyama, K., 1993. Components of the agarwood smoke on heating. Journal of Essential Oil Research 5: 419–423. |**6**| Jalaluddin, M., 1977. A useful pathological condition of wood. Economic Botany 31: 222–224. |**7**| Lok, E.H. & Ahmad Zuhaidi, Y., 1996. The growth performance of plantation grown Aquilaria malaccensis in Peninsular Malaysia. Journal of Tropical Forest Science 8: 573–575. |**8**| Näf, R. & Velluz, A., Brauchli, R. & Thommen, W., 1995. Agarwood oil (Aquilaria agallocha Roxb.). Its composition and eight new valencane-, eremophilane- and vetispirane-derivatives. Flavour and Fragrance Journal 10: 147–152. |**9**| Qi Shu-Yuan, 1995. Aquilaria species: in vitro culture and the production of eaglewood (agarwood). In: Bajaj, Y.P.S. (Editor): Biotechnology in Agriculture and Forestry 33. Medicinal and aromatic plants 8. Springer Verlag, Berlin, Germany. pp. 36–46. |**10**| Sidiyasa, K., Sutomo, S. & Prawira, S.A., 1986. Eksplorasi dan studi permudaan jenis-jenis penghasil gaharu di wilayah hutan Kintap, Kalimantan Selatan [Exploration and study of regeneration of 'gaharu' producing species in Kintap forest region, South Kalimantan]. Buletin Penelitian Hutan 474: 59–66.

R.C.K. Chung & Purwaningsih

Blumea balsamifera (L.) DC.

Prodr. 5: 447 (1836).
COMPOSITAE
$2n = 18$

Synonyms *Conyza balsamifera* L. (1763), *Baccharis salvia* Lour. (1793), *Conyza appendiculata* Blume (1826).

Vernacular names Ngai camphor plant (En). Camphrier (Fr). Indonesia: sembung, capa (Indonesian), sembung gantung (Javanese), sembung utan (Sundanese). Malaysia: chapa, chapor, sembong. Philippines: sambong (Tagalog), lakadbulan (Bikol), subsub (Ilocano). Burma (Myanmar): poung-ma-theing. Cambodia: bai mat. Laos: nat. Thailand: kamphong (northern), nat-yai (central), naat (south-eastern). Vietnam: c[aa]y d[aj]i bi, c[aa]y t[uwf] bi, c[aa]y mai phi[ees]n.

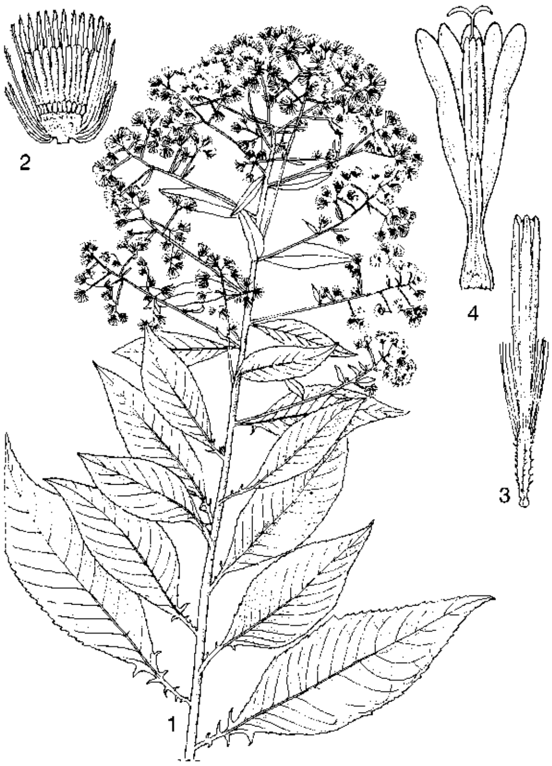
Origin and geographic distribution *B. balsamifera* occurs from India to Indo-China, southern China, Taiwan, Malaysia, Indonesia and the Philippines. It is also cultivated widely throughout East and South-East Asia.

Uses In China ngai camphor oil, an essential oil obtained by steam distillation of young leaves of *B. balsamifera*, is widely used in medicine and in rituals. The refined camphor 'ngai p'ien' is considered of higher quality than camphor from *Cinnamomum camphora* (L.) Presl, but is not rated as high as that from *Dryobalanops* spp. Preparations from *B. balsamifera* have been used in Chinese medicine since ancient times as carminative, mild stimulant, vermifuge and as topical application for septic ulcers. In South-East Asia it is one of the most common and widely used medicinal plants for a number of ailments, mainly as a stomachic, vermifuge, expectorant and sudorific. It is also used to treat bronchitis, arthritis, insomnia and dysmenorrhoea. In the Philippines a diuretic and kidney-stone medicine is prepared commercially from *B. balsamifera*. In Thailand, cigarettes containing the chopped, dried leaves are smoked to relieve the pain of sinusitis. An infusion from the leaves is taken as a stomachic, diaphoretic expectorant and emmenagogue, while a decoction of fresh leaves, alone or in combination with other plant preparations, used as a bath for women after childbirth and also for young children. In Vietnam a decoction of the leaves is prescribed against influenza, cough and dyspepsia. Inhalation of the vapour from a boiling decoction of fresh leaves is used against the same afflictions. Poultices of pounded leaves are applied to treat haemorrhoids and an alcoholic maceration serves as a liniment for rheumatism. The roots and leaves are used as natural pesticides e.g. against storage pests and leaf hoppers in rice.

Production and international trade Ngai camphor and ngai camphor oil are only produced and traded locally; production and trade statistics are not available.

Properties The leaves of *B. balsamifera* contain about 0.5% of a volatile oil whose main component is borneol (about 25%), a compound closely related to camphor and easily converted into it by oxidation. Other components are 1,8-cineole, limonene, and camphor; other sources also mention β-eudesmol, β-camphene and myrcene. Camphor is an important component of true *B. balsamifera* oil, but its content may vary strongly. The variation may be due to environmental conditions. Some samples, e.g. from China, are free of it, while other samples contain as much as 75%. The camphor may be an admixture from oil of other *Blumea* species. *B. lacera* (Burm.f.) DC. from China has been suggested as a source of the adulterant, but other sources do not indicate camphor as a component of its oil. *B. balsamifera* contains small amounts of flavonoids and sesquiterpenes that may have medicinal properties. The main component of ngai camphor, borneol, is also produced synthetically. See also: Composition of essential-oil samples.

Description Erect, evergreen undershrub or shrub, rarely a herb or small tree, up to 4 m tall, smelling strongly of camphor; bark greyish-brown, smooth; wood soft, white. Stem erect, 2–8 cm in diameter, simple at base, then repeatedly trifid; branches terete, densely woolly villous with yellow-white hairs. Leaves simple, alternate, petiolate or with tapering base; petiole 0–3.5 cm long, mostly with 1–3 pairs of basal, patent appendages; blade very variable, ovate-oblong to oblong-lanceolate, 6–30(–40) cm × 1.5–12(–20) cm, entire or somewhat pinnately lobed, margin usually serrate or serrulate with upcurved teeth, lower surface densely silky-woolly, upper surface rugose and pilose. Inflorescence a head, 6–10 mm in diameter, the numerous heads arranged in a usually terminal, sometimes axillary panicle 10–50 cm long and 6–30 cm in diameter; peduncle 3–10 mm long; involucre campanulate; bracts in many rows, imbricate, linear-subulate, 1–9 mm long, inner ones longest, outer ones gradually shorter, densely woolly outside; receptacle 2–4 mm in diameter, slightly convex, alveolate, glabrous or with fimbriate margins of the pits, glabrescent; florets heterogamous, numerous, tubular, hardly



Blumea balsamifera (L.) DC. – 1, flowering branch; 2, section through flower head; 3, bisexual floret; 4, opened bisexual floret.

exserting from the involucre, yellow, marginal florets female, disk florets 8–28, bisexual; corolla of female florets filiform, up to 6 mm long, 2–4-lobed, glabrous; corolla of bisexual florets tubular, 5–7 mm long, 5-lobed, lobes triangular-ovate, acute, papillate, pubescent with colleters; stamens 5, anthers basally tailed, connective prolonged; style exserted, 2-branched at apex. Fruit a minute, slightly curved, obscurely 5-ribbed achene, about 1 mm long, brown, with sparse, short, white hairs; pappus uniseriate, 4–7 mm long, soft, white or more often reddish-yellow.

Growth and development *B. balsamifera* flowers throughout the year. It produces seed abundantly and easily propagates spontaneously.

Other botanical information *Blumea* species differ markedly in their content of phenolic compounds. In an analysis of 12 *Blumea* species, 147 compounds were separated. None of these occurred in more than 4 species, while the number of compounds per species ranged from 12–23. *B. balsamifera* is widely distributed and very variable in its foliage and degree of pubescence; the flower heads and florets, however, are remarkably uniform in size and morphology throughout its range. Plants growing in a montane habitat appear more woolly than those from the lowland. It is the most woody and fragrant *Blumea*. *B. malcolmii* (Clarke) Hook.f. is another strongly fragrant species which only occurs in Maharashtra (India); it smells strongly of turpentine and its volatile components are different from those of *B. balsamifera*.

Ecology *B. balsamifera* grows naturally along roadsides, in upland fields, fields infested with *Imperata*, and natural grazing lands, brushwood and forest, including bamboo and teak forests and sometimes in wet places on river banks, from sea-level up to 2200 m altitude. It sometimes grows gregariously and hardly tolerates shade. It is often considered a weed, but is easily eradicated. *B. balsamifera* is frequently found in regularly burned grassland, as it readily sprouts from underground parts after the leaves and branches have been killed by fire.

Agronomy *B. balsamifera* can be propagated by seed and by root and stem cuttings. Cuttings are placed in containers under shade. Watering should be carried out with care, as too much water is harmful. Seedlings and rooted cuttings can be transplanted after about 2 weeks to a place receiving full sunlight. Young plantations should be weeded regularly.

In the Philippines *B. balsamifera* suffers from the following diseases: *Endophyllum blumeae*, a leaf rust causing premature defoliation when the attack is severe; *Cercospora* sp., a circular leaf spot, may cause serious losses during the rainy season; while an orange leaf spot also caused by a *Cercospora* sp. occurs occasionally. *B. balsamifera* is reported to be a host of the mites *Amblyseius* sp., *Brevipalpus obovatus* and *Typhlodromus jackmickleyi*.

In gardens, leaves are picked when required. On a larger scale, leaves are cut up to four times a year or whole plants are harvested.

Yield In Vietnam 50 t/ha of leaves of *B. balsamifera* have been harvested annually, yielding 50–200 kg borneol.

Handling after harvest For home use, fresh leaves are washed and chopped very finely and given to patients. Commercially, leaves are first air-dried in a well ventilated place before use. On distillation the leaves can yield 0.1–0.5% of a yellow oil.

Genetic resources and breeding No germplasm collections of *B. balsamifera* are known to be maintained and no breeding work has been done.

Prospects Ngai camphor is likely to remain an important component of pharmaceutical products, especially in China and the Philippines, where most research is currently done.

Literature |1| Barua, N.C. & Sharma, R.P., 1992. (2R,3R)-7,5'-dimethoxy-3,5,2'-trihydroxyflavanone from Blumea balsamifera. Phytochemistry 31: 4040. |2| Co, L.L., 1989. Common medicinal plants of the Cordillera Region (Northern Luzon, Philippines). Bustamante Press, Quezon City, the Philippines. pp. 232–233. |3| Divinagracia, G.G. & Ros, L.B., 1985. Diseases of selected medicinal plants in the Philippines. The Philippine Agriculturist 68: 297–308. |4| Fujimoto, Y., Soemartono, A. & Sumatra, M., 1988. Sesquiterpenes from Blumea balsamifera. Phytochemistry 27: 1109–1111. |5| Manalo, J.B. & Coronel, V.Q., 1983. Pharmaceutical and cosmetic application of some Philippine essential oils. NSTA – Technology Journal 8(1): 7–12. |6| Markham, K.R., 1989. A reassessment of the data supporting the structures of Blumea malcolmii flavonols. Phytochemistry 28: 243–244. |7| Nguyen Van Duong, 1993. Medicinal plants of Vietnam, Cambodia and Laos. Mekong Printing, Vietnam. pp. 123–124. |8| Randeria, A.J., 1960. The composite genus Blumea, a taxonomic revision. Blumea 10: 205–279. |9| Ruangrungsi, N., Tappayuthpijarn, P., Tantivatana, P., Borris, R. & Cordell, G.A., 1981. Traditional medicinal plants of Thailand. 1. Isolation and structure elucidation of 2 new flavonoids (2R,3R)-dihydroquercetin-4'-methyl ether and (2R,3R)-dihydroquercetin-4',7-dimethyl ether from Blumea balsamifera. Journal of Natural Products 44: 541–545. |10| World Health Organization, 1990. Medicinal plants in Vietnam. WHO Regional Publications, Western Pacific Series No 3. Regional Office for the Western Pacific, Manila, the Philippines and Institute of Materia Medica, Hanoi, Vietnam. p. 71.

Norma O. Aguilar

Cananga odorata (Lamk) Hook.f. & Thomson

Fl. ind. 1: 130 (1855).

ANNONACEAE

$2n = 16$

Synonyms *Uvaria odorata* Lamk (1785), *Canangium odoratum* (Lamk) Baillon (1868), *Cananga scortechinii* King (1922).

Vernacular names Ylang-ylang, cananga, perfume tree (En). Ylang-ylang, cananga (Fr). Indonesia: kananga (general), kenanga (Javanese), sepalen (Moluccas). Malaysia: kenanga, chenanga, kenanga utan (wild forms). Philippines: ylang-ylang, ilang-ilang, alangilang. Burma (Myanmar): kadatngan, kadapgnam, sagasein. Cambodia: chhkè srèng. Thailand: kradangnga-thai (central), kradangnga-songkhla (central, var. *fruticosa*), sabannga-ton (northern). Vietnam: ng[oj]c lan t[aa]y, ho[af]ng lan, ylang ylang.

Origin and geographic distribution *C. odorata* is thought to originate from South-East Asia and occurs naturally throughout South-East Asia, Australia and several Pacific islands. It has been introduced into China, India, Africa and the Americas. Commercial cultivation of *C. odorata* for the production of ylang-ylang oil started in the Philippines, later followed by the production of cananga oil in Indonesia. The First World War almost destroyed ylang-ylang cultivation in the Philippines, only one plantation continuing cultivation until the Second World War. In the Philippines *C. odorata* is now a smallholder crop grown almost exclusively for local use. In 1770 *C. odorata* was brought from the Philippines to Réunion, where commercial production of ylang-ylang oil started a century later. Production grew steadily, but declined sharply during the First World War; it never recovered and production virtually ceased during the economic depression of the 1930s. In the beginning of the 20th Century *C. odorata* was introduced into the Comoro Islands, where an important industry developed. Production peaked during the 1980s, but then declined due to the development of tourism and expansion of food production. Similarly, an ylang-ylang industry developed in the northern Madagascan island Nosy Bé; it peaked around 1950 and then gradually declined. In Guangdong Province in southern China, production started recently and is still expanding. Indonesia, the Comoro Islands and Nosy Bé are the main exporters of ylang-ylang oil. Java is the main producer of cananga oil; outside Java, the production of cananga oil is only important in Fiji.

Uses The fragrant flowers of *C. odorata* are used for personal adornment and decoration at festivities and other celebrations. Malaysians and Indonesians are very fond of the scent, and the women like to hide a flower in their hair. Fresh flowers of *C. odorata* mixed with flowers of *Jasminum sambac* (L.) Aiton, *Rosa* spp., *Michelia champaca* L. and leaves of *Pandanus amaryllifolius* Roxb. are used in various ceremonies in Java and Bali. The flowers are also put away with clothes, or scattered about the bed. The Thai apply an infusion of the flowers on the body after bathing. Two forms of *C. odorata* are grown commercially: cv. group Ylang-ylang, which produces ylang-ylang oil and cv. group Cananga yielding cananga oil. Both oils are distilled from the flowers. Ylang-ylang oil and cananga oil are used to supply the dominant odour note of many perfumes. 'Extra' quality ylang-ylang oil is much used in high-class perfumery; 'Third' grade ylang-ylang oil and cananga oil have a harsher, more tenacious odour and are mainly used in soaps and toiletries for men. Both oils are sometimes used in foods and beverages. Cananga oil mixed with coconut oil is used as a hair oil named Macassar oil (this oil differs from the seed oil from *Schleichera oleosa* (Lour.) Oken that is also called Macassar oil).

C. odorata has several uses in traditional medicine. The dried flowers are used in Java against malaria and the fresh flowers are made into a paste for treating asthma. In Perak the leaves are rubbed on the skin against itch, and in West Java the bark is applied against scurf. The seed used to be used externally to cure intermittent fever.

In Malaysia, *C. odorata* is mainly planted as a roadside shade tree. The timber is white to grey, non-durable and mainly used for boxes. It has potential for making small drums and matchsticks. The bark can be beaten to make coarse ropes; this is done in Sulawesi.

Production and international trade In the late 1980s the value of world production of ylang-ylang oil was about US$ 7 million, compared with about US$ 1.35 million for cananga oil. Indonesia is by far the most important exporter of cananga oil, and the oil is known in international trade as Java cananga oil. In 1995 Indonesia cultivated about 160 000 ha cananga, producing 120 t oil. In many countries flowers are the main product and they are traded only locally.

Properties Both cananga oil and ylang-ylang oil are obtained by distillation of the flowers of *C. odorata*; cananga oil from cv. group Cananga (forma *macrophylla*), ylang-ylang oil from cv. group Ylang-ylang (forma *genuina*). In the Comoro Islands and Nosy Bé ylang-ylang concrete is produced by petroleum ether extraction of the flowers. A volatile oil can be distilled from the leaves but it has no economic value. Whereas cananga oil is traded as a complete oil, ylang-ylang oil is fractionated into different grades; in Madagascar 4 qualities are recognized: 'Extra', 'First", 'Second' and Third'. An additional grade, 'Premier' quality, is only produced to order. 'Extra' and 'First' are used mostly in fine perfumery, 'Second' and 'Third' in soap perfumery; 'Extra' and 'Third' are most important in trade.

Ylang-ylang oil 'Extra' is the first and most volatile fraction containing 20–40% of the total distillate. It is a stable, pale yellow, mobile liquid. It has a floral top note, a floral, fruity, spicy body, and a light flowery, balsamic powdery dry-out lasting about 48 hours. The main chemical components are: (E,E)-farnesene, benzyl acetate, linalool, δ-cadinene, p-methylanisole, β-caryophyllene, methyl benzoate, benzyl benzoate, geranyl acetate. It is used as a lifting agent in high-quality perfumes of floral, floral aldehydic, chypre and Oriental types. 'Third' grade ylang-ylang is a clear, yellow, somewhat oily liquid. Its odour is tenacious, sweet and floral and different from 'Extra' quality oil for which it is not a substitute. Its main chemical components are: (E,E)-farnesene, β-caryophyllene, α-humulene, δ-cadinene, γ-cadinene, benzyl benzoate, linalool, geranyl acetate, (E)-nerolidol. Several samples of ylang-ylang oil from Yunnan, southern China were found to be remarkably rich in γ-muurolene.

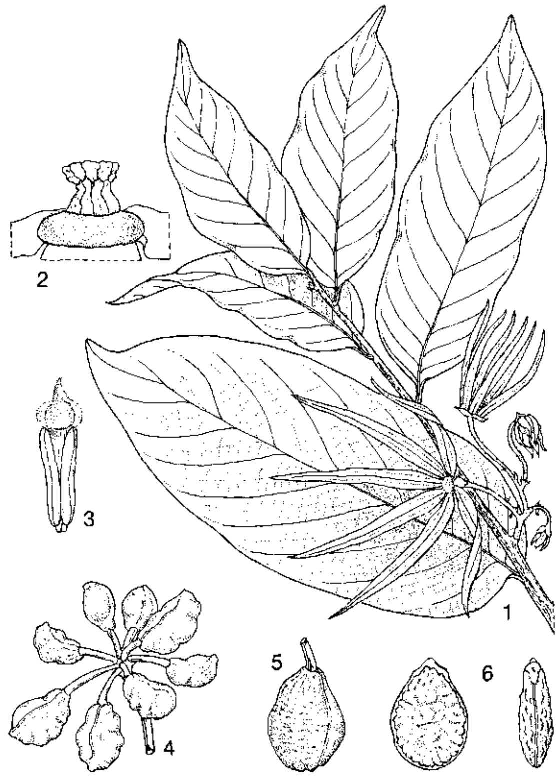
Cananga oil is a stable, yellow to greenish-yellow, mobile liquid. It has a floral, woody, medicated top note, a sweet, floral, medicated body and a sweet floral dry-out lasting 24 hours. Its main chemical components are: β-caryophyllene, α-humulene, (E,E)-farnesene, γ-cadinene, δ-cadinene, benzyl benzoate, linalool, geranyl acetate. It is used largely in soap perfumery, in floral fragrances such as jasmine, lilac and hyacinth and also in Oriental-type perfumes.

Ylang-ylang oil blends well with bois de rose oil, methyl salicylate, phenylethyl cinnamate and vetiver oil. It is much used as a modifier in artificial violet and lilac perfumery products. It may be fixed with any of the synthetic or natural plant gums and resins. Important minor components contributing to the odour of ylang-ylang oil and cananga oil are p-cresol, eugenol and isoeugenol. Hypersensitivity to cosmetics containing ylang-ylang or cananga oils attributed to eugenol and related compounds has been reported.

Commercial ylang-ylang absolute is usually a mixture of 2 types of absolutes obtained from the flowers. The first type is obtained by alcohol washing the concrete obtained by solvent extraction. The exhausted flowers from this extraction are steam distilled and the essential oil obtained is washed with alcohol to produce the second type. Both the absolute and the concrete have the true scent characteristics of the flowers. The absolute is very powerful, intense sweet floral and is used in very small concentrations in high-quality perfumes. The taste is bitter, but can be modified for use in sweets and drinks. The main chemical components of the absolute are: (E,E)-farnesene, linalool, benzyl benzoate, δ-cadinene, β-caryophyllene, benzyl salicylate, geranyl acetate, methyl benzoate, α-humulene. The Food and Drug Administration of the United States has given ylang-ylang and cananga oil the 'generally recognized as safe' (GRAS) status in alcoholic beverages, bakery products, candies, chewing gum, puddings and soft drinks at levels up to 5 ppm for ylang-ylang oil (GRAS No 3119) and 32 ppm for cananga oil (GRAS No 2232). See also: Composition of essential-oil samples and the Table on standard physical properties.

Adulterations and substitutes The flowers of climbing ylang-ylang (*Artabotrys uncinatus* (Lamk) Merrill) are sometimes mixed with true ylang-ylang flowers as adulterants. They bear some resemblance to true *C. odorata* flowers and are also fragrant.

Description An evergreen tree, 10–40 m tall, in cultivation often pruned to 3 m; trunk up to 75 cm in diameter, without buttresses; bark pale grey or silvery, smooth. Branches drooping, or slightly erect with dangling leafy twigs; young twigs minutely pubescent, glabrescent. Leaves alternate, distichous, simple, exstipulate; petiole slender, 1–2 cm long, narrowly grooved, glabrous; blade elliptical to ovate-oblong, 13–29 cm × 4–10 cm, base often oblique, rounded cordate, margin more or less undulating, apex acutely acuminate, membranous, midrib and lateral veins mostly whitish-pubescent on both sides, secondary veins in 8–9 pairs, clearly visible on both sides, often with small, hairy, pitted glands in vein axils. Inflorescence a raceme, 1–4 cm long, with 2–6 flowers on short, leafless, axillary shoots, dangling in clusters of 1–3 from the older branches behind the leaves; flowers 5–7.5 cm long, bisexual, green turning light dull yellow, overpoweringly fragrant when mature; pedicel 2–5 cm long; sepals 3, ovate, 5–7 mm × 5 mm, reflexed; petals 6, in 2 whorls of 3, linear-lanceolate, 3–9 cm × 5–16 mm, often curled or wavy, with purple brown spot at the base inside; stamens numerous, closely arranged, linear, 2–3 mm long, with a broad, cone-shaped appendix of the connective; staminodes absent; carpels many, with slender style and discoid stigma. Fruit pendulous, consisting of many (7–16) separate, globose-obovoid monocarps, about 2.5



Cananga odorata (Lamk) Hook.f. & Thomson – 1, flowering branch; 2, flower, with petals and stamens cut away; 3, stamen, front view; 4, fruit, consisting of 8 monocarps; 5, monocarp; 6, seeds, two views.

cm × 1.5 cm on stalk 1–2 cm long; monocarp dark green, ripening blackish, 2–12-seeded, with seeds embedded in yellow oily pulp arranged in 2 rows. Seed flattened, ellipsoid, 9 mm × 6 mm × 2.5 mm, pale brown, surface pitted, hard, with a rudimentary aril.

Growth and development At sea-level, saplings of cultivated trees of *C. odorata* flower when 1.5–2 years old and 2 m tall; at 500 m altitude flowering may start only after 7 years. Wild trees do not flower until they are 9–12 m tall. When the buds open, the flowers are not yet fragrant and the petals are green and covered with white hairs; the petals enlarge, become glabrous and turn from green to yellow after 15–20 days and then the flowers emit their powerful and agreeable odour, discernable at a distance. Both cultivated and wild trees flower throughout the year, but with marked seasonal peaks after periods of dry weather. In Peninsular Malaysia there is regular flowering for several weeks between February and May and often a second flowering between August and October. In Java there are 3–4 peaks in flowering; flowering is most abundant at the end of the rainy season, while flowers are richer in oil during the dry season. The oily fruits are eaten by squirrels, bats, monkeys and birds, by which means the seed is dispersed. A well managed plantation may remain productive for 50 years.

Other botanical information The habit of *C. odorata* is typically a straggling, pendulous tree: branches and leaves droop, long leafy sprays may dangle for a length of 3–6 m, flowers hang in loose bunches, and the petals are flaccid. Although the trunk continues to the top of the tree, it is commonly bent. A dwarf variety of *C. odorata* known as var. *fruticosa* (Craib) Sinclair, is often seen in tropical gardens. It is a bush 1–1.5 m tall, with frequently supernumerary, very curly petals. It flowers throughout the year, but never sets fruits. It probably originates from Thailand. Two groups can be distinguished in cultivated *C. odorata*: cv. group Cananga (forma *macrophylla* Steenis), flowers are the source of cananga oil; branches perpendicular to the stem; leaves 20 cm × 10 cm; cultivated in Java, Fiji and Samoa; and cv. group Ylang-ylang (forma *genuina* Steenis), the source of ylang-ylang oil; branches more drooping; leaves smaller; probably originating from the Philippines and cultivated throughout the tropics.

Ecology *C. odorata* thrives in the more humid lowland tropics with an annual rainfall of (650–)1500–2000(–4000) mm and an average annual temperature of 21–27°C. In Java it grows gregariously in moist evergreen forest and in teak forest. In New Guinea it grows up to 850 m altitude. When planted it is found up to 1200 m. It grows well on light, well-drained soils with pH 4.5–8, preferring rich volcanic or fertile sandy soils. Because of the long taproot, deep soils are required. Waterlogging for prolonged periods, but not permanent marshy conditions are tolerated; saline and alkaline soils should be avoided.

Propagation and planting Propagation of *C. odorata* is by seed or wildlings. Fresh seed germinates erratically; after 6–12 months storage the germination rate is higher. Hot water treatment of seed is used successfully in Nosy Bé. Vegetative propagation by stem cuttings and budding have been tried with varying success. Plants may be raised in nursery beds, but should be handled with great care during transplanting to avoid damage to the long taproot. Direct sowing is common and seed is placed 5 cm deep in well-cultivated and fertilized planting pits of at least 50 cm depth. Plant spacing is at least 6 m × 6 m.

Husbandry Young plantations of *C. odorata* are often intercropped with food crops. Ring weeding and slashing of the inter-rows are important for optimal growth. For ylang-ylang production, trees are usually topped at about 3 m after 2–3 years. Topping promotes the growth of low, drooping branches, which are also tied down to pegs to keep the flowers within easy reach. In traditional production of cananga oil, often in home gardens, the trunk is left to grow. A well-managed plantation may remain productive for 50 years.

Diseases and pests Very little is known about diseases and pests of *C. odorata*. Stem borers, flower-eating beetles and insects that cause the leaves to wilt have been reported.

Harvesting A first small harvest of *C. odorata* may be taken in the second year, but profuse flowering starts in the 4th or 5th year. Flowers are picked individually 15–20 days after opening, when they have turned yellow and their smell has become strong. The appearance of a small purple-brown spot at the base of the petals indicates that flowers are ready for picking. Picking is done early in the morning up to 10 a.m., as strong sunlight rapidly diminishes the oil content. Only ripe flowers should be picked as immature ones have not yet developed their full smell and reduce the quality of the oil. Flowers are picked manually, long-handled cutters being used to reach flowers higher up in the tree. Ladders are needed in large trees; they should be used with great care as the branches are very brittle. Chemical removal of flowers using ethylene is possible, but is not yet practised. Rain has little direct effect on flower quality but diminishes the efficiency of the distillation process.

Yield A fully developed, well managed tree will produce 30–100 kg flowers per year, but topped trees of cv. group Ylang-ylang rarely produce more than 20 kg. The flowers contain about 1–2% volatile oil.

Handling after harvest As soon as the flowers of *C. odorata* are plucked they should be distilled. If distillation has to be postponed, flowers should be spread thinly in the shade as it is essential to avoid fermentation. Wilting or delayed distillation reduces oil yield but has little effect on oil composition. Steam distillation is the most common method of extraction; extraction with petroleum ether or benzene is occasionally used. Distillation is mostly done in direct-fired water stills; heating

the water to near-boiling point before adding the flowers results in higher quality oil. To avoid spot-fermentation and overheating, stills should not be overcharged. The distillation process of ylang-ylang oil should be carefully controlled so that different fractions match grade standards.
A modern still yields about 2% oil, about 25% being 'Extra' or 'First' grade. Small traditional stills yield about 1% oil. Prolonged distillation may increase yield, but the oil so obtained is of poor quality. Small operators producing cananga oil frequently prolong distillation, merely removing spent flowers and topping up water. This reduces the oil quality, as unwanted compounds react with the desired esters.

Genetic resources and breeding No systematic collection work has yet been done and only very small collections of germplasm of *C. odorata* exist. In the Philippines, wild plants are threatened by extinction. No breeding programmes are known to exist.

Prospects Artificial cananga and ylang-ylang oil can be compounded at the price of ordinary cananga oil, with many times its strength. Modern perfumes, however, contain only the finest, natural ylang-ylang oil, while the demand for cananga oil, especially for toiletry products, is still growing. If a reliable supply of cananga and ylang-ylang oil can be assured, the demand for both will probably remain strong. Germplasm collection and agronomic research is strongly recommended.

Literature |**1**| Acda, R.I., Reblora, M.A. & Gonzales, E.D., 1995. Solvent extraction of essential oils from ylang-ylang (Cananga odorata). Philippine Agriculturist 78: 345–353. |**2**| Buccellato, F., 1982. Ylang survey. Perfumer and Flavorist 7(4): 9–12. |**3**| Dassanayake, M.D. & Fosberg, F.R. (Editors), 1987. A handbook to the flora of Ceylon. Vol. 6. Amerind Publishing Company, New Delhi, India. pp. 69–71. |**4**| Fekam Boyom, F., Amvam Zollo, P.H., Menut, C., Lamaty, G. & Bessière, J.M., 1996. Aromatic plants of tropical Africa. Part 27. Comparative study of the volatile constituents of five Annonaceae species growing in Cameroon. Flavour and Fragrance Journal 11: 333–338. |**5**| Gaydou, E.M. et al., 1986. Composition of the essential oil of ylang-ylang from Madagascar. Journal of Agricultural and Food Chemistry 34: 481–487. |**6**| Muhamad Hijaz, S., 1994. Kenanga dari aspek aromatik dan estetik di dalam periandskapan [Cananga, its aromatic and aesthetic aspects in landscaping]. Universiti Pertanian Malaysia, Serdang. 65 pp. |**7**| Stashenko, E.E., Martinez, I.R., Macku, C. & Shibamoto, T., 1993. HRGC and GL-MS analysis of essential oil from Colombian ylang-ylang (Cananga odorata Hook. Fil. et Thomson, forma genuina). Journal of High Resolution Chromatography 16: 441–444. |**8**| Stashenko, E.E., Torres, W. & Martinez Morales, I.R., 1995. A study of the compositional variation of the essential oil of ylang-ylang (Cananga odorata Hook. Fil. et Thomson, forma genuina) during flower development. Journal of High Resolution Chromatography 18: 101–104. |**9**| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 10–23. |**10**| Wiyono, B. & Rosid, M., 1989. Studi perbandingan sifat-sifat minyak kenanga dari Blitar, Boyolali dan Cirebon [Comparative study on the characteristics of cananga oil from Blitar, Boyolali and Cirebon]. Penelitian Hasil Hutan 6(5): 288–291.

Umi Kalsom Yusuf & V.O. Sinohin

Cinnamomum camphora (L.) J.S. Presl

Bercht. & J.S. Presl, Prir. rostlin 2: 36, 47–56, t. 8 (1825).

LAURACEAE

$2n = 24$

Synonyms *Laurus camphora* L. (1753), *Cinnamomum camphora* (L.) Siebold (1830), *C. camphora* (L.) Nees & Ebermaier (1831).

Vernacular names Camphor tree, Japanese camphor tree, Chinese sassafras (En). Camphrier, laurier à camphre (Fr). Indonesia: kamper, kapur barus, nanang. Thailand: opchoai-yuan (general), phromseng (northern). Vietnam: c[aa]y long n[ax]o.

Origin and geographic distribution *C. camphora* occurs naturally in Japan, the Ryukyu Islands, China south of the Yangtze river, Hainan, Taiwan and Vietnam. It is cultivated in many tropical and subtropical countries including South-East Asia. It has become naturalized in Australia, where in wetter areas it is considered a weed.

Uses The leaves, wood and roots of *C. camphora* yield essential oils whose main component, camphor, was formerly a very important medicine and disinfectant. Industrially it was a raw material for the production of celluloid, explosives and plasticizers. Medicinally, camphor is used mainly in liniments to relieve chest congestion, muscle pains and arthritis. It was also highly regarded as a cardiac and circulatory stimulant. In traditional medicine it has been an abortifacient, anti-aphrodisiac, contraceptive, cold remedy and suppressor of lactation. Camphor has long been used as an insect repellent, especially of moths in clothing. It was one of the first antiseptics used in hospitals.

The various essential oils obtained from *C. camphora* are important in perfumery mainly as sources of specific aroma chemicals, as fixing agents and in scenting soaps. The heaviest fractions are used as drying solvents in paints and lacquers.

The wood is often considered too valuable to be used as timber, except for cabinet work, such as chests for linen and clothes. The fine odour of the wood and the observation that it repelled insects led to the first extraction of the oil.

In Australia *C. camphora* was first introduced as a shade tree in streets and gardens, but has become a weed in wetter areas of Queensland and New South Wales.

Production and international trade Prior to the First World War, most camphor traded internationally originated from natural stands in Taiwan, Chinese production being used locally. When natural stands became depleted, plantations were established, first in Taiwan and after the Second World War in Japan. Since the 1990s large plantations have also been established in China. Small plantations exist in India and Sri Lanka. No comprehensive information is available on the production and trade in camphor and camphor oils from *C. camphora*. The major producers are Taiwan and Japan. Japan used to produce several thousands of tonnes per year, but production has declined as a result of the manufacturing of synthetic camphor. In 1994 China produced about 1.5 t camphor oil.

Properties Originally, camphor was the most important constituent of the essential oil distilled from the wood of *C. camphora*. Natural camphor is a transparent or whitish, crystalline solid, usually easy to break into pieces and having a characteristic odour. Chemically it is a ketone derivative of a dicyclic terpene; it vaporizes slowly at room temperature, is insoluble in water, but soluble in various alcohols. Camphor is a very toxic substance with a probable human lethal dose of 50–500 mg/kg; low doses cause vomiting, higher doses severe gastrointestinal irritation and convulsions. Its use in non-prescription medicines is considered unacceptable by some. After the introduction of synthetic camphor (similar in appearance to natural camphor, but optically inactive), the importance of natural camphor greatly diminished and the camphor-free residual oil became the main product.

Chemically, *C. camphora* is very variable. Based on analyses of essential oils from China and Vietnam, 8 chemotypes of *C. camphora* have been described, but in international trade 3 main groups of essential oils are generally recognized: 'true camphor oil', 'ho oil' and 'apopin oil'.

'True camphor oil' or 'hon-sho oil' is rarely traded as a complete oil but is usually distilled into several fractions, named white, brown (or red) and blue (or green) camphor oil. White camphor oil is the first fraction distilled and amounts to 20% of the camphor-free oil. Its chief constituent is 1,8-cineole and it also contains other monoterpenoids. White camphor oil is an almost colourless liquid with an eucalypt-like odour. It is rarely used as such in perfumery, but is an important source of perfumery chemicals, including cineole, pinene, terpineol, para-cymene, menthol and thymol. In the United States the Food and Drugs Administration (FDA) classified white camphor oil as 'generally recognized as safe' (GRAS No 2231). The oil is also used as a solvent in the lacquery and paint industry. Brown camphor oil is the medium-heavy fraction amounting to 20–22% of the camphor-free oil and containing about 80% safrole. It is a pale yellow liquid with the characteristic odour of sassafras oil. This is the most important camphor oil in perfumery, because of its great masking effect, e.g. in soap perfumes. One of its components, safrole, is also isolated and then serves as a starting point for the production of heliotropine, vanillin and other perfumery chemicals and a herbicide. The residue after extraction of safrole is traded as yellow camphor oil. An artificial sassafras oil, traded as 'oil camphor sassafrassy', is made from brown camphor oil by rectifying and adjusting the content of safrole and terpenes. Blue camphor oil is the heaviest fraction and is distilled in vacuum from true camphor oil. It has a weak odour consisting mainly of sesquiterpenes, sesquiterpene alcohols and azulenes. It is of minor interest in perfumery, used occasionally for its fixative and masking effect and also finds use as a drying solvent for porcelain paints.

Residual camphor oil may also be characterized by its main component: cineole, safrole, linalool, or terpineol. In general, oil from Taiwan contains mainly linalool or safrole, oil from Japan mainly safrole, and oil from China mainly terpineol and cineole.

'Ho oils' are camphor oils distilled from the wood of forms of *C. camphora* known as 'sho-ho' or 'ho-sho'. The oils are characterized by a high content of linalool. Ho oil from China is generally a com-

plete oil containing camphor and linalool; ho oil from Taiwan and Japan (also named shiu oil) is a fractionated residual oil. The fraction amounts to about 20% of the decamphorized oil.
'Apopin oil' is distilled in China from the most common form of *C. camphora* in China and Taiwan named 'yu-sho' or 'shu-yu'. The crude oil is liquid and does not contain crystalline camphor, but contains about equal amounts of camphor, cineole and terpineol. It is used in China as a low-cost perfume and is also an important source material for the isolation of camphor, cineole and terpineol. Fractions of this oil are used as a basis for the production of very low-priced substitute of eucalypt oil and for adulteration of true eucalypt oil.
Essential oil distilled from the leaves of *C. camphora* is comparable in chemical composition to the residual camphor oil distilled from the wood. Commercially, the most important one is 'ho leaf oil'. Rectified or high-grade ho leaf oil is almost colourless and practically free of camphor-like notes and has a very pure linanool fragrance. The fragrance changes very little on evaporation, but its tenacity is only moderate. It is used in high concentrations in many perfume types. See also: Composition of essential-oil samples and the Table on standard physical properties.

Adulterations and substitutes Camphor for industrial purposes is currently made only from turpentine, petroleum derivatives or coal tar. Camphor can also be obtained from the African *Ocimum kilimandscharicum* Gürke. Camphor oil is a low-priced source of several aroma chemicals that are often used in reconstituting or upgrading other essential oils.

Description Large, evergreen, fragrant tree, 15(–30) m tall; root system extensive and shallow; trunk short, stout; bark deeply furrowed; crown spreading, up to 30 m wide; twigs brown, yellowish or pinkish when young, glabrous; buds stout, ovoid, pubescent, with many imbricate scales. Leaves alternate, aromatic; petiole slender, 1.5–3 cm long; blade broadly ovate-elliptical to oblong-lanceolate, 5–12 cm × 2–7 cm, base obtuse, margin slightly undulate, apex acute or acuminate, chartaceous, deep green, shiny, glabrous above, glabrous or sparsely hairy beneath, with 3 main veins and 2 conspicuous, impressed glands in vein axils, major veins prominent on both sides. Inflorescence an axillary, many-flowered panicle, up to 7 cm long; pedicel 1–1.5 mm long, glabrous; flowers bisexual, small; perianth tubular, 6-lobed, membranaceous, partly persistent in fruit; lobes ovate, 2.5–3 mm × 1 mm, obtuse, yellowish-green,

Cinnamomum camphora (L.) J.S. Presl – 1, flowering branch; 2, flower; 3, longitudinal section through flower; 4, stamen with 2 basal glands; 5, fruit.

glabrous outside, pubescent inside, transversely tearing off near the base; fertile stamens 9, in 3 whorls, pubescent; 1st and 2nd whorls eglandular, anthers oblong, 0.5 mm long, introrse; 3rd whorl with 2 subsessile, ovate glands at the base and extrorse anthers; 4th, innermost whorl consisting of 3 eglandular staminodes, ovoid, with short filaments; anthers open upwards by flaps; ovary superior, ovoid, subsessile, glabrous; style up to 2 mm long. Fruit a compressed-globose berry, 7–10 mm in diameter, violet-black when ripe, one-seeded. Seed 6–7 mm in diameter.

Growth and development Under favourable circumstances trees of *C. camphora* may grow up to 10 m tall with a diameter of 15 cm in 10 years. They may become very old, the oldest specimen known in Taiwan was 1400 years old, the largest tree in Japan is estimated to be 1200 years old. Although it is evergreen, *C. camphora* sheds its leaves annually in spring, but is never leafless. Leaf growth is fast; young flushes are strikingly reddish, whereas new leaves mature in 2–3 months. In East Asia and Australia flowering occurs in spring and fruiting in autumn. Trees start flowering when 7–25 years old; only trees older than 20 years produce viable seed. Outside its natural area of distribution viable seed is produced only occasionally. Fruits are eaten and distributed by birds. Trees coppice well and form root suckers.

Other botanical information There are numerous subclassifications of *C. camphora*, mainly based on the chemical contents of the trees. Although the exact processes regulating the chemistry of the trees are not yet well understood, it is certain that environmental factors such as climate and soil play an important role. Morphologically, however, the differences do not merit special distinction. Once a more stable chemotype classification has been established, the best solution may be a classification into cultivar groups and cultivars. Extensive surveys of essential oils distilled from the wood, leaves and flowers from *C. camphora* in China and Vietnam found a large number of different types of oil; at least 8 chemotypes can be described on the basis of these analyses: a camphor type, a 1,8-cineole type, a linalool type, a camphor-sesquiterpene type, a camphor-1,8-cineole type, a sesquiterpene type, a safrole type, and a phellandrene type.

C. pedatinervium Meissner is a 15 m tall tree of the dense, moist forest of Fiji Islands and Micronesia, the bark of which contains safrole. It is also used to prepare a tea and against haemorrhages.

C. vimineum C. Nees is a rare species of hill and mountain forests in Peninsular Malaysia and Indonesia and is said to have a strong camphor smell. It is a small tree with lanceolate leaves. Numerous other *Cinnamomum* species yield essential oils, but are primarily used as spice or timber; many also have medicinal properties.

Ecology The natural habitat of *C. camphora* is primary forest, but it occasionally also occurs in open sites, up to 3000 m altitude, though below 1000 m is considered optimal. In West and Central Java it is cultivated at 600–1500 m altitude. It flourishes in warm temperate to subtropical climates, but also under tropical highland conditions. Mature trees can withstand frost to –5°C, but young trees often succumb to it. In its natural habitat annual rainfall ranges between 1000–3500 mm; higher rainfall is tolerated on free draining soils as *C. camphora* with its shallow root system does not tolerate waterlogging. In areas with very high rainfall or after prolonged periods of very heavy rain, the camphor content of the essential oil is low. Unshaded trees have the highest essential oil content. Trees growing in the shade and even shaded leaves of a specific tree usually have lower essential oil and camphor contents. Fertile, well-drained sandy loams are most suitable for cultivation of *C. camphora*. Soil type affects both the essential oil content and its composition. Trees on lighter soils tend to have a higher essential oil content. Neutral to slightly alkaline (pH 6.5–8) soils are preferred for plantations.

Propagation and planting Propagation of *C. camphora* is mostly by seed, although propagation by stem and root cuttings and root suckers is also possible. Seed starts to germinate after 3–4 weeks. Seed is normally sown within a few months after collection, as viability after 6 months is usually low. In parts of China with a cold winter, the seed is kept until the following spring. Cleaning and soaking the seed in water for 24 hours improves and hastens germination. Seed is sown in well-prepared and fertilized seedbeds. Germination begins after 3–4 weeks. Seedling plants are ready for transplanting into the field after 12–24 months. Before transplanting they are cut back to 5–10 cm, while in India the roots are also pruned. Planting density is 2000–2500 trees per ha, in some areas even up to 5000 per ha. Where trees are grown for the leaf oil, the chemotype of the planting material is checked by crushing and smelling a leaf.

Husbandry Plantations of *C. camphora* are managed like most other intensively managed forest plantations. Some weeding is necessary during the first 4–7 years. When grown for the leaves, trees are topped at about 1.5 m and coppiced to encourage a bushy growth. Ideally, fertilizers should then be applied to maintain a good yield, but this is only rarely done. Where a still is located near the plantation, spent leaves are sometimes returned as green manure or mulch.

Diseases and pests Many diseases and pests that damage cinnamon (*C. verum* J.S. Presl) also affect *C. camphora*. Diseases generally cause only minor damage. *Clitocybe tabescens* causing root rot in tropical Asia may affect individual trees. Leaf blight caused by *Glomerella cingulata* can be controlled to some extent by spraying with a fungicide such as 'benlate'. *Acrocercops ordinatella*, *Attacus atlas*, *Euproctis lunata* and *Suana concolor* are serious leaf pests in most of Asia, as is the camphor silk moth *Dictyoploca japonica*. Adults and larvae of the cockchafer *Leucopholis pinguis* cause considerable damage in nurseries in Asia. The weevil *Cratopus punctum* is a serious leaf pest in Mauritius.

Harvesting Formerly, wild trees of *C. camphora* were harvested in a manner similar to timber logging. In plantations, trees are harvested at 16–20-year intervals. Regrowth is normally rapid, as trees coppice readily and vigorously. Plantations to supply leaves are harvested annually in Japan between October and March; in some districts 2 harvests are possible. In India and Sri Lanka up to 4 harvests a year are common. Leaves are generally collected manually, using hand-held strippers or cutters. The feasibility of fully mechanical harvesting is being investigated, but it seems that the shape and the management of the bushes may have to be modified.

Handling after harvest Camphor oil used to be obtained by reducing the stems to chips, steam distilling of the chipped wood and then filtering the camphor crystals from the oil. The residual oil was then rectified under vacuum, yielding an additional 50% camphor, and a camphor-free residual oil. Steam distillation of the leaves to extract camphor was first developed in the United States and was later adopted in Japan and Taiwan, when natural stands of mature *C. camphora* trees became depleted.

Genetic resources and breeding Small collections of germplasm of *C. camphora* exist but cover only a small part of the natural range and the variation in chemotypes. The segregation of the progenies of different chemotypes is being studied, as a first step in the development of high quality strains with specific essential oil characteristics.

Prospects Although natural camphor is no longer used industrially, the essential oils distilled from *C. camphora* remain important as they yield several other components that are important for the industrial manufacture of aroma compounds. The various compounds, rectified essential oils and fractions will remain important in low-price perfumery, in soap perfumes, and as fixing agents in compounded perfumes because of their low price and easy and regular supply. The most important medicinal role of camphor will probably continue to be in rubbing liniments.

Literature |**1**| Committee on Drugs (United States), 1978. Camphor, who needs it? Pediatrics 62: 404–405. |**2**| Craker, L.E. & Simon, E., 1986–1988. Herbs, spices and medicinal plants. Recent advances in botany, horticulture and pharmacology. Oryx Press, Phoenix, Arizona, United States. |**3**| Dung, N.X., Khieu, P.V., Chien, H.T., Leclercq, A.X. & Leclercq, P.A., 1998. Chemical segregation of progeny of camphor trees with high camphor c.q. linalool content. Journal of Essential Oil Research (in press). |**4**| Ibrahim bin Jantan & Goh, S.H., 1992. Essential oils of Cinnamomum species from Peninsular Malaysia. Journal of Essential Oil Research 4: 161–171. |**5**| Liao, Jih-Ching, 1996. Lauraceae. In: The Editorial Committee of the Flora of Taiwan: Flora of Taiwan, Vol. 2, Second Edition. Department of Botany, National Taiwan University, Taipei, Taiwan. pp. 437–448. |**6**| Nguyen Xuan Dung, Pham Van Khien, Ho Trung Chien & Leclercq, P.A., 1993. The essential oil of Cinnamomum camphora (L.) Sieb. var. linaloolifera from Vietnam. Journal of Essential Oil Research 5: 451–453. |**7**| Sastri, B.N. (Editor), 1950. The wealth of India. A dictionary of Indian raw materials and industrial products. Vol. 2. Cinnamomum. Publications and Information Directorate, Council of Scientific and Industrial Research, New Delhi, India. pp. 173–183. |**8**| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 156–168. |**9**| Zhu, L.F., Ding, D.S. & Lawrence, B.M., 1994. The Cinnamomum species in China: resources for the present and future. Perfumer and Flavorist 17(4): 17–22.

F. Indah Windadri & S.S. Budi Rahayu

Citrus aurantium L. cv. group Bouquetier

Sp. pl.: 782 (1753); cultivar group name is proposed here.

RUTACEAE

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Synonyms *Citrus bigaradia* Risso & Poiteau (1818), *C. amara* Link (1831), *C. aurantium* L. subsp. *amara* (Link) Engler (1897).

Vernacular names Bouquetier (En). Bouquetier (Fr). For *C. aurantium* in general: Sour orange, bitter orange, Seville orange, bigarade (En). Bigaradier, orange amère (Fr). Indonesia: lemon itam (Moluccas). Malaysia: limau samar. Philippines: cabiso. Burma (Myanmar): kabala, leinmaw. Cambodia: krôôch loviing, léang sat. Thailand: som. Vietnam: b[oor]ng, d[aj]i d[aj]i hoa.

Origin and geographic distribution *C. aurantium* most probably originated in north-eastern India and adjoining areas of Burma (Myanmar) and China. It spread north-eastward to Japan and westward through India to the Middle East and from there to Europe, where it rapidly became established in the Mediterranean some 1000 years ago. It became especially common in Spain, hence its vernacular name Seville orange. It was one of the first citrus taken to South America in the 16th Century, where it soon escaped from cultivation and naturalized in many areas. It is now cultivated in many tropical and subtropical countries, but only rarely in South-East Asia. *C. aurantium* has been grown in France since the early 1400s, initially mainly as an ornamental. Later on special perfumery cultivars grown for their fragrant flowers were developed in the French Riviera region and became known as 'Bouquetiers'.

Uses The flowers of several citrus species yield essential oil called 'neroli oil' in the perfume trade. The flower oil of sweet orange (*C. sinensis* (L.) Osbeck) is called 'neroli Portugal', that of lemon (*C. limon* (L.) Burm.f.) 'neroli citronier'. Flowers of *C. aurantium* yield an essential oil called 'neroli bigarade oil'. The best quality is obtained from Bouquetier cultivars formerly from southern France and Italy and nowadays from Morocco and Tunisia. Neroli oil is a component of high quality perfumes and of the toilet water 'eau-de-Cologne'. Significant amounts (up to 25%) of aroma compounds remain in solution in the water left in the still after distillation of *C. aurantium* flowers. The oil obtained by extraction of these compounds is traded as 'orange flower water absolute' and is mainly used in the reconstitution of other essential oils and of the formerly popular 'orange flower water'. Neroli bigarade oil is sometimes used as a flavour component in food products, including alcoholic and non-alcoholic beverages, especially in tea.

'Petitgrain oil' is produced by distilling the leaves and green twigs of several citrus species; those of *C. aurantium*, including the Bouquetiers, yield 'petitgrain bigarade oil'. Petitgrain oils are often used as a substitute for the much more costly neroli oils. Petitgrain water absolute or 'eau-de-brouts' is the equivalent of orange flower water absolute and is obtained as a by-product from petitgrain bigarade oil. It enhances the 'naturalness' of several other fragrances, e.g. jasmine, neroli, ylang-ylang and gardenia. Petitgrain bigarade oil is used as a flavouring in food products, including alcoholic and non-alcoholic beverages.

The peel of the fruits of *C. aurantium* is used extensively in the manufacture of citrus marmalade. It also yields the essential oil 'bitter orange oil' (also called 'bitter orange peel oil') mainly used as a flavouring, such as 'orange sec' and 'triple sec' liqueur flavours, and to modify or strengthen the flavour of sweet-orange soft drinks. The average maximum concentration used in food products and drinks is about 0.04%. The sour fruit juice can be used like vinegar. The wood of sour orange is strong and takes a fine polish; it is sometimes used to make furniture.

C. aurantium has been used extensively as a rootstock for other citrus species (particularly sweet orange, lemon and grapefruit) because it produces a well-developed root system and has a high degree of resistance to many important diseases (e.g. gummosis, root rot) and to cold. Its popularity as a rootstock has decreased, however, because of its susceptibility to the viral disease tristeza.

C. aurantium has several medicinal uses, e.g. in the Caribbean against gall bladder problems; in the Philippines as a stimulant and against ringworm and as an antiseptic against *Staphylococcus aureus*. Bitter orange peel oil has stomachic, carminative and laxative properties. Dried bitter orange peel is used as tonic and carminative in treating dyspepsia. Preparations from unripe and nearly ripe fruits are used against stomach pains and indigestion in North Africa and China, and against colds and influenza in the Bahamas and China. In aromatherapy neroli bigarade oil is primarily a relaxing oil, but is also applied for its antiseptic, antispasmodic and carminative effect. Because of its sedative effect its use is incompatible with driving.

Production and international trade In trade statistics a distinction is rarely made between petitgrain and neroli oil from different citrus sources. The total annual world production of petitgrain oil in 1985–1988 was valued at US$ 5.4 million, that of neroli oil at US$ 3.75 million. The annual world production of bitter orange peel oil was valued at US$ 1.1 million (major producers are Jamaica, Dominican Republic, Haiti, Brazil and Italy). Besides France and Italy, the cultivation of *C. aurantium* is most important in Paraguay (especially for petitgrain oil), Morocco and Spain.

Properties On water distillation, 1 kg of Bouquetier flowers yield about 1 g neroli bigarade oil and about 0.7 l orange flower water. Neroli bigarade oil is a pale yellow, mobile oil becoming darker and more viscous on ageing. Its fragrance characteristics are a light, floral, pleasantly bitter top note, a floral, herbal, green body and a floral, orange flower dry-out lasting about 18 hours. The major chemical components of neroli bigarade oil are: linalool, limonene, linalyl acetate, nerolidol, geraniol, and methyl anthranilate. Extraction of flowers with supercritical CO_2 yields a neroli bigarade oil much richer in linalyl acetate (23%) than neroli oil obtained by water distillation. The content of methyl anthranilate (1%) is also significantly higher. The olfactive and physical characteristics of neroli bigarade oils from the Mediterranean countries are very similar, but neroli bigarade oil from Haiti has a different odour and a distincly higher optical rotation (18–27°). The odour intensity of the CO_2 extract is about twice that of water-distilled oils. Orange flower water absolute, prepared by extracting orange flower water several times with highly rectified petroleum ether, is a yellowish to orange-yellow or pale brownish oil which discolours significantly on ageing. It has a dry floral, musty herbaceous odour, reminiscent of mandarin leaf oil, petitgrain oil and slightly of orange flower absolute. Some sources describe it as having a fresh floral orange flower top note, a rich and heavy floral body with orange flower and animal notes and a floral, heavy, green, animalic dry-out lasting about 24 hours.

As neroli bigarade oil and orange flower water both contain only some of the aromatic components of the flowers, attempts have been made to obtain a more representative extract. Combining neroli bigarade oil and orange flower water absolute does not give the desired result. Extraction of flowers with petroleum ether and then extraction of the resulting concrete with alcohol yields orange flower absolute, a dark brown or orange-coloured viscous liquid with a very intensely floral, heavy and rich, warm, but also delicate and fresh, long-lasting odour, closely resembling the fragrance of fresh bitter orange blossoms. Its fragrance is not unlike that of jasmine, less intensely floral, but with a greater freshness. It is used in many perfumes and flavourings and combines well with a wide range of natural and artificial aroma products.

Petitgrain bigarade oil (also called bitter orange petitgrain oil) is obtained by steam distillation of the leaves and green twigs of *C. aurantium*. It is a pale yellow to amber, mobile liquid with a fresh, floral, orange flower top note, a bitter, floral, herbal and woody body and a dry herbal dry-out lasting about 36 hours.

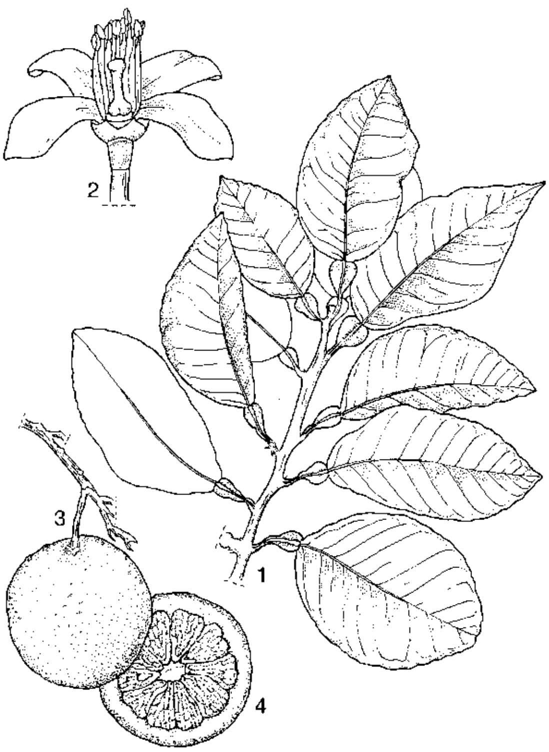
The main chemical compounds constituting petitgrain bigarade oil are linalool, linalyl acetate and the monoterpene aldehydes geranial and citronellal. Analysis of an oil from China indicated a very similar composition, but a higher proportion of linalool derivatives.

Bitter orange peel oil is obtained by cold expression of the fruit peel of *C. aurantium*. It is only rarely made from Bouquetier cultivars. It is a dark-yellow to olive-yellow or pale-brownish-yellow, mobile liquid with a very characteristic fresh, yet bitter or dry taste, and a lasting, sweet undertone. It consists mainly of limonene (94%), with small quantities of myrcene (2%).

The Food and Drug Administration (FDA) in the United States has approved for food use and given 'generally recognized as safe' status to neroli bigarade oil, petitgrain bigarade oil and bitter orange peel oil respectively by the GRAS Nos 2771, 2855 and 2823. The Research Institute for Fragrance Materials (RIFM) has published monographs on those 3 oils and the International Fragrance Association (IFRA) has issued restrictions relating to the concentrations permitted. In the European Union the oils have been registered under No 136n. See also: Composition of essential-oil samples and the Table on standard physical properties.

Adulterations and substitutes In Paraguay, *C. aurantium* occurs naturalized and is very common. It has been assumed that it is a hybrid with sweet orange, or a mutation and has been classified as 'Bittersweet orange'. It is the main source of Paraguayan *C. aurantium* essential oils. These oils differ markedly in fragrance and composition from Bouquetier and other *C. aurantium* oils. Neroli oil from Haiti is obtained by steam distillation of a mixture of flowers of *C. aurantium* and other *Citrus* species, mainly *C. maxima* (Burm.) Merrill.

Description Tree, 3–10 m tall, much branched with a rounded crown. Young twigs angled and bearing slender short spines, older branches with stout spines up to 8 cm long. Leaves simple, alternate, subcoriaceous, dotted with glands, aromatic when bruised; petiole 2–3 cm long, upper half narrowly to broadly winged, wing triangular-obovate, up to 2.5 cm wide; blade broadly ovate to elliptical, 7–12 cm × 4–7 cm, base cuneate or obtuse, margin subentire to slightly crenulate, apex obtuse to bluntly pointed. Flowers axillary, single or in a fascicle of 2–3, very fragrant, white, usually bisexual but 5–12% male flowers occur; calyx cupular, 4–5 mm long, 3–5-lobed, lobes broadly ovate-triangular, glabrous to pubescent; petals 4–5, oblong, 1.5 cm × 4 mm; stamens 20–25, often in 4–5 groups, filaments 6–10 mm long, anthers oblong; pistil with glabrous ovary, stout style and capitate stigma. Fruit a depressed-globose hesperidium, 5–8 cm in diameter, with 8–12 segments, central core usually hollow, peel thick, smooth to warty, yellow-orange, strongly aromatic, pulp very acid and slightly bitter. Seeds numerous, polyembryonic, with a high number of nucellar embryos.



Citrus aurantium L. – 1, leafy shoot; 2, flower in longitudinal section; 3, fruit; 4, fruit in transverse section.

Bouquetier cultivars are small, subspineless trees, flowering profusely with very large single flowers.

Growth and development Flowering of *C. aurantium* is strongly influenced by weather conditions. Bright, sunny and dry weather with mild temperatures is most suitable for flower production and harvesting. Cloudy, misty or hot and humid conditions reduce flower numbers and oil content. In France and most of the Mediterranean flowering occurs in late spring (May–June). Bitter orange has a long life span; orchards 80–100 years old can still be productive.

Other botanical information The taxonomy of *C. aurantium* as species and at sub-specific level is very confused and in dire need of revision, as is the taxonomy of the entire genus *Citrus* L. It is possible that *C. aurantium* originated as a hybrid between the mandarin (*C. reticulata* Blanco) and the pummelo (*C. maxima* (Burm.) Merrill), which perpetuates chiefly apomictically. In Europe, sour orange was known long before the sweet orange, and for a long time sweet orange has been considered as a variety of sour orange. Now sweet orange (*C. sinensis*) is considered as a completely different species (main differences: sour orange has longer and broader winged petioles, leaf blades are narrower and more pointed, fruits are brighter orange and have a rougher peel and oil glands are sunken in the peel). Cultivars grown for the production of essential oils are often referred to as *C. aurantium* L. subsp. *amara* Engl., but a cultivar group classification is more appropriate for cultivated plants. Bouquetiers are a small group of cultivars grown mainly in France for the perfume industry. Some well known cultivars are: 'Bouquetier à Grandes Fleurs' (the most important perfume cultivar; synonym: 'Bouquetier à Peau Epaisse'), 'Bigaradier de Grasse', 'Bouquetier à Fruits Dur', 'Bouquetier à Fruits Mous', 'Bouquetier de Nice à Fleurs Double' (cultivar with double flowers; synonyms: 'Bouquetier de Nice à Fruits Plats', 'Bouquetier de Nice') and 'Bouquet' (a cultivar very well suited as ornamental hedge plant; synonym: 'Bouquet de Fleurs').

Ecology *C. aurantium*, including the Bouquetier cultivars, requires a warm climate with an optimum average annual temperature of 22–24°C, but temperatures of up to 45°C are tolerated, provided soil moisture is adequate. Plantations are mostly located below 500 m altitude and perform best up to 300 m. Cold weather may cause damage, especially to trees weakened by diseases or pests. Frost causes serious damage and a few days with minimum temperatures of -4°C may kill the young, non-lignified branches, while severe frost or icing is often fatal. In some years, late spring frosts destroy a great part of the flowers in France and other Mediterranean countries. Growth and flowering are optimal under sunny conditions. Annual rainfall of 1000 mm falling mainly in spring and summer is the optimum, and irrigation is required where annual rainfall is below 750 mm. Very strong winds may cause tree damage, while dry hot winds in spring may reduce leaf size and number and cause extensive withering during flowering. If the climate is favourable, *C. aurantium* can be planted in almost any kind of soil that is not compacted, wet for long periods or contains excessive amounts of clay, lime or silica.

Propagation and planting Like other bitter oranges, Bouquetiers are propagated by seed or grafting. In France, seed is planted in seedbeds in spring and seedlings are transplanted into a nursery after 2 years at a spacing of 1 m × 30 cm. When planted out in the field, the spacing is 4 m × 4–5 m, but the spacing between rows may be reduced to 1–1.5 m if all cultivation is manual. Grafting is usually performed at the beginning of summer, when the bark of the rootstock can be loosened easily from the wood.

Husbandry During the first year after planting out, sour orange must be pruned to keep the foliage off the ground. Weed control is essential until the young plants are well established and growing vigorously. In France, the ground between trees is cultivated several times per year when applying fertilizer: in spring, twice during summer and after application of manure in September–October. In many other locations fertilizer is seldom used. Trees are commonly mulched with spent material from stills. Irrigation is applied when necessary and is particularly important during the first years after transplanting. Pruning to keep an open crown is done after the harvest of the flowers. The leaf material removed may be used to distill petitgrain bigarade. When prices are low, orchards are often neglected for long periods. When prices recover, trees can be coppiced without harm and resume normal growth and production.

Diseases and pests The principal disease of bitter orange in France is sooty mould. It often follows aphid attack and is caused by fungi living on honeydew and covering the leaves with a black dust, thus impeding their functioning. *C. aurantium* is resistant to gummosis, caused by *Phytophthora* spp., but susceptible to scab, caused by *Elsinoe fawcetti*, and intolerant of the tristeza virus. Scale insects are the main pests in the Mediterranean region.

Harvesting The first harvest of flowers and leaves of bitter orange takes place 3–4 years after planting in the field. Seedling trees are then cut back to 12–15 cm above the ground. Flowers are picked by hand when they are just open, as early in the morning as possible for the best quality oil. Unopened buds and wilted flowers impart a grassy odour to the oil, leaves impart an off-note. Flowers are kept overnight, spread out in a thin layer, and brought to the still early the next morning.

Leaves are harvested annually or, in the tropics, even at 9-month intervals. Where flowers are harvested, pruning is done afterwards, i.e. in July-October in France. In Haiti trees are pruned throughout the year. All prunings are transported to the still, where leaves and twigs are stripped, and larger branches are used as fuel.

In southern Italy and Spain, where bitter orange is often grown for its fruit, harvesting is done in January–February, sometimes up to March.

Yield Flower yields of bitter orange increase until trees are about 20 years old. A 10-year-old tree may yield about 6 kg of flowers per year, a full-grown tree up to 20 kg. The average annual yield per tree is somewhat higher in North Africa than in France, where trees are kept smaller. About 1 g neroli oil can be obtained from 1 kg flowers. The oil content of the leaves increases as temperatures rise (from April–June in Italy). The yield of leaves depends on the management of the trees. Leaves from trees exposed to sunlight generally have a higher oil content than those from shaded trees, and distilling fresh leaves gives the highest yields. In Haiti, leaves can be harvested throughout the year, but the best quality oil is obtained in May–October after the flower harvest. In Paraguay, annual leaf oil yields increase steadily until the 5th year, after which they remain constant for decades under good management. In Paraguay, individual trees may produce 10–15 kg leaves annually, while 200–300 kg leaves yield about 1 kg oil. In Haiti 300–400 kg leaves yield about 1 kg oil; in France 500 kg are needed for 1 kg oil.

Handling after harvest Neroli oil is extracted from the flowers of bitter orange by water distillation. Treating the flowers with steam would cause them to clump together, so instead they are put directly in the water in the still, which is then heated indirectly. In modern stills in France, 250–300 kg of flowers are distilled in 200–250 l of water. About 15% of the water containing about 75% of the volatile compounds is distilled over, yielding neroli oil by separation. About 25% of the aroma compounds remain dissolved in the water; they are recovered by solvent extraction, yielding orange flower water. On average, distillation of 1 kg flowers yields 1 g neroli bigarade oil plus 0.7 l of orange flower water and takes about 3 hours. Some producers prefer a more concentrated product and use a higher proportion of flowers to water.

Petitgrain bigarade oil is obtained by steam distillation of the leaves and green twigs. Care should be taken to remove all wood, young fruits and prunings of other citrus species.

Bitter orange oil is expressed from the peel of the fruit by hand or machine. In southern Italy the old 'sponge' method of extraction has long been used, as this allowed the subsequent use of the peel in marmalade manufacturing.

Genetic resources A collection of 39 accessions of *C. aurantium* cultivars including Bouquetiers is maintained by the Institut National de la Recherche Agronomique in St. Ghjulianu, Corsica, France, while the National Germplasm Repository in Riverside, the United States holds 45 accessions. Most other Mediterranean countries and several countries in South America also hold collections of *C. aurantium* germplasm.

Breeding No current breeding programmes are known to exist.

Prospects The importance of the various essential oils obtained from *C. aurantium* for the production of high quality perfumes and their excellent qualities for the improvement of the odour of other aroma materials guarantee the continued interest in this crop. This applies especially to the Bouquetiers, as they provide oil of the best quality. The wide adaptibility of *C. aurantium* indicated by its wide area of distribution and production justifies trialling it in South-East Asia.

Literature |1| Boelens, M.H., 1991. A critical review on the chemical composition of the Citrus oils. Perfumer & Flavorist 16: 17–34. |2| Boelens, M.H. & Jimenez, R., 1989. The chemical composition of the peel oils from unripe and ripe fruits of bitter orange, Citrus aurantium L. ssp. amara Engl. Flavour and Fragrance Journal 4: 139–142. |3| Boelens, M.H. & Oporto, A., 1991. Natural isolates from Seville bitter orange tree. Perfumer & Flavorist 16: 1–7. |4| Guenther, E., 1949. The essential oils. Vol. 3. Van Nostrand, New York, United States. pp. 197–260. |5| Hodgson, R.W., 1967. Horticultural varieties of Citrus. In: Reuther, W., Webber, H.J. & Batchelor, L.D. (Editors): The citrus industry. Vol. 1. History, world distribution, botany, and varieties. Revised Edition. University of California, United States. pp. 489–496. |6| Lin Zheng-kui, Kua Ying-fang & Gu Yu-hong, 1986. The chemical constituents of the essential oil from the flowers, leaves and peels of Citrus aurantium. Acta Botanica Sinica 28: 635–640. |7| Mondello, L.M., Dugo, G., Dugo, P. & Bartle, K.D., 1996. Italian Citrus petitgrain oils. Part 1. Composition of bitter orange petitgrain oil. Journal of Essential Oil Research 8: 597–609. |8| Swingle, W.T. & Reece, P.C., 1967. The botany of Citrus and its wild relatives. In: Reuther, W., Webber, H.J. & Batchelor, L.D. (Editors): The citrus industry. Vol. 1. History, world distribution, botany, and varieties. Revised Edition. University of California, United States. pp. 374–379. |9| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 444–459.

L.P.A. Oyen & P.C.M. Jansen

Citrus bergamia Risso & Poiteau

Hist. nat. orangers 1: 111, t. 53–56 (1819).
RUTACEAE
$2n = 18$

Synonyms *Citrus aurantium* L. var. *bergamia* (Risso & Poiteau) Wight & Arnott (1834), *C. aurantium* L. subsp. *bergamia* (Risso & Poiteau) Engler (1896).

Vernacular names Bergamot, bergamot orange (En). Bergamote, bergamotier (Fr). Indonesia: bergamet.

Origin and geographic distribution The origin of bergamot is unknown. It is said that Columbus brought it from the West Indies or Canary Islands to the Spanish town of Berga from where it was taken to Calabria in Italy, then a Spanish dependency. Others, however, have suggested that the origin must be sought in China or Turkey. Bergamot is almost exclusively grown in the narrow coastal plain of the south-western tip of Calabria in southern Italy between the towns of Villa San Giovanni and Brancaleone. Small but well established industries also exist in Ivory Coast near Sassandra and Soubré and in Guinea on the Foutah Djallon plateau. In northern Africa and Turkey bergamot is grown on a very minor scale. In South-East Asia its cultivation is not common.

Uses Bergamot is mainly grown for the essential oil present in the peel of its fruit (bergamot oil). Bergamot oil is an important component of toilet water 'eau-de-Cologne', which was first developed around 1675 in Cologne (Germany) by the Italian immigrant Gian Paolo Feminis. His relatives further developed the industry and brought it to several other cities. As a result several formulae of eau-de-Cologne were developed, all characterized by bergamot oil. Later, bergamot oil became a constituent of high quality perfumes and of men's perfumes, such as aftershaves. Bergamot oil is also a characteristic additive of Earl Grey tea and of tobacco flavourings. In the Castelli area south of Rome it is customary to put a bergamot fruit in a cask of Frascati wine to impart its characteristic aroma. The oil is further used in skin care products (bronzers), soaps, lotions and creams. A different oil is obtained from the leaves (bergamot petitgrain oil), but is only produced to order. The juice of the fruit was formerly used to prepare calcium citrate and citric acid, while nowadays it is a component of citrus soft drinks. The pulp is used as animal feed or for the extraction of pectins.

Production and international trade The production of bergamot oil is almost entirely confined to Calabria (about 3000 ha in the early 1990s); only about 5% of the total production comes from Ivory Coast and Guinea. World production was 18 000 t fruit in the 1991/1992 season yielding about 100 t oil. Production of bergamot oil has been gradually declining since the early 1980s from 100–150 t annually. Bergamot oil fetches a price of about US$ 125/kg (1997). Although the oil is highly appreciated in perfumery, production did not increase with the increasing production of perfumery goods. This may be due to the frequent reconstitution or adulteration of bergamot oil by compounding it with cheap natural or synthetic aroma chemicals.

Properties Bergamot oil is a mid-green to olive-green oil becoming yellowish or paler with age and exposure to sunlight. Its odour has a fresh citrusy top note; the body is extremely rich, sweet oily-herbal, peppery fruity and somewhat balsamic; the dry-out is dry and woody. It is characterized by a higher content of oxygenated compounds than in any other commonly encountered citrus oil. The main oxygenated compounds are linalool and linalyl acetate. The linalool content is highest at the beginning of the harvest season, after which it decreases gradually, while the linalyl acetate content exhibits an opposite trend. The content of oxygenated compounds varies from (20–)30–45(–60)%, of which on average linalool accounts for about 8% (5–15%) and linalyl acetate for about 28%. Bergamot oils from Ivory Coast have a somewhat higher linalool and linalyl acetate content than Italian oils. Bergamot oil of the best olfactive characteristics does not always contain high levels of linalool and linalyl acetate. Other quantitatively important compounds are: limonene, β-pinene and γ-terpinene. The limonene content is lower than in other citrus oils.

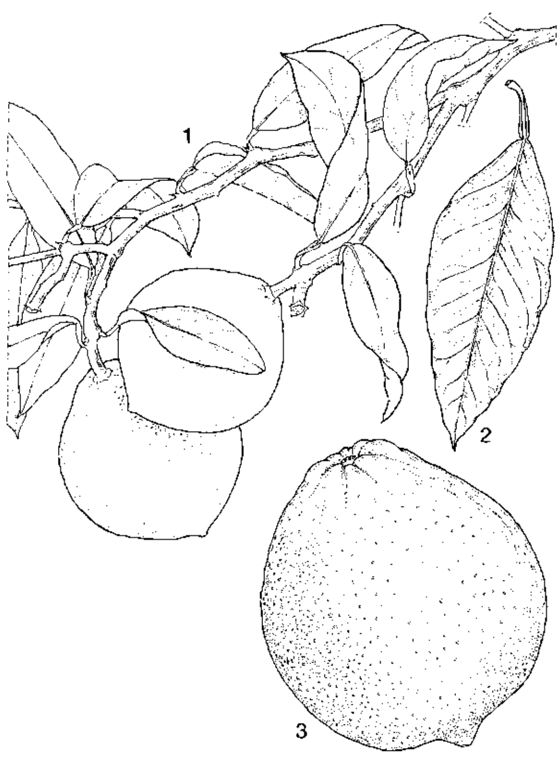
Bergamot oil is in the Food Chemical Codex. In the United States it is 'generally recognized as safe' (GRAS No 2153) and has been approved by the Food and Drug Administration (FDA) under paragraph 182.20. The maximum permitted use level in foods is 0.02% (gelatins and puddings).

Bergamot oil contains bergapten which may cause skin irritation and photosensitivity and is thus a danger in sunscreen products. Bergamot oil NS (non-sensitizing) has been developed to overcome this risk; terpeneless grades produced by vacuum distilling whole oil can also be used.

In assessing the oil quality of a crop, samples must be taken from several trees and from several positions in these trees, as there are significant differences in oil content and oil composition between fruits growing in different positions on a tree. The degree of maturity also affects the quality of oil. The marketed product is often obtained from a mixture of ripe and immature fruits, but unripe ones produce inferior quality oil. See also: Composition of essential-oil samples and the Table on standard physical properties.

Adulterations and substitutes Bergamot oil has been adulterated by cheap orange oil (d-limonene) and by the addition of synthetic linalool and its acetate. The presence of orange can be detected by the presence of small amounts (up to 0.5%) of δ-carene, a characteristic constitutent of orange peel oil. The latter adulterations can be detected because the synthetic compounds are chirally inactive and may contain impurities such as dihydrolinalool, dehydrolinalool and phenols.

Description Erect, unarmed, much branched tree up to 12 m tall, with trunk up to 25 cm in diameter; in cultivation trees are pruned up to 4–5 m in height with crown diameter of about 5 m. Leaves alternate, simple, glandular, aromatic when bruised; petiole about 13 mm long, moder-



Citrus bergamia Risso & Poiteau – 1, leafy branch with fruits; 2, leaf; 3, fruit.

ately winged, articulated near the blade; blade lanceolate, up to 12 cm × 6 cm, in upper third part weakly indented. Inflorescence terminal, racemose, many-flowered; pedicel up to 8 mm long; flowers bisexual, 4–5(–10)-merous, fragrant; calyx cup-shaped with short lobes, yellow-green; corolla 3.8 cm in diameter, most often with 5, narrow-elongate, pure-white petals without any purple tinge; stamens (13–)21(–28), in (2–)4(–6) groups, sometimes petaloid; disk nectariferous; pistil with subglobose ovary, short and thick style, distinct to indistinct stigma. Fruit a slightly flattened subglobose to pyriform berry (hesperidium), 6.5–7 cm × 6–7.5 cm, often with a small navel and a persistent style; peel 6–7 mm thick, with numerous glands, tough, smooth to rough, sometimes ridged, adherent, shiny green turning yellow when ripe; flesh yellowish, firm, very acid and bitter, divided into 8–14 segments. Seed (0–)3(–13) per fruit, flattened, 11 mm × 6 mm × 4.4 mm, pale yellow, usually monoembryonic.

Growth and development Bergamot trees develop slowly; a small harvest may be expected 7 years after planting, increasing annually to 12–15 years. Trees remain productive for 50–60 years if well maintained.

Temperatures during the first stage of fruit development and during mid-summer can greatly influence the essential oil accumulation. In Italy flowering is in March–April, fruits are harvestable in December–February.

Other botanical information *C. bergamia* is most probably of hybrid origin. It has been suggested that it is a hybrid between sour orange (*C. aurantium* L.) and lemon (*C. limon* (L.) Burm.f.), or a mutation of the latter. Others hold it as a hybrid between sour orange and lime (*C. aurantifolia* (Christm. & Panzer) Swingle). Bergamot is only known from cultivation and consists of a limited and well defined number of cultivars.

Four cultivar groups are recognized in bergamot: Common Bergamot, Melarosa (fruit rather flattened), Torulosa (fruit ridged) and Piccola (dwarf cultivars). Only Common Bergamot is commercially cultivated for the essential oil and 3 cultivars are grown: 'Castagnaro', 'Femminello' and 'Inserto'. Formerly, 'Femminello' and 'Castagnaro' constituted virtually all commercial plantings in the world, but they have largely been replaced by 'Inserto' ('Fantastico'), a hybrid of 'Femminello' and 'Castagnaro'. 'Femminello' is somewhat less vigorous and smaller than 'Castagnaro', but is earlier and more regular in bearing. Its fruit is spherical or nearly so, the rind smooth and more aromatic and hence it is preferred. 'Castagnaro' is more upright and vigorous, attaining a larger size than 'Femminello', but is less fruitful. Its fruit is roundish but frequently exhibits a short neck and obovate outline and is sometimes slightly ribbed; the rind is usually rougher and the oil usually less aromatic than in 'Femminello'. 'Inserto' is a fairly vigorous tree, that yields well and has only a slight tendency to alternate-bearing; its fruit is medium in size, averaging about 130 g with a rough rind texture.

Ecology In Calabria bergamot is grown in coastal areas protected from cold northerly winds by the nearby mountain range. The area has the highest average annual temperature and the highest number of sunshine hours in Italy and is further characterized by mild winters, a small difference between day and night temperatures and the absence of frost. The monthly average daily temperature varies between 26°C in August to 12°C in January. The average number of sunshine hours reaches a maximum of 10 h per day in July and is lowest in December and January with 3 hours per day. Average annual rainfall is about 550 mm with a maximum in December–January and a minimum in July. The soils are mainly alluvial. Although it was long thought that bergamot was adapted to a narrowly defined climate, it has proven to grow well in tropical conditions too, such as in Ivory Coast.

Oils obtained from fruits harvested in the interior of Calabria, where bergamot is not traditionally grown, show a high linalyl acetate and linalool content, but poor olfactive qualities.

Propagation and planting In Italy, bergamot is grown mainly from budded seedlings. Until the beginning of the 20th Century lime (*C. aurantifolia*) was used as rootstock because it combined a high yield of essential oil of high quality with a short juvenile period. Nowadays sour orange (*C. aurantium*) is the only rootstock used. Rootstocks are grafted at a height of 60–70 cm. Planting distances range from 4 m × 4 m in the oldest groves in Italy to 5 m × 5 m or 6 m × 4 m in younger ones. Plantations are generally intercropped initially, to reduce establishment costs.

Husbandry Young trees of bergamot are trained from 90–120 cm above ground level to produce a vase with 3–4 branches. Pruning is usually done every 2–3 years, only occasionally annually. In Calabria it is done in February after harvesting. The operation requires skilled labour to maintain each tree in a good shape. Weed control is usually done manually, though the use of herbicides is becoming more frequent. In older plantations on sloping land a grass cover is often maintained to control erosion. Ring weeding is then often practised, to reduce damage by diseases and pests. Irrigation is mostly by overhead sprinklers, but in the oldest groves basin irrigation is still practised. The amount of irrigation water applied annually in Italy is about 600 mm/ha. The amount of fertilizer applied and its timing varies from place to place and from farmer to farmer.

Diseases and pests Little is known about diseases and pests affecting bergamot. Apart from diseases and pests attacking citrus in general, it is particularly sensitive to stylar end rot, a physiological disease affecting the fruit.

Harvesting In Italy, fruits of bergamot are picked during winter (November–February) when the peel has turned yellowish and the fruit is fully grown but still unripe. Manual harvesting is still common, but tree shakers are occasionally used where possible. After picking, fruits are kept in the shade and quickly transported to the factory for processing.

Yield The average annual fruit yield of bergamot in Italy is less than 12 t/ha with an essential oil yield of about 0.55%. In well-managed plantations yield per tree may reach 200–300 kg of fruit, yielding on average 300–600 g oil.

Handling after harvest In Italy, bergamot oil is almost exclusively obtained by the 'Pelatrice' method, only a small amount is still produced by the traditional 'Calabrese' process. In the 'Pelatrice' process the essential oil is obtained by rasping the rind of whole fruits to cause the oil glands to break and release the oil. To remove the oil, rasping is done under water sprayers. The oil is extracted from the water by centrifugation. The residual peel is subsequently distilled, yielding a 'distilled essence' of slightly lower quality. The 'Calabrese' method is a 'sponge process', which gives low yields and requires much labour.

Genetic resources and breeding No extensive germplasm collections and breeding programmes for bergamot are known to exist.

Prospects Selection of cultivars of bergamot with a lower content or free of the toxin bergapten is important to improve the quality of the essence. Replacing the oldest groves with newly planted ones could increase yields and reduce production costs. However, the lack of relevant information on cultural practices, e.g. propagation, training, nutrition, irrigation, pest control and harvesting holds down production, therefore research in these fields is urgently needed. The growing interest in natural essential oils and the success of bergamot in tropical Africa justifies research into its suitability for South-East Asia.

Literature |1| Barone, E., Bounous, G., Gioffre, D., Inglese, P. & Zappia, R., 1988. Survey and outlook of bergamot (Citrus aurantium subsp. bergamia Sw.) industry in Italy. In: Goren, R. & Mendel, K. (Editors): Citriculture. Proceedings of the 6th International Citrus Congress, Middle East, 1988. Margraf Publishers, Welkersheim, Germany. pp. 1603–1611. |2| Chapot, H., 1962. Le bergamotier [The bergamot tree]. Al Awamia 5: 1–27. |3| Hodgson, R.W., 1967. Horticultural varieties of citrus. In: Reuther, W., Webber, H.J. & Batchelor, L.D. (Editors): The citrus industry. Vol. 1. University of California, Division of Agricultural Sciences, Berkeley, United States. pp. 489–494. |4| Huang, Y.Z., Chen, S.Q., He, C.Y., Chen, Q.Y. & Wu, Y.L., 1990. A study of chemical components of essential oils from Citrus bergamia and its close relatives and its taxonomy. Acta Phytotaxonomica Sinica 30: 239–244. |5| Huet, R. & Dupuis, C., 1967. L'huile essentielle de bergamote en Afrique et en Corse [The essential oil of bergamot in Africa and Corsica]. In: Essential oil production in developing countries. Tropical Products Institute, London, United Kingdom. pp. 79–95. |6| Mosandl, A. & Juchelka, D., 1997. Advances in the authenticity assessment of citrus oils. Journal of Essential Oil Research 9: 5–12. |7| Swingle, W.T. & Reece, P.C., 1967. The botany of Citrus and its wild relatives. In: Reuther, W., Webber, H.J. & Batchelor, L.D. (Editors): The citrus industry. Vol. 1. University of California, Division of Agricultural Sciences, Berkeley, United States. pp. 190–430. |8| Tanaka, T., 1954. Species problem in Citrus: a critical study of wild and cultivated units of Citrus, based upon field studies in their native homes. Revisio aurantiacearum 9. Japanese Society for the Promotion of Science, UENO, Tokyo, Japan. p. 112. |9| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 459–464.

Sumeru Ashari

Clausena anisum-olens (Blanco) Merrill

Bur. Gov. Lab. (Publ.) 17: 21 (1904).

RUTACEAE

$2n = 18$

Synonyms *Cookia anisum-olens* Blanco (1837), *Clausena laxiflora* Quis. & Merrill (1928), *Clausena sanki* (Perr.) Molino (1994).

Vernacular names Philippines: anis, kayumanis (Tagalog), danglais (Bagobo).

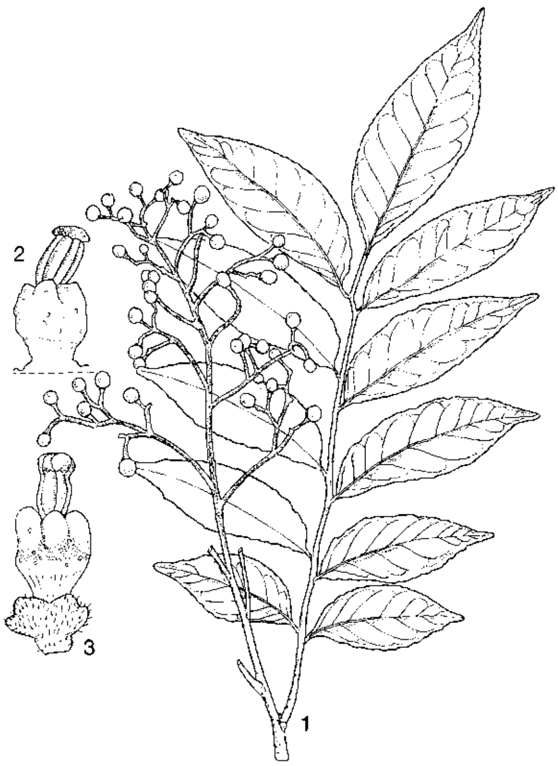
Origin and geographic distribution *C. anisum-olens* is endemic to the Philippines and Borneo. In the Philippines it is distributed all over the archipelago and is also cultivated occasionally. It is sporadically cultivated in gardens in China, Taiwan, Vietnam and Indonesia. In China (Guangxi, Guangdong, Yunnan) it seems to occur naturalized as well.

Uses In the Philippines leaves of *C. anisum-olens* are used as a condiment in preparing local dishes and beverages and to flavour cigarettes. The essential oil from the leaves is a potential substitute of anise oil, e.g. for the preparation of the Philippine drink 'Anisado'. It is also well known in traditional medicine in the Philippines: the leaves are stuffed into pillows for a soporific effect, they are used in baths against rheumatism, or in decoction for nausea during pregnancy. Cough with fever is treated with a decoction of the roots and fruit.

Production and international trade *C. anisum-olens* is of local importance only and is not traded internationally. Production and trade statistics are not available.

Properties On steam distillation or alcoholic extraction, the leaves of *C. anisum-olens* yield 1–3.5% essential oil. The oil is a mobile pale-yellow liquid with an odour similar to that of star-anise oil. The physical characteristics of an oil distilled in Java are: specific gravity (26°C/4°C): 0.96, optical rotation: −0.1°, refractive index (30°C): 1.56. The chemical composition of the oil varies among individual plants from almost pure methyl chavicol (estragol) to almost pure anethol. A minor component is anisaldehyde.

Description Evergreen shrub or small tree, 2–6(–15) m tall, bearing essential-oil glands on all aerial parts which emit a strong anise or anise-like smell when crushed. Leaves alternate, imparipinnately compound, 20–55(–100) cm long, glabrous to villose; petiolules 1–5 mm long; leaflets 7–13(–19), alternate to subopposite, ovate to lanceolate, 3–25 cm × 1–10 cm, the largest ones near the apex, base oblique, margin undulate-crenulate, apex acute-acuminate, densely dotted with pellucid glands. Inflorescence a terminal (rarely axillary), conical panicle, 6–40 cm long; pedicel up to 2 mm long; flowers globose in bud, when opened 6–8 mm in diameter, regular, 5-merous, fragrant; calyx 5-lobed, 0.5–1 mm long, green; petals 5, free, ovate-elliptical, 4–5 mm long, membranaceous, whitish-green; stamens 10, free, filaments geniculate, white, anthers yellow; ovary globose to somewhat pentagonal, about 1 mm long and wide, 5-locular, born on gynophore 0.3–0.5 mm long, style 1 mm long, stigma slightly 5-lobed. Fruit a globose (rarely ovoid) berry, 0.8–1.6 cm in diameter, whitish-green turning pinkish at maturity, 1(–3)-seeded. Seed green.



Clausena anisum-olens (Blanco) Merrill – 1, branchlet with immature fruits; 2, pistil (var. anisum-olens); 3, calyx and pistil (var. mollis (Merrill) Molino).

Growth and development No data are available on growth and development of *C. anisum-olens* in its natural habitat. In the Bogor Botanical Garden cultivar Clausanis produced only few viable seeds and seedlings grew slowly, attaining barely 3 m height in 3 years. Better results were obtained when 'Clausanis' was grafted on *Clausena excavata* Burm.f.: in 2 years a height of 4.5 m was reached. *C. excavata* is widespread in most parts of South-East Asia; it flowers year-round, so seed is always available and seedlings can be grafted when they are 6–12 months old. Healthy plants of *C. anisum-olens* including those grafted on *C. excavata* tolerate pollarding fairly well. Weak plants, however, suffer severe setback from low pollarding, especially when cut back to less than 50 cm in height.

Other botanical information *C. anisum-olens* (Blanco) Merrill is formally invalidated by *Clausena sanki* (Perr.) Molino (based on *Illicium sanki* Perr. (1824), a name that antedates the basionym *Cookia anisum-olens* Blanco of 1837). In order to avoid an unnecessary name change, it has been proposed that *Illicium sanki* Perr. be rejected, also because it is based on material of 2 different species.

C. anisum-olens is subdivided into 3 botanical varieties:

- var. *anisum-olens*: distributed as the species, except Borneo; whole plant subglabrous; leaves up to 50 cm long with 7–13(–15) leaflets; fruit globose, up to 1 cm in diameter;
- var. *calciphila* (B.C. Stone) Molino: synonym: *C. calciphila* B.C. Stone; occurring in Borneo (Sarawak and Kalimantan); whole plant subglabrous; leaves up to 1 m long with 11–19 leaflets; fruit ovoid, 1.5–1.6 cm × 1–1.1 cm;
- var. *mollis* (Merrill) Molino: synonym: *C. mollis* Merrill; occurring in the Philippines (Luzon, Mindanao); almost whole plant densely golden-yellow pilose; leaves with 11–15(–19) leaflets.

All information about uses and essential oil content refer to var. *anisum-olens* only. Data on cultivation refer to only a single cultivar of this variety: 'Clausanis'. 'Clausanis' developed from plants collected in the Philippines in 1820 that were subsequently taken to Réunion Island and Paris. From Réunion a few plants were taken to the Botanical Garden in Bogor. There, through cultivation and successive self-pollination it developed its typical character: a very short and asymmetrical style, an unusual feature in *Clausena* Burm.f. 'Clausanis' has been cultivated and studied from 1905 onwards in Bogor as *C. anisata*. However, *C. anisata* (Willd.) Hook.f. ex Benth. (synonyms: *C. dentata* (Willd.) M. Roemer, *C. dunniana* A. Léveillé) is a related, but completely different species occurring in tropical and southern Africa, southern India and from Bangladesh to southern China and Thailand. It has only axillary inflorescences. Its leaves yield an essential oil very rich in anethol and similar to the oil of *C. anisum-olens*.

Ecology *C. anisum-olens* grows naturally in the understorey of rainforest, on various soil types (including limestone), up to 1500 m altitude. In cultivation in Indonesia it only performed well up to 500 m altitude. In Solok (west-central Sumatra) it grows well with 2000 mm annual rainfall with maxima in March and November and a minimum of about 75 mm per month from June to August, with maximum temperatures of about 30°C and minima of about 20°C throughout the year, and on poor, acid (pH 4.0–4.2) soils.

Propagation and planting 'Clausanis' produces very little seed and is propagated vegetatively. Grafting 'Clausanis' on a rootstock of *C. excavata* is the easiest and most efficient way of propagation. Other rutaceous rootstocks (*Citrus* spp., ×*Citrofortunella* spp.) have also been tested, but gave poorer results. Propagation by cuttings proved to be very difficult, as it requires constant high temperatures (above 23–25°C) and adequate soil moisture. Budding onto *C. excavata* has given poor results. In vitro propagation of 'Clausanis' has also been tested in Bogor, with promising preliminary results.

In Solok, densities of 10 000–15 000 plants/ha have given good results; earlier about 3000 plants/ha had been recommended in Java.

Husbandry In Solok, plants of 'Clausanis' grafted on *C. excavata* are pruned back to a height of about 1 m once or twice a year after harvest. If this pruning process starts early, it leads to the formation of a flat-topped, sometimes bushy shrub, from which leaves can be picked easily from above (as in tea plantations).

Harvesting At high planting densities, all leaves of *C. anisum-olens* above 0.8–1 m can be plucked 2–4 times per year. Trees should be maintained at about 1 m height by means of post-harvest prunings. Frequency and timing of harvests should be guided by the rate of regrowth and depend on the availability of water. When water and nutrient requirements are met, leaf production is highest under unshaded conditions. The first harvest can be 1 year after grafting on 2–4-year-old rootstocks.

Yield The first year, a single harvest amounts to 0.6–1 kg leaves per tree. In the second year 1.7–2.2 kg are collected in two harvests. In subsequent years a tree yields 2.5–4 kg leaves annually, independent of the frequency of harvesting.

Handling after harvest After harvesting the leaves it is recommended to extract the oil as soon as possible. Fermentation of the leaves should absolutely be avoided because it leads to production of unpleasant notes in the essential oil. If necessary, it is possible to store the leaves for 2–3 days in a properly ventilated room where they may slightly dry without fermentation. A too strong desiccation would lead to a severe loss of the oil by evaporation, either directly through the thin walls of the pellucid glands or by crumbling them during handling of the fragile dried leaves. Essential oil is mostly extracted from the leaves by steam distillation. Distillation for 4–5 hours in a still with a 120 kg capacity yields more than 90% of the total essential-oil content. Prolonged distillation would negatively affect the quality of the oil. Oil yield is 1.6–2 kg oil from 100 kg fresh leaves. Preliminary estimates for production of essential oil per ha suggest that yields of 350–750 kg per year may be possible.

Genetic resources and breeding Little is known about wild representatives of *C. anisum-olens* from the Philippines. They may be more vigorous, have a higher growth rate, produce more seed and have a higher essential-oil content than 'Clausanis', and could be used for breeding and genetic improvement. However, no germplasm collections or breeding programmes are known to exist.

Prospects The essential oil from the leaves of *C. anisum-olens* has potential use as a cheap source of natural anethol. It could compete not only with star-anise and anise oils in food, beverage and pharmaceutical industries, but also with semi-synthetic anethol, a by-product of the turpentine-oil industry in the United States, in soaps, detergents and cosmetics.

Literature |1| Brown, W.H., 1941 (reprint 1954). Useful plants of the Philippines. Vol. 2. Department of Agriculture and Natural Resources. Technical Bulletin 10. Bureau of Printing, Manila, the Philippines. pp. 227–231. |2| Molino, J.-F., 1993. History and botany of Clausena anisum-olens (Blanco) Merr. Cv. 'Clausanis' (Rutaceae), a promising essential oil crop plant. Acta Horticulturae 331: 183–190. |3| Molino, J.-F., 1994. Révision du genre Clausena Burm.f. (Rutaceae) [Revision of the genus Clausena Burm.f. (Rutaceae)]. Bulletin du Muséum National d'Histoire Naturelle, Section B, Adansonia 16: 105–153. |4| Molino, J.-F, 1995. Proposal to reject Illicium sanki Perr., a threat to Clausena anisum-olens (Blanco) Merr. (Rutaceae). Taxon 44: 427–428. |5| Quisumbing, E., 1951. Medicinal plants of the Philippines. Katha Publishing Co., Manila, the Philippines. pp. 456–457. |6| Toxopeus, H.J., 1950. Clausena anisata. In: van Hall, C.J.J. & van de Koppel, C. (Editors): De landbouw in de Indische Archipel [Agriculture in the Indonesian Archipelago]. Vol. 3. W. van Hoeve, the Hague, the Netherlands. pp. 719–722. |7| Wiersum, L.K., 1949. Enige gegevens voor een mogelijke cultuur van Clausena [Some data on a possible cultivation of Clausena]. Landbouw (Buitenzorg) 21(9): 445–455.

J.-F. Molino

Corymbia citriodora (Hook.) K.D. Hill & L.A.S. Johnson

Telopea 6: 388 (1995).
MYRTACEAE
$2n = 22$

Synonyms *Eucalyptus citriodora* Hook. (1848), *E. melissiodora* Lindley (1848), *E. maculata* Hook. var. *citriodora* (Hook.) Bailey (1900).

Vernacular names Lemon-scented gum, spotted gum, lemon-scented iron gum (En). Thailand: yukhalip. Vietnam: b[aj]ch d[af]n d[or], b[aj]ch d[af]n chanh.

Origin and geographic distribution *C. citriodora* is endemic to Queensland (Australia). It occurs mainly in the region from north-west of Maryborough to north of Rockhampton and west for up to 400 km. There are also extensive stands on the tablelands inland between Mackay and Cairns, and an occurrence west of the Great Dividing Range north of Hughenden.

C. citriodora has been extensively planted as an ornamental tree in many regions of the world, and has been planted for commercial purposes in South America, especially Brazil (6 million trees), southern China, India, Sri Lanka, Congo (Zaire), Kenya and most countries in southern Africa and in Fiji. In South-East Asia it is mainly planted in Peninsular Malaysia. In Thailand it was introduced in 1949, but commercial plantations no longer exist.

Uses The pleasant, lemon-scented essential oil from the leaves of *C. citriodora* is widely used in less expensive perfumes, soaps and disinfectants. It has antibacterial and insecticidal activity. The citronellal-rich oil is a preferred natural source for the production of hydroxycitronellal, citronellylnitrile and menthol. Hydroxycitronellal is one of the most widely used of all perfumery materials. Other minor constituents recovered during fractionation of the essential oil, such as citronellol, are also used by the fragrance industry.

The timber of *C. citriodora* is used for general and heavy construction such as frame and bridge construction, flooring, cladding, tool handles and case manufacturing. The wood of young trees has been successfully used for certain grades of pulp and paper, but wood from old trees is generally not suitable because of its high extractive content and high density. Young trees or coppice stems produce straight poles or posts which can be pressure impregnated with preservatives for many industrial purposes. In Brazil large plantations have been established for charcoal production.

C. citriodora is widely used in park and avenue plantings as an attractive, large ornamental noted for its bark colour, straight trunk, branching habit and glossy leaves. However, its crown is too sparse for shelter-belts. It is a source of nectar and pollen in apiculture and gives a light amber honey.

Production and international trade Estimates of annual world production of *C. citriodora* indicate that in 1991 only three countries produced substantial quantities of this oil: China with 900–1100 t, Brazil with 400–600 t and India with 50 t. About 400 t are exported annually from China; Brazil exports about half of its annual production. The oil is no longer produced to any extent in Australia. *C. citriodora* oil was priced at US$ 6/kg by dealers in New York in May 1997.

Properties Commercial essential oils of *C. citriodora* are colourless to pale yellow with a strong, very fresh rosy-citronella scent and a sweet balsamic-floral dry-out. They consist principally of citronellal and other monoterpenes including citronellol, neral, isopulegols and smaller amounts of 1,8-cineole, linalool, geraniol, α-terpineol, γ-cadinene and β-caryophyllene. Oils are assessed on their odour characteristics and the portion of citronellal in the total aldehyde content. Producers of hydroxycitronellal prefer the higher citronellal levels.

At least four chemical forms are recognized in the natural stands of *C. citriodora* in Australia; their citronellal contents range from 1% to 91%. In addition to the form yielding citronellal-rich (65–91%) 'type' oils, there are: a 'var. A' form yielding oils containing citronellol (about 50%) and citronellal (1–14%), an 'intermediate form' with citronellal (20–50%) and guaiol, and a 'hydrocarbon form' with citronellal (<10%) and hydrocarbons. The presence of such diverse chemotypes in nature may, in part, account for the substantial variation in citronellal content between oil batches from different regions where *C. citriodora* is cultivated. See also: Composition of essential-oil samples and the Table on standard physical properties. Myrtillin, found in the leaf extract, is reported to induce temporary hypoglycemia. Other compounds reported from the leaves include several fatty acids (including shikimic acid), flavonoids and sterols.

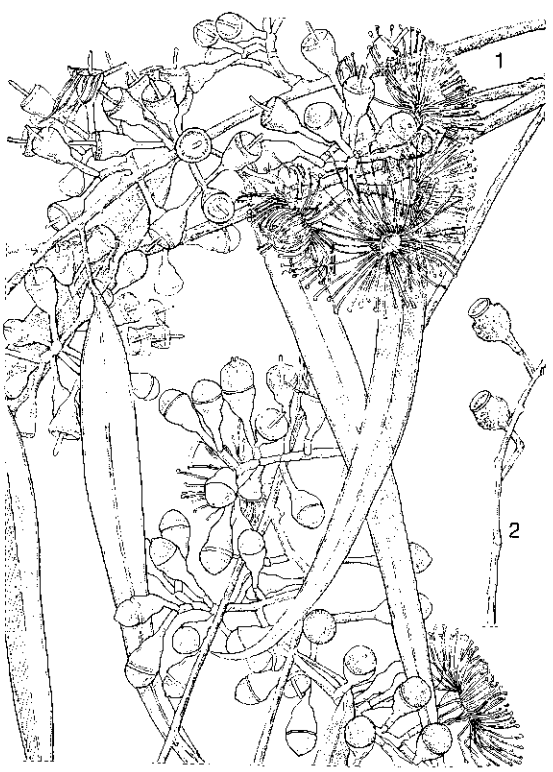
A monograph on the physiological properties of the essential oil has been published by the Research Institute for Fragrance Materials (RIFM). An exudate from the bark contains citriodoral, a compound with antibiotic properties. The bark also contains about 10% tannin.

The wood of *C. citriodora* has a white or cream sapwood up to 60 mm wide and is very susceptible to *Lyctus* borer attack; the heartwood is pale grey-brown to dark brown. The sapwood is permeable but the heartwood extremely resistant to preservative treatment. The grain is straight or interlocked and occasionally wavy, the texture open and coarse. The timber is hard, strong and tough. Air-dry density of wood from natural stands is about 1000 kg/m^3 (12% moisture) with basic density of 800 kg/m^3. It saws easily, planes well, but is rather difficult to nail and prone to checking and collapsing during drying. The timber is susceptible to marine borer and termite attack. Chemical pulp of reasonable quality can be obtained from wood of young (9-years-old) trees.

There are about 109 000 viable seeds/kg seed and chaff mix.

Adulterations and substitutes Both citronellal and the derived hydroxycitronellal are produced from two other sources, citronella oil from the citronella grasses (*Cymbopogon nardus* (L.) Rendle and *C. winterianus* Jowitt) of Sri Lanka and Indonesia, and turpentine. Price and the slight odour differences caused by accompanying minor constituents determine customer preference. Natural citronellal has a marketing advantage over synthetic, turpentine-derived citronellal, especially in flavour applications.

Description Medium to large, often straight stemmed tree, 25–40(–50) m tall, of handsome appearance, with pale grey, cream or pink powdery bark, smooth throughout, decorticating in flakes, and somewhat sparse foliage. Twigs slender, slightly flattened, light green, tinged with brown. Leaves petiolate, strongly lemon-scented when crushed; seedling leaves opposite for a few pairs then alternate, peltate, ovate, 6.5–17 cm × 2.3–7.5 cm, pale green, slightly discolorous, setose; juvenile leaves alternate, ovate to broad-lanceolate, up to 14–21 cm × 4.5–8 cm, in some plants setose, pale green and peltate for many pairs, in others becoming glabrous and glossy green soon after the seedling stage; stems, petioles and leaves setose with bristle glands up to 0.5 cm long in both the seedling and juvenile stages; intermediate leaves petiolate (up to 2.2 cm), disjunct, broad-lanceolate, 13–30 cm × 2–5 cm, apex acute to obtuse; adult leaves on flattened petioles 13–22 mm long, disjunct, lanceolate to narrow-lanceolate, 7–22 cm × 0.5–2.2 cm, concolorous, very glossy, green, venation very densely reticulate with numerous large island oil glands, lateral veins just visible, at 35°–50°, intramarginal vein distinct, up to 1 mm from margin, stomata on both surfaces. Inflores-



Corymbia citriodora (Hook.) K.D. Hill & L.A.S. Johnson – 1, flowering and fruiting branches; 2, branchlet with ripe fruits.

cence an umbelliform condensed and reduced dichasium (usually called a conflorescence), combined into clustered terminal or sometimes axillary, corymbose panicles; peduncle terete, 3–8 mm long; umbels 3-flowered; pedicel 1–6 mm long; buds pedicellate, clavate, up to 10 mm × 6 mm, scar absent; operculum hemispherical, 3–4 mm long, 4–5 mm wide, apiculate; flowers creamy-white; hypanthium hemispherical, 5–6 mm × 4–5 mm; stamens numerous, prominent, 6 mm long, spreading 12 mm across, all fertile with subulate filaments and oblong, dorsifixed anthers dehiscing by parallel slits; pistil inferior with 3-celled ovary. Fruit a capsule, truncate-ovoid to urceolate, 8–15 mm × 7–11 mm, brown, often warty, 3-locular; disk about 2 mm wide. Seed dorsiventrally compressed, 2–3 mm × 1.5–2.5 mm, glossy red-brown, with a median dorsal keel. Seedling with epigeal germination.

Growth and development Lignotubers develop early in the life of *C. citriodora* seedlings. As in other eucalypts no dormant buds develop and trees will grow whenever conditions are favourable. *C. citriodora* grows rapidly during its early years. In Congo trees reached a mean height of 13 m in 4 years. In southern China it can average 2.5–3.7 m growth in height per year and reach a diameter at breast height of 25 cm in 5 years. In fuelwood trials in southern Nepal, *C. citriodora* reached 5 m in 3 years from planting. A mean annual height increment of 2 m can be attained in southern Africa over the first 5 or even 10 years. Trunk form varies from straight to sinuous; frequent forking and sparse foliage are less satisfactory crown characteristics. Flowering usually starts within 2 years after planting and seeds are produced abundantly by 5 years of age. Pollination is mainly by insects but also by birds and small mammals. Flowering in natural stands in Australia has been observed in all months of the year with a peak during April–June. The main seed collection months are September through January with seedfall timed to coincide with the rainy season. In wild stands it is often difficult to obtain good seed crops; in contrast, plantations often have abundant seed crops. In Thailand the optimum time for seed collection is April.

Other botanical information *C. citriodora* belongs to the spotted gums, part of the bloodwood group of eucalypts. Under the informal classification of Pryor and Johnson (1971), *C. citriodora* (as *Eucalyptus*) was placed in the series *Maculatae* of the subgenus *Corymbia* of *Eucalyptus*, along with its close relatives *E. maculata* Hook. and *E. henryi* S.T. Blake. Hill and Johnson (1995) have placed the bloodwoods in a new genus *Corymbia* K.D. Hill & L.A.S. Johnson. Under this classification, which is adopted here, *Eucalyptus citriodora* becomes *Corymbia citriodora* of the series *Maculatae* and section *Politaria*. Four closely related species are recognized in this section: *C. citriodora*, *C. maculata* (Hook.) K.D. Hill & L.A.S. Johnson, *C. henryi* (S.T. Blake) K.D. Hill & L.A.S. Johnson and a new species *C. variegata* (F. v. Mueller) K.D. Hill & L.A.S. Johnson. The latter one was reinstated from synonymy, to cater for the populations in northern New South Wales and south-eastern Queensland that are morphologically intermediate between *C. citriodora* and *C. maculata* and whose leaves are not lemon-scented. In regions where the distributions of *C. citriodora* and *C. variegata* overlap intergrading populations occur with a gradient in the amount of citronellal in the leaves.

Hybrids between *C. citriodora* and *C. torelliana* (F. v. Mueller) K.D. Hill & L.A.S. Johnson have appeared spontaneously in Australia, India, Nigeria and Papua New Guinea, and have been created artificially in India. Hybrids with other *Corymbia* spp. are also found occasionally.

Ecology The climate in the natural range of *C. citriodora* is warm humid to warm subhumid. Temperature varies from the higher rainfall, coastal areas to the drier inland locations. In the wetter sites the mean maximum temperature of the hottest month is about 30–32°C and the mean minimum of the coldest month about 9–12°C; for inland locations the corresponding values are 34–36°C and 5–10°C. Light frosts may occur at higher elevations. The mean annual rainfall is about 650–1600 mm with a well developed summer maximum, most distinct in the north. Late winter and spring are dry. Climatic requirements for *C. citriodora* derived from both its natural distribution area and the sites where it grows well as an exotic are estimated to be: mean annual temperature 17–28°C, mean maximum temperature hottest month 28–39°C, mean minimum temperature coldest month 8–22°C, absolute minimum temperature over −3°C, mean annual rainfall 650–2500 mm and a dry season (i.e. less than 40 mm/month) of 0–7 months. Although it originates from summer rainfall zones it can also grow successfully in locations with a winter rainfall or uniform rainfall distribution pattern.

In its original habitat *C. citriodora* occurs mostly on poor gravelly soils, podzols and residual podzols of lateritic origin, usually well drained and undulating. Other stands occur on deep red loams, hard gravelly clays and on sandstone-derived soils. In Sao Paulo (Brazil) it grows well on lateritic soils, in Congo (Zaire) excellent growth is obtained on rich volcanic and young alluvial soils, while in India it is grown on various soils ranging from fertile loams to poor acid sands. It is not very tolerant of waterlogging.

Propagation and planting Seedlots of *C. citriodora* vary in germination rate but usually average 30–50%. Rapid and complete germination is achieved under moist, warm conditions (25–30°C is optimal in the laboratory) in the presence of light. In seed tests a leachate from the seed has been found to inhibit germination on filter paper. Direct seeding into carefully prepared ground has been successful in southern Africa, but is unreliable and not generally recommended, as favourable weather and freedom from weeds are critical to success. Containerized planting stock is preferred, because bare-rooted seedlings tend to show poor lateral root development and losses due to transplanting shock. The seeds are relatively large for a eucalypt and can be sown directly without pretreatment into containers filled with a sterilized freely draining mixture of loam and sand and covered with a light sprinkling of fine sand. *C. citriodora*, like other eucalypts, is highly susceptible to damping-off and other fungal pathogens in the nursery. Disease problems can be limited by good hygiene, reducing watering and shade, and allowing good ventilation. Seedlings are planted out in the field when they reach a height of about 25 cm, 10–12 weeks after sowing. This should coincide with the onset of the rainy season in tropical countries. *C. citriodora* can be multiplied vegetatively by micropropagation, but so far this technique has only been applied experimentally. Propagation by cuttings is very difficult. Intensive site preparation by ploughing is beneficial; on compacted soils deep ripping may also be used. Spacing varies, depending on the purpose of the plantation. When grown solely for oil production with frequent coppicing, 3 m × 1.5 m (2222 plants/ha) is appropriate. For fuelwood, poles or charcoal production with harvesting cycles of 7 years, a spacing of 3 m × 2 m (1667 plants/ha) is common. Several planting arrangements have shown favourable economic returns in India: block plantings at 1 m × 1 m spacing in a farm forestry programme; planting along bunds at 1–2 m spacing in an agroforestry programme; and interplanting essential oil-yielding grasses (*Cymbopogon* spp.) with *C. citriodora* at 2–3 m × 2 m spacing in a social forestry programme, to obtain essential oil as well as fuelwood and pole wood.

Husbandry The ability of young *C. citriodora* to compete with weeds is so poor that inadequate weed control may lead to the complete failure of a planting. Mechanical and manual cultivation are the most common means of control. *C. citriodora* has a strong self-pruning ability and is only hand pruned when leaves are harvested for oil production. Light demand is high and frequent and regular thinning is a prerequisite for healthy, vigorous plantations. In China, where it is grown principally for poles and fuelwood on 20 year rotations, thinning is prescribed at ages 3–5, 7 and 10–12; the first thinning reduces the initial stocking rate from 4000 to 2000 stems/ha; the two additional thinnings reduce the final stocking rate to 900 stems/ha. A handy indicator of growth stagnation and the need to undertake the first thinning has been developed in Brazil, based on measurements of the outer rows of a plantation. The first thinning should be carried out when the mean diameter of the trees in the second row exceeds that of the trees in the third row by 10% or more.

Plantations are not normally irrigated but good results have been achieved in trials in Pakistan, where irrigated *C. citriodora* intercropped with such crops as wheat, maize, berseem (*Trifolium alexandrinum* L.) and sesame (*Sesamum orientale* L.) grew to 16.4 m in height with a diameter at breast height of 17.7 cm at 7 years.

Although organic or chemical fertilizers are rarely used, fertilizer application on sites of very low soil fertility may be necessary to increase productivity. For example, in the savanna (cerrado) region of Brazil, application of 100–150 g of an NPK mixture (10-28-6) per plant regardless of soil type or time of planting used to be standard practice for *C. citriodora* and other eucalypts. Today a blend of several macro- and micro-nutrients is applied, depending on the nutritional status of coppice leaves from a particular site. A microcomputer programme has been developed to assist in determining the optimum treatments. When planted on sites with severe water deficit (more than 4 months of drought), *C. citriodora* is very sensitive to boron deficiency and application of 1.0–1.5 g B per plant reduces dieback and increases volume growth up to 30%. The effect of fertilizers on oil production has given variable results, sometimes increasing production but often giving no response.

Diseases and pests Within Australia *C. citriodora* has remained relatively free of diseases and pests. In Brazil, it has been damaged sometimes by a range of diseases including: damping-off and leaf spot caused by *Cylindrocladium* spp., a rust (*Puccinia psidii*), and a stem canker (*Cryphonectria cubensis*). Gummosis and cankers from infection by *Endothia havanensis* have also been noted. In China, gummosis induced by *Cytospora* sp. and *Macrophoma* sp. has caused severe damage. In India, it is susceptible to a range of diseases including: *Cylindrocladium* seedling blight, a rust (*Melampsora* sp.), pink disease (*Corticium salmonicolor*), and *Ganoderma* root rot. The root rot fungus *Pseudophaeolus baudonii* attacked plantings of *C. citriodora* in Sege (Ghana), causing 50% mortality over 3 years. Most problems arise on sites with high rainfall and humidity. Prevention is the best cure, so appropriate nursery techniques should be applied and planting sites should be selected carefully.

C. citriodora is very susceptible to termites. In India, *Microcerotermes minor* can cause 20–30% mortality and *Odontotermes horni* over 10%. Use of dangerous pesticides such as dieldrin, aldrin and chlordane for the protection of seedlings against termites has been phased out in most countries. Carbosulfan, a non-persistent carbamate insecticide, is being used as an effective replacement in several African countries. A range of defoliating insects and a stem borer (*Apate indistincta*) have been noted as causing occasional damage to plantations.

Harvesting Optimum rotation length for plantations of *C. citriodora* depends on site, management and end products required. In southern China and Brazil, the rotation length for plantations for roundwood, fuel and citronellal oil production is 20–21 years, after which time the clear-felled areas are replanted. However, there are numerous plantings elsewhere that are much older and are regularly harvested for oil and wood. Elsewhere in Brazil, the initial seedling crop is commonly harvested for wood in the 7th year after planting, yielding 110 m^3/ha. The harvest is followed by two coppice harvests at 7-year intervals yielding 120 m^3/ha and 88 m^3/ha of wood respectively. The best time of the year for harvesting the seedling crop is in the winter or dry season. The development of new growth from buds on the stump begins shortly after harvest and within 10 months several shoots have become dominant. At this point, rigorous thinning to 2–3 stems per stump is carried out.

When *C. citriodora* is grown principally for oil production the aim is to maximize the yield of oil per ha and to minimize harvesting costs or, as most harvesting is done by hand, to minimize the cost of labour. In Brazil the smaller branches are cut from the stem 18 months after planting. This is repeated every 6 months or so, until the branches are too high to be reached (after about 3 years). The stem is then cut at about knee height and 2–3 stems are allowed to grow over a period of about 12 months, when the harvesting cycle is repeated. A cutting height of 0.8 m gave greater oil production than a 0.4 m cutting height after an initial harvest at 2 years in Taiwan, but other reports indicate that coppicing gives higher yields than pollarding. Most *C. citriodora* oil produced in India comes from smallholders who harvest at irregular times depending on convenience and oil prices. In north-western India, major harvests are undertaken in April and November with a supplementary cut in July if regrowth has been vigorous. Although 2–3 harvests per year may give maximum yields, harvesting once a year is often most profitable. Overcutting may also have an adverse effect on tree longevity. In China, tall trees in wood-producing plantations are climbed, and all but the very top foliage is removed for oil production in small roadside stills. Many factors influence oil yield, including seasonal differences. Harvesting in February, April, July and October gave maximum yields at Kodaikanal in India, while February and November are the best months to harvest in Cuba. Local experimentation should be undertaken to determine the optimum time to harvest on a particular site.

Yield Reports of concentration of essential oil in fresh leaves of *C. citriodora* vary from 0.5–5.0%, but mainly fall within the range of 1–3%. Oil content and citronellal content in that oil are greatest in young leaves (4 months) and both decline with leaf age. The reduction in oil content and citronellal content from 4–9 months is significant but is offset by an increase in leaf numbers over this period. Coppiced trees give 2–5(–10) kg of leaves per tree annually. Theoretically, therefore, an annual harvest of 1 ha of coppiced plantation (2000 stems/ha) would yield about 150 kg of oil. Mature trees yield 300–500 kg of leaves when felled for timber.

Mean annual increments in wood production of 15 m^3/ha have been recorded in China and Brazil with a maximum of 25 m^3/ha achieved on some sites in China. In the Guinea zones of Nigeria mean annual increments of 9.2–14.7 m^3/ha have been reported.

Handling after harvest Extraction of oil from *C. citriodora* leaves is done by water or steam distillation. Foliage from the harvesting operation should be distilled either the same day or the following day. Evidence suggests that both oil yield and aldehyde content of the oil decline rapidly after harvesting. The crude oil of *C. citriodora* is not subjected to any particular treatment before marketing, beyond clarification and filtration to ensure freedom from water and suspended matter. Storage in a cool location away from light is recommended.

Genetic resources In the wild *C. citriodora* is locally abundant over a wide area and is not considered to be at risk. In addition, it is very widely planted and local landraces in many countries are another reserve of genetic material. Seed trees have seldom been tested for their oil characteristics in Australia, and seed exported from Australia for plantation establishment could be representative of one or more of the four chemical forms of *C. citriodora*. When propagating *C. citriodora* for oil production, care should be taken that the seed has been selected from provenances with oil characteristics that meet the requirements of the intended market. The Australian Tree Seed Centre of CSIRO Forestry and Forest Products in Canberra maintains a collection of seed of provenances of *C. citriodora* including some individual tree collections that have been tested for oil characteristics.

Breeding Despite the early identification of *C. citriodora* as a useful multipurpose tree and its widespread dissemination, few comprehensive provenance trials exist. The sporadic occurrence of seed crops in the natural stands contributes to the difficulty of making a comprehensive seed collection for such trials. Existing provenance trials mostly show genetic variability between and within populations in growth traits and point to the need to select provenances locally before embarking on a planting programme. Brazil is most advanced in the improvement of the species. It started selection work in the 1970s using only imported seed of approved quality. In the 1980s it identified certified seed production areas; these are phenotypically superior stands in which some management practices have been conducted. In the state of Minas Gerais, a tree improvement programme was initiated in 1978, with elite trees selected for growth characteristics in a seed production area. The aim was to establish seedling seed orchards and clonal seed orchards by grafting. A study of mating system parameters indicated reasonably high levels (14.7%) of self fertilization and low levels of heterozygosity in progeny from these stands.

Prospects *C. citriodora* is already widely planted for roundwood, fuel, essential oil and amenity throughout the tropics and subtropics. Although not of outstanding growth rate, it gives acceptable growth on a wide range of sites. *C. citriodora* is also a useful multipurpose tree grown for wood and oil, which can be profitable for smallholder farmers. In general, it is considered that the potential of *C. citriodora* may not have been fully exploited. No breeding or selection work is being done on *C. citriodora* to improve the production of essential oil. Improvement of wood production is in its infancy.

Literature |1| Boland, D.J., Brophy, J.J. & House, A.P.N., 1991. Eucalyptus leaf oils: use, chemistry, distillation and marketing. Inkata Press, Melbourne, Australia. 252 pp. |2| Coppen, J.J.W., 1995. Flavours and fragrances of plant origin. Non-Wood Forest Products No 1. Food and Agriculture Organization of the United Nations, Rome, Italy. 101 pp. |3| Coppen, J.J.W. & Hone, G.A., 1992. Eucalyptus oils: A review of production and markets. Natural Resources Institute Bulletin 56. Chatham, United Kingdom. 45 pp. |4| Dung, N.X., Hang, N.T., Versluis, K., Tinh, H.M., Be, N.V. & Loi, L.V., 1995. Results of the study on Eucalyptus citriodora from Vietnam. Proceedings of the NCST of Vietnam 7(1): 51–57. |5| Hill, K.D. & Johnson, L.A.S., 1995. Systematic studies in the eucalypts 7. A revision of the bloodwoods, genus Corymbia (Myrtaceae). Telopea 6: 185–504. |6| Poynton, R.J., 1979. The eucalypts. Tree planting in Southern Africa, Vol. 2. Department of Forestry, Pretoria, South Africa. 882 pp. |7| Pryor, L.D. & Johnson, L.A.S., 1971. A classification of the eucalypts, Australian National University Press, Canberra, Australia. |8| Sugimoto, S. & Kato, T., 1983. Composition of Eucalyptus oils. Kanzei Chuo Busekisho Ho [Reports of the Central Customs Laboratory] 23: 31–34. |9| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 272–278.

J.C. Doran

Cymbopogon citratus (DC.) Stapf

Kew Bull. 1906: 357 (1906).

GRAMINEAE

$2n = 40, 60$

Synonyms *Andropogon citratus* DC. (1813), *A. ceriferus* Hackel (1883), *A. nardus* (L.) Rendle var. *ceriferus* Hackel (1889).

Vernacular names Lemongrass, West Indian lemongrass (En). Herbe-citron, verveine des Indes (Fr). Indonesia: serai dapur (general), sereh (Sundanese), bubu (Halmahera). Malaysia: sereh, serai, serai dapur. Philippines: tanglad, salai (Tagalog), balioko (Bisaya). Cambodia: slek krey sabou. Laos: 'si khai, 'sing khai. Burma (Myanmar): sabalin. Thailand: cha khrai (northern), khrai (peninsular), soet-kroei (eastern). Vietnam: s[ar] chanh.

Origin and geographic distribution The exact origin of *C. citratus* is not known but a Malesian origin is most likely. *C. citratus* is only known from cultivation and it has been cultivated for several centuries in South and South-East Asia. After the First World War large-scale cultivation was taken up in South and Central America and later in Madagascar and nearby islands and in Africa. Lemongrass is now found cultivated and often naturalized throughout the tropics and warm subtropics e.g. in southern parts of the Russian Federation and northern Australia. It is very commonly cultivated throughout South-East Asia both as an industrial and as a garden crop, e.g. in Java it is planted in nearly every home garden.

Uses The original use of *C. citratus* leaves was probably as a food and beverage flavouring, but it is currently grown both for its essential oil and as a condiment. The earliest references from India to lemon-scented waters made from *C. citratus* date back several centuries. Fresh leaves crushed in water are still used in India as a hair wash and toilet water. In the perfume industry the oil, consisting mainly of citral, is an important starting material for the production of α- and β-ionones, which in low concentrations have the odour of violets. As a condiment, *C. citratus* is grown in home gardens throughout South-East Asia. In Java, leaf sheaths are added to spicy sauces e.g. 'sambal goreng' and 'sambal petis' and to cooked fish and fish sauces, while the heart of young shoots is eaten as a side dish with rice. It is also a popular constituent of many curries. In Java, it is used in making a popular sherbet ('bandrek' in West Java, 'serbat' in East Java). Lemongrass is excellent for planting on bunds for soil conservation, and as a mulch. Sometimes it is grown for cellulose and paper production. Lemongrass has carminative and anticholeric properties and is applied in traditional medicine against several intestinal problems and the oil is used as a massaging agent against rheumatism. West Indian lemongrass is used in Chinese medicine to treat a great variety of ailments, including eczema, colds, headache, stomach-ache, abdominal pain and rheumatic pain. External application of the oil provides effective control of ticks in cattle and several ectoparasites in chicken. Spent grass mixed with bagasse and made into silage is a common cattle feed in lemongrass-producing areas.

Production and international trade In trade statistics hardly any distinction is made between the 2 major sources of lemongrass oil: West Indian lemongrass (*C. citratus*) and East Indian lemongrass (*C. flexuosus* (Nees ex Steudel) J.F. Watson). In 1986 world production of lemongrass oil was estimated at 650 t, valued at about 4.3 million US$, most of the oil originating from Central and South America (Argentina, Brazil, Guatemala, Honduras). In 1992–1994 average annual import of lemongrass oil in the United States was 80 t and the price per kg averaged US$ 7.35. East Indian lemongrass oil is mainly produced and consumed in India.

Properties On steam distillation *C. citratus* leaves yield West Indian lemongrass oil. Lemon-

grass oil is a yellow or amber-coloured, somewhat viscous liquid with a very strong, fresh-grassy, lemon-like, herbaceous or tea-like odour with an earthy undertone reminiscent of Ceylon citronella oil. The main chemical constituent of the oil is citral, a mixture of the stereoisomers geranial and neral. The geranial content is 40–62%, the neral content 25–38%. Other components include myrcene, limonene, and geraniol. The solubility of freshly distilled oil of *C. citratus* declines rapidly in storage, due to polymerization of myrcene. East Indian lemongrass oil contains no or very little myrcene and is more soluble in alcohol. Lemongrass oil from the Ethiopian highlands has a very low citral content (14%) and also differs in the composition of minor components.
West Indian lemongrass oil has been approved for food use by the Food and Drug Administration (FDA) of the United States under paragraph 182.20. The oil has been 'generally recognized as safe' in the United States (GRAS No 2624) and is registered by the Council of Europe under No 38n. Lemongrass oil is used in food products, including alcoholic and nonalcoholic beverages. The Research Institute for Fragrance Materials (RIFM) has published a monograph on the physiological properties of lemongrass oil. See also: Composition of essential-oil samples and the Table on standard physical properties.
West-Indian lemongrass oil has antibacterial and anti-fungal properties and is used medicinally e.g. in homeopathic drugs.

Adulterations and substitutes Lemongrass oil is rarely adulterated; the citral content being the quality criterion of overriding importance. *Litsea cubeba* (Lour.) Persoon is an important alternative source of citral. Synthetic citral is too costly to be used as an adulterant.

Description Perennial, tufted, aromatic grass with numerous erect culms arising from a short, oblique, ring-shaped, sparingly branched rhizome. Culm (stem) up to 2(–3) m tall, solid below, pruinose below the nodes, smooth and glabrous. Leaves sheathing; sheath coriaceous, terete, tightly embracing the culm, glabrous, smooth, striate, basal ones persistent; ligule rounded or truncate, less than 2 mm long, chartaceous, glabrous; blade linear, 50–100 cm × 0.5–2 cm, long-attenuate at both ends, apex acuminate, drooping, glabrous, glaucous-green, midrib prominent below and white above, smooth on both surfaces but top part and margins often scabrid. Inflorescence a large, loose, decompound, nodding panicle, up to 60 cm long, 4–9-noded, repeatedly branched, each division issuing from a spathe-like sheath with or without a leaf until the final ramification is a peduncle issuing from a spatheole and carrying a pair of racemes; raceme 1.5–2.5 cm long, rachis villous with hairs 2–3 mm long, bearing 4–7 pairs of spikelets, 1 of each pair sessile, the other pedicellate, terminated by 1 sessile and 2 pedicellate spikelets; sessile spikelet 5–6 mm × 0.7 mm, bearing 2 florets; lower glume flat or shallowly concave on the back, size and shape like the spikelet, 2-keeled, glabrous, veinless; upper glume boat-shaped, 1-keeled on the back; lower floret reduced to an empty lemma; upper floret hermaphrodite, awnless, with hyaline, 2-lobed lemma, palea mostly absent, lodicules 2, cuneate or truncate, stamens 3, styles 2 with plumose stigmas; pedicellate spikelet 4.5 mm long, male or reduced to empty glumes; lower glume 7–9-veined, upper glume 3-veined. Seed a cylindrical to subglobose caryopsis with basal hilum.

Cymbopogon citratus (DC.) Stapf – 1, habit of flowering plant; 2, plant base; 3, two leaves; 4, part of inflorescence; 5, pair of spikelets; 6, fertile sessile spikelet.

Growth and development *C. citratus* tillers strongly and the number of tillers is directly correlated with the number of leaves and with oil yield. Only young, expanding leaves synthesize and accumulate essential oil. The root system is rather superficial. In most places *C. citratus* flowers very rarely or not at all. Plants usually do not become older than 4–6 years.

Other botanical information *C. citratus* is one of several species yielding lemongrass oil, the 2 most important other ones being East Indian lemongrass (*C. flexuosus* (Nees ex Steudel) J.F. Watson) and Jammu lemongrass (*C. pendulus* (Nees ex Steudel) J.F. Watson). Both species are cultivated in India, the former one also in Indonesia and Madagascar.

Most of the about 55 species of *Cymbopogon* Sprengel are aromatic grasses, mainly confined to the Old World tropics and subtropics (in South-East Asia, about 13 species occur in addition to the cultivated ones). The aromatic oil in the leaves sometimes remains perceptible for a very long time, even in dried specimens (e.g. in 3000-year-old Egyptian tombs).

Ecology *C. citratus* grows best under sunny, warm and humid conditions. It performs best below 500 m altitude, but is grown up to 750 m in Madagascar and the Comoros. Average daytime temperatures of 23–30°C without extremely low night temperatures are optimum for growth and yield. Short periods with a daily maximum temperature over 30°C do not harm growth but severely reduce oil content. Hot dry winds may not only desiccate the crop but can also evaporate the oil. Frost is normally fatal. Water requirement is very high, the highest yields are obtained where the average annual rainfall is 2500–3000 mm evenly distributed over the year. Up to 5000 mm is tolerated on well drained soils. Long periods of dry sunny weather strongly reduce herbage yield and oil yield, although oil content is generally higher during the dry season. Good drainage is the most important soil requirement for *C. citratus* and in many countries plantations are on sandy soils, though loamy soils are used e.g. in China, Madagascar and Vietnam. Generally, soils of *C. citratus* plantations have a pH of 5.5–7.5, although good growth has been observed in Australia on a clay soil with pH 9.6. Good growth was also found on acid peat soils in Sarawak, Malaysia (pH 4.5). Saline soils are considered unsuitable, although fair growth and oil yield on saline soils have been obtained in greenhouse experiments.

Propagation and planting As *C. citratus* only rarely produces seed it is usually propagated vegetatively. Well-grown, healthy plants from mature or exhausted plantations are dug up and divided into offshoots; a single plant clump yields 50–200. The size of offshoots used depends on local preference; larger shoots normally root quicker and grow faster. Offshoots are cut back to 10–15 cm, trimmed of dead and excess roots and are preferably treated with fungicide. The use of growth hormones is not necessary. Planting is mostly done on the flat, 10–15 cm deep, at a spacing of 50–90 cm × 50–60 cm. In Guatemala lemongrass is commonly grown in rows 120 cm apart with 30 cm between plants. A high plant density maintained by filling in gaps is required for high yields. Deep planting and earthing-up may be beneficial on sandy soils, but on heavy soils those practices are not advisable as the young plants are susceptible to root rot. *C. citratus* is rarely intercropped when grown for its oil, as it needs ample water and full sunshine, but e.g. in Malaysia it has been underplanted in young rubber plantations to help defray the cost of plantation establishment. When grown as a condiment, *C. citratus* is mostly grown in home gardens, interplanted with many other crops.

Husbandry Careful weeding of lemongrass is extremely important, as weedy grasses may quickly invade a new plantation and once established are very difficult to remove. After establishment of the plantation, weeding is usually done after each harvest. *C. citratus* is often irrigated. Small farmers usually irrigate after each harvest, large estates irrigate whenever water stress may affect growth. In the Ord Valley in Western Australia, irrigating every 10 days during the dry season gave the highest yields. Limited water stress prior to harvesting generally reduces herbage yields, but increases oil content, thus reducing the cost of transport while maintaining oil yield.

West Indian lemongrass is generally considered to have a modest nitrogen requirement, but experimental data on fertilizer requirements are very scarce. Small farmers in India commonly return spent grass as compost at a rate of 5 t/ha supplemented with 2 t/ha wood ash; a similar practice is reported from Guatemala. For chemical fertilizers, a basic dose of 30 kg each of N, P_2O_5 and K_2O, followed by 60 kg N per year in split applications after each harvest is commonly recommended. It is recommended to remove diseased and dead plants and spot spraying with a herbicide after each harvest. In cultivation the economic life of *C. citratus* rarely exceeds 4–5 years.

Diseases and pests *Helminthosporium cymbopogi* causes a serious leaf-spot disease in lemongrass resulting in great damage in Guatemala. *Curvularia lunata* causes another leaf disease, starting with elongated, discoloured lesions that ultimately become brown with a paler border. Brown-tip disease is a physiological disorder, resulting from a low water content of the leaves at the end of the dry season. No serious pests of *C. citratus* are known.

Harvesting First harvest of leaves of lemongrass may start about 6–8 months after planting. Subsequently leaves can be cut 3–6 times per year during 4–6 years. In South America the cutting cycle is generally maintained at 3-4 months, which is believed to promote tillering and leaf yield. Cutting begins when the morning dew has dried, as wet grass very easily starts to ferment. When harvesting manually, plants are cut at about 10 cm above the ground. Mechanical harvesters are adjusted to cut at about 20 cm. In trials, cutting at a height of 20 cm gave the highest yields. To reduce the amount of green material to be transported and distilled, small farmers sometimes harvest only the top parts of the leaves. After several harvests plants are pruned back to promote regrowth. Burning is sometimes used as an alternative to rejuvenate a plantation.

Yield The average annual herbage yield of lemongrass is 30–50 t/ha, yielding 75–250 kg lemongrass oil (0.25–0.50%). Under good management annual yields of this magnitude can be maintained during 4–6 years of plantation life. Herbage yield of 100 t/ha has been achieved under optimum circumstances, and with efficient management and improved selections the oil yield can be increased to 0.4–0.6%. Harvesting the top parts gives an oil yield of 0.6%, while the lower parts yield only 0.15%. In hilly districts in the Philippines, oil content of naturalized *C. citratus* is about 0.25% during the cool season and 0.35–0.5% during the hot, dry season.

Handling after harvest Wilting the herbage of lemongrass before distillation reduces moisture content and has little effect on oil yield, but increases citral content. Drying in full sunlight often reduces oil content, but has little effect on oil quality. Drying for up to 3 days prior to distillation is common. The leaves of *C. citratus* are steam-distilled to extract the essential oil. In Indonesia wilting for 2 days and distilling for 1.5 hours has given the highest yields (0.43%). Increasing distillation time resulted in higher yields but reduced citral content. Adding salt to the distillation water increases yield, e.g. up to 30% in Puerto Rico. Spent grass can be dried, composted and returned to the field or used as fodder.

Genetic resources and breeding Several institutions in South and South-East Asia are involved in germplasm collection and conservation of aromatic grasses. Systematic collection of germplasm of *Cymbopogon* began at the Lemongrass Breeding Station, Odakkali, Kerala, India as early as 1951. The collection now has over 450 accessions. Other major institutions include: the Research Institute for Spice and Medicinal Crops (RISMC), Bogor, Indonesia; the Thailand Institute of Scientific and Technological Research (TISTR), Bangkok, Thailand; the University of the Philippines, Los Baños, the Philippines; the Central Institute of Medicinal and Aromatic Plants, Lucknow, India and the National Board of Genetic Resources, New Delhi, India. There are no known breeding programmes for *C. citratus*.

Prospects Lemongrass oil from *C. citratus* is likely to remain an important source of citral for use in low-cost perfumery, while its use as a masking fragrance in deodorants, detergents and pesticides is still growing. However, the essential oil from *Litsea cubeba* is a serious competitor.

Literature |**1**| Bor, N.L., 1953, 1954. The genus Cymbopogon Spreng. in India, Burma and Ceylon. Journal of the Bombay Natural History Society 51: 890–916 (Part 1, 1953); 52: 149–183 (Part 2, 1954). |**2**| Brandares, M.F.T., Vuelban, A.M., Dar Juan, B.B., Ricalde, M.R. & Anzaldo, F.E., 1987. Stability studies of essential oils from some Philippine plants. 2. Cymbopogon citratus (D.C.) Stapf. The Philippine Journal of Science 116: 391–402. |**3**| Juida de Carlini, D.P., 1986. Pharmacology of lemongrass (Cymbopogon citratus). Journal of Ethnopharmacology 17: 37–83. |**4**| Ng, T.T., 1972. Growth performance and production potential of some aromatic grasses in Sarawak – A preliminary assessment. Tropical Science 14: 47–58. |**5**| Soenarko, S., 1977. The genus Cymbopogon Sprengel (Gramineae). Reinwardtia 9: 225–375. |**6**| Virmani, O.P., Srivastava, R. & Datta, S.G., 1979. Oil of lemongrass. Part 2: West Indian. World Crops 31: 120–121. |**7**| Weiss, E.A., 1997. Essential oil crops. CABI, Wallingford, United Kingdom. pp. 86–103.

L.P.A. Oyen

Cymbopogon flexuosus (Nees ex Steudel) J.F. Watson

in Atkins., Gaz. N.W. Prov. India 10: 392 (1882).
GRAMINEAE
$2n = 20$ (diploid), 40 (tetraploid)

Synonyms *Andropogon flexuosus* Nees ex Steudel (1854), *A. nardus* L. var. *flexuosus* (Nees ex Steudel) Hackel (1889), *Cymbopogon travancorensis* Bor (1954).

Vernacular names East Indian lemongrass, Malabar grass, Cochin grass (En). Herbe de Malabar (Fr). Vietnam: s[ar] d[ij]u.

Origin and geographic distribution *C. flexuosus* possibly originates from India (Western Ghats) but it is also native in Burma (Myanmar) and Thailand. It is also often cultivated as a garden plant throughout the tropics as well as in its native area. In South-East Asia it is commonly cultivated and sometimes naturalized (e.g. in Indonesia in Java, Bali and Sumbawa). Cultivation is most important in India, Indonesia and Madagascar.

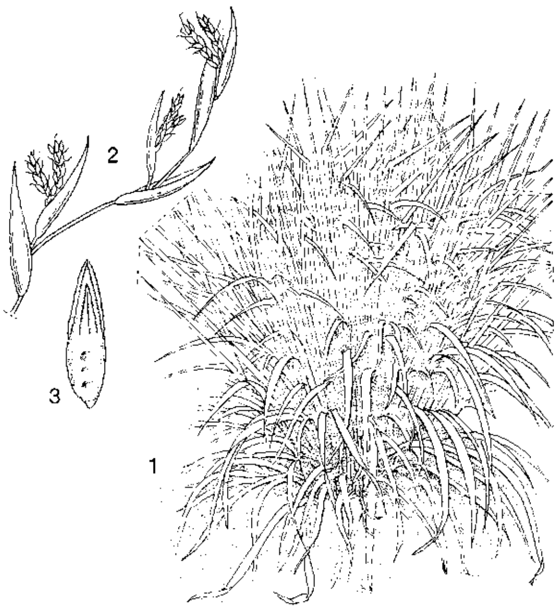
Uses Distillation of the leaves of *C. flexuosus* yields East Indian lemongrass oil. The oil is very similar to West Indian lemongrass oil and is used as a flavouring and fragrance material, mainly in soaps, detergents and industrial perfumes. The oil is a source of citral, which is either used directly or converted to α- and β-ionones. Lemongrass oil is applied as a fumigant against flies and mosquitoes, although the repellent action is rather poor. Spent grass is dried and used to fuel the distillery, as animal feed, or returned to the field as manure. *C. flexuosus* is also planted to control erosion and sometimes it is used as a source of cellulose and for paper production.

Production and international trade In trade statistics hardly any distinction is made between the 2 major sources of lemongrass oil: West Indian lemongrass (*C. citratus* (DC.) Stapf) and East Indian lemongrass (*C. flexuosus*). In 1986 world production of lemongrass oil was estimated at 650 t, valued at about 4.3 million US$, most of the oil originating from Central and South America (Argentina, Brazil, Guatemala, Honduras). In 1992–1994 average annual import of lemongrass oil in the United States was 80 t and the price per kg averaged US$ 7.35. Most East Indian lemongrass oil is produced and used in India, but there are no reliable production and trade statistics.

Properties East Indian lemongrass oil is a yellow or amber-coloured, somewhat viscous liquid with a strong, sweet, fresh-grassy, citral and lemon-like, herbaceous or tea-like odour. The main chemical constituent of the oil is citral, which is a mixture of the stereoisomers geranial (50%) and neral (30%); minor components include limonene, linalool, geraniol and myrcene. The oil from *C. flexuosus* is more soluble in alcohol and is said to be of better quality than West Indian lemongrass oil from *C. citratus* (DC.) Stapf.
East Indian lemongrass oil has been approved for food use by the Food and Drug Administration of the United States under paragraph 182.20 and 'generally recognized as safe' (GRAS No 2627). See also: Composition of essential oil-samples and the Table on standard physical properties.

Adulterations and substitutes Lemongrass oil is rarely adulterated; the citral content being the quality criterion of overriding importance. The essential oil from *Litsea cubeba* (Lour.) Persoon is an important alternative source of natural citral. Occasionally, the oil is adulterated with synthetic citral.

Description Perennial, tufted, aromatic grass with numerous erect culms arising from a short, thick rhizome. Culm (stem) up to 2.5(–3) m tall, terete, solid, reddish or whitish, smooth and glabrous but often short-bearded at the nodes. Leaves sheathing, glaucous-green, sometimes tinged purplish; sheath clasping the culm (lower sheaths very loose), striate, smooth and glabrous



Cymbopogon flexuosus (Nees ex Steudel) J.F. Watson – 1, habit; 2, part of inflorescence branch; 3, lower glume of sessile spikelet.

but densely hairy at the junction with the blade; ligule chartaceous, 2–5 mm long; blade linear-acuminate, tapering at both ends, about 1 m × 1.5 cm, apex attenuating to a long, filiform tip, minutely scabrid on both surfaces, coarsely scabrid on the margins, with densely tomentose triangular patches at the base of both surfaces. Inflorescence a large, loose, repeatedly branched panicle, up to 60 cm × 30 cm, with many long flexuous drooping branches; branches of highest order ending in a spatheole subtending a pair of racemes; axis up to 12-noded, internodes tomentose in upper part, nodes villous; spatheole narrowly elliptical-acuminate, 1–2 cm long; peduncle 3–3.5 mm long, wiry, smooth and glabrous; racemes 15–20 mm long, one subsessile, the other stalked, very hairy in the fork, bearing pairs of spikelets, 1 of each pair sessile, the other pedicellate; sessile spikelet subcylindrical with acute apex, 4.5–5 mm long, with a short bearded callus; lower glume size and shape of the spikelet, 2-keeled from the middle upwards, winged on the keels, smooth, scabrid on the margins of the keels, 1–3 veined; upper glume boat-shaped, 4.5–5 mm long, keeled in the upper third, winged and scabrid on the keel; lower floret reduced to an empty lemma; upper floret hermaphrodite with a narrow lemma cleft to the middle and bearing an awn 10–12 mm long, palea absent, 2 truncate-cuneate lodicules, stamens 3, styles 2 with plumose, purple stigmas; pedicelled spikelet male or sterile, elliptical-acuminate, 3.5–4 mm long; lower glume many veined, glabrous; upper glume boat-shaped, 3-veined, glabrous.

Growth and development In areas with a cold winter *C. flexuosus* perennates through its rhizomes and resumes growth in spring. The root system is extensive but not deeply penetrating into the soil. *C. flexuosus* is a short-day plant and flowering is common. In tropical India at low elevation flowering starts in November; at higher elevations flowering is delayed by 2–3 months. Flowering starts in the middle of the panicle and proceeds upward and downward, taking about 1 month before the whole panicle has flowered. Most flowers open in the early morning; cross pollination is normal because of the protogynous nature of the bisexual florets. In commercial production only selected plants are allowed to flower for seed production because profuse flowering prior to cutting substantially reduces oil yield. Normally plants become (4–)6–8 years old.

Other botanical information *C. flexuosus* is rather variable and several varieties have been distinguished on the basis of the size and degree of compactness of the panicle; this has little practical value, however, as many intermediates occur. The characteristics of *C. flexuosus* most useful for distinguishing it from other species are its ample panicle with drooping branches, its crowded raceme pairs with its small sessile spikelets and its densely tomentose triangular patches at the base of the leaf blade. Based on the colour of the culm 2 forms can be distinguished: one reddish, the other whitish. All cultivars for essential oil production have reddish culms because the white-stemmed forms produce oil with a lower citral content. Sometimes the whitish form is considered as a separate species: *C. travancorensis* Bor.
Several cultivars have been developed in India. 'Sugandhi' (OD 19) is the most popular and is adapted to a wide range of soils and to the northern Indian climate; plants tiller profusely, are up to 1.75 m tall and under rainfed conditions reach an oil yield of 80–100 kg/ha with 85–88% citral. 'Pragati' (LS 48) is adapted to tropical and subtropical climates of northern India; the plants are tall with dark purple leaf sheaths, average oil content is 0.63% with 86% citral. 'Cauvery' is a recently released high-yielding cultivar adapted to South Indian conditions. 'Dhanrosa', also called 'Thatha-1', is a high-geraniol selection from southern India, tentatively classified as *C. flexuosus*. It affords up to 10 harvests per year under irrigated conditions.
In north-eastern India and Nepal *C. pendulus* (Nees ex Steudel) J.F. Watson (Jammu lemongrass) is a locally important species which also produces a lemongrass oil. Several promising cultivars with high oil yield and citral content have been selected from it. All Jammu lemongrass oil is consumed locally.

Ecology *C. flexuosus* occurs naturally in fields, roadsides, in mixed deciduous, dipterocarp and teak forest, often on limestone, and on slopes and ridges at 100–2200 m altitude. It requires a warm, per-humid climate with ample sunshine, average daytime temperatures of 25–30°C with no extremely low night temperatures and 2500–3000 mm annual rainfall evenly distributed over the year. In drier areas growth is less luxuriant, but oil and citral content are higher. Long, dry, sunny periods, however, reduce oil content. In northern India, low temperatures inhibit growth during the winter and frost kills the plant. *C. flexuosus* is mostly grown up to 300 m altitude, but in Kerala State, India, it is grown up to 1000 m. It grows best on fertile sandy loams, but in Kerala it is mostly grown on poor lateritic soils on slopes. It requires a well-drained soil and waterlogging is not tolerated. Soil salinity up to EC 1 S/m has little influence on yield.

Propagation and planting *C. flexuosus* is generally propagated by seed, as offshoots often fail to establish. Seed, usually produced in large amounts (100–200 g/plant), is sown very densely in nurseries; 10–12 kg seed is needed to produce seedlings for 1 ha. At the onset of the monsoon seedlings are transplanted in the 3–4-leaf stage, when 50–70 days old, topped to 15–20 cm and dipped in fungicide. A close spacing of 15 cm × 15 cm is recommended to suppress weed growth, but farmers often plant at a wider spacing. Direct sowing in the field is also practised, for which about 35 kg seed/ha is needed, but this often results in very heavy weed infestation. *C. flexuosus* may be interplanted with other crops but it is generally the major component when grown for oil.

Husbandry Although *C. flexuosus* is a vigorous crop, 2–3 weedings are required after transplanting, followed by a weeding in the first month after each harvest. In direct-sown crops early weeding should be more intensive. Annual earthing-up encourages tillering. In India fertilizer applications vary according to growing conditions; a general recommendation is to apply annually 30 kg/ha each of N, P_2O_5 and K_2O plus 60 kg/ha N, in 3–4 split applications. Burning the dry grass and stubble at the end of the dry season is common in Kerala; it rejuvenates the crop and controls termite and stem borer attack. In Kerala *C. flexuosus* is grown as a rainfed crop; in northern India 4–6 irrigations are required during the dry season, i.e. between February and June.

Diseases and pests Though several diseases are reported for *C. flexuosus*, none causes serious reduction in oil yield. *Balansia sclerotica* reduces seed yield, several *Drechslera* spp. and *Curvularia* spp. cause leaf-spot diseases, while in northern India smut caused by *Tolyposporium christensenni* or *Ustilago andropogonis* is common. Serious pests do not occur, but *Chilo* stem borer sometimes causes damage. It can be controlled by pesticides and by burning the stubble after the harvest. Young plantations should be protected from grazing by domestic stock especially when other forage is not available.

Harvesting In southern India, harvesting rainfed *C. flexuosus* starts in May–June (about 6–8 months after planting) and cuts are taken every 6–7 weeks. If cut too early, the oil obtained is of very poor quality because of a very low aldehyde content. Usually 2–3 harvests can be taken during the year of planting and 4–6 harvests in subsequent years. At higher elevations fewer are possible. The leaves are cut, usually with a sickle, at 10–20 cm above the ground, preferably on sunny days when the leaves are dry.

Yield The annual herbage yield of *C. flexuosus* in the first 2 years after planting is 15–20 t/ha in India. In subsequent years yields decline, the rate of decline being directly related to the standard of management and maintenance of soil fertility. Average oil yield in India is 0.2–0.5% from fresh herbage weight (on average about 75 kg/ha). Herbage harvested in the dry season usually has a much higher oil content (0.3–0.7%) than herbage harvested in the rainy season.

Handling after harvest Wilting the herbage of *C. flexuosus* in the shade for up to 2 days and chopping it into pieces 3 cm long increases still efficiency and oil yield. Many end-users prefer oil distilled from fresh herbage, since it is said to have a finer odour than oil obtained from wilted or dried herbage. In India the leaves of *C. flexuosus* are generally distilled in small, scattered, primitive stills. Water distillation is commonly used, but direct and indirect steam distillation is applied in more modern plants. Distillation takes about 3 hours. In India a unit for 100 kg grass and 140 l water requires 2–2.5 hours to produce 0.35 kg oil, using 40 kg fuel wood. The oil deteriorates during prolonged storage, because of photo-oxidation. It should be protected from air, heat and sunlight. For conservation, indigenous antioxidants are added to the oil in India. An extract of betel leaves (*Piper betle* L.), for instance, maintains the citral content of the oil at 83% compared to 72% in non-treated oil.

Genetic resources Several institutions in South and South-East Asia are involved in germplasm collection and conservation of aromatic grasses. Systematic collection of germplasm of *Cymbopogon* was initiated at the Lemongrass Breeding Station, Odakkali, Kerala, India as early as 1951. The collection now has over 450 accessions. Other major institutions include: the Research Institute for Spice and Medicinal Crops (RISMC), Bogor, Indonesia; the Thailand Institute of Scientific and Technological Research (TISTR), Bangkok, Thailand; the University of the Philippines, Los Baños, the Philippines; the Central Institute of Medicinal and Aromatic Plants, Lucknow, India and the National Board of Genetic Resources, New Delhi, India.

Breeding Breeding work on *C. flexuosus* in India aims at higher herbage yields (especially of leaves) with improved oil and citral contents. These characters are all polygenic. Methods have been developed to obtain induced pollen sterility, including hot water treatment and application of malic hydrazide. Several new cultivars have been released by the Aromatic and Medicinal Plants Research Station, Odakkali (India) and the Central Institute of Medicinal and Aromatic Plants, Lucknow (India). Clones R8P6 and R16P3 were selected in Bangalore (India) having significantly higher essential oil contents than 'Sugandhi'. The essential oil content of clones PC5 and PC8 is only slightly lower than that of R8P6, but is less affected by seasonal temperature fluctuations.

Prospects The various essential oils of *Cymbopogon* are likely to retain an important place as low-price aroma chemicals for many products ranging from soaps to detergents and insect repellants. *C. flexuosus* remains the preferred lemongrass oil in perfumery in India; elsewhere oil from *C. citratus* is more highly valued.

Literature |1| Boelens, M.H., 1994. Sensory and chemical evaluation of tropical grass oils. Perfumer and Flavorist 19: 29–45. |2| Bor, N.L., 1953, 1954. The genus Cymbopogon Spreng. in India, Burma and Ceylon. Journal of the Bombay Natural History Society 51: 890–916 (Part 1, 1953); 52: 149–183 (Part 2, 1954). |3| Kulkarni, R.N. & Ramesh, S., 1992. Development of lemongrass clones with high oil content through population improvement. Journal of Essential Oil Research 4: 181–186. |4| Soenarko, S., 1977. The genus Cymbopogon Sprengel (Gramineae). Reinwardtia 9: 225–375. |5| Thomas, J., 1995. Lemongrass. In: Chadha, K.L. & Rajendra Gupta (Editors): Advances in Horticulture. Vol. 11. Medicinal and aromatic plants. Malhotra Publishing House, New Delhi, India. pp. 717–733. |6| Virmani, O.P., Srivastava, R. & Datta, S.G., 1979. Oil of lemongrass. Part 1: East Indian. World Crops 31: 72–74. |7| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 86–103.

L.P.A. Oyen

Cymbopogon martini (Roxb.) J.F. Watson

in Atkinson, Gaz. N.W. Prov. India 10: 392 (1832).

GRAMINEAE

$2n = 20$ (diploid, var. *sofia*), 40 (tetraploid, var. *martini*)

Synonyms
- var. *martini*: *Andropogon martini* Roxb. (1820), *Cymbopogon martini* (Roxb.) J.F. Watson var. *motia* auct., p.p., *C. motia* Gupta (1970);
- var. *sofia*: *Andropogon martini* Roxb. (1820).

Note: Although the specific epithet was originally published as '*martini*', it is often written as '*martinii*'.

Vernacular names
- var. *martini*: Palmarosa grass, motia, rosha grass (India) (En). Vietnam: s[ar] hoa h[oof]ng.
- var. *sofia*: Gingergrass, sofia, russa grass (India) (En).

Origin and geographic distribution *C. martini* originates from the Indian subcontinent where wild stands have been exploited since antiquity and still produce an important portion of the essential oil. At the beginning of the 20th Century palmarosa grass was also taken into cultivation in India. In the 1930s palmarosa grass was introduced to Java where it yielded promising quantities of high quality oil. Production in Java grew steadily. It declined sharply during the Second World War, but was resumed on a smaller scale in the 1990s. In addition to India and Java, it is now also grown commercially in Brazil, Guatemala, Honduras, Madagascar and on a smaller scale in other African countries. In most of South-East Asia it is only grown occasionally. Var. *sofia* is sometimes cultivated in India.

Uses Two different oils are obtained from *C. martini*, preferably from the flowering tops: var. *martini* yields palmarosa oil, confusingly also named East Indian geranium oil, while gingergrass oil is obtained from var. *sofia*. Palmarosa oil is applied in perfumes for soaps and cosmetics and for flavouring tobacco and liqueurs. It is also an important source of natural geraniol, which is an excellent extender in many floral, rose-like perfume compounds and a starting material for the production of aroma chemicals, notably geranyl esters that have a lasting rose-like aroma. Palmarosa oil is an active component of mosquito repellents. Gingergrass oil was once a popular perfumery material for rose compounds, particularly in soaps, but lost its popularity due to frequent adulteration. It is now mainly applied in the soap and detergent industry in India.

C. martini is also grown extensively to control erosion on erodible hillsides and to stabilize edges of terraces and gullies. In traditional medicine *C. martini* and its oils are used to treat rheumatism, hair loss, arthritis, lumbago and spasms.

Production and international trade In India palmarosa oil is mainly produced in Assam, Andhra Pradesh, Madya Pradesh and Maharashtra; gingergrass oil mainly in Andhra Pradesh, Punjab and Tamil Nadu. World production of palmarosa oil was about 55 t in 1984, valued at about 2.5 million US$. Gingergrass oil is of only minor importance, its annual world production being less than 2 t.

Properties All aboveground parts of *C. martini* contain essential oil, the oil content of the flowers being higher than that of the stems and leaves. The oil content in high-yielding selections grown under optimum conditions can reach 0.5–1.5%; the average yield from traditional stills, however, is only 0.2–0.3% (both on a fresh weight basis).

Palmarosa oil is a pale yellow or pale olive liquid with a sweet, floral-rosy odour with variable top notes and undertones depending on the quality and age of the oil; notes of rye bread, tea and clary sage have also been reported. Chemically, palmarosa oil consists mainly of geraniol and geranyl acetate and smaller amounts of linalool, farnesol, nerol, α-humulene and terpineols. In soap perfumes palmarosa oil shows great tenacity, much greater than commercial geraniol obtained from other sources, e.g. citronella oil. It blends well with most soap perfume compounds and forms an excellent perfume base with geranium oil and oakmoss absolute. Palmarosa oil from Indonesia has a significantly higher geranyl acetate content than Indian oil. This is due not only to differences in growing conditions, but also to the use of more modern distilleries. In the United States, palmarosa oil is 'generally recognized as safe' (GRAS No 2831). Gingergrass oil has a harsher, turpentine-like, somewhat fatty, herbal and cumin-like odour with a rose nuance and woody undertone. The chemical composition of gingergrass oil is characterized by high proportions of limonene, p-mentha-1(7),8-dien-1-ol (trans-isoperillyl alcohol), p-mentha-2,8-dien-1-ol, carveol and carvone. See also: Composition of essential-oil samples and the Table on standard physical properties.

Palmarosa oil is a strong fungicide. In laboratory tests it was more effective than several synthetic fungicides against 9 pathogenic fungi and yeasts, including *Aspergillus* spp., *Candida albicans*, *Monilia sitophila* and *Trichophyton tonsurae*.

Adulterations and substitutes Ninde oil produced from *Aeolanthus gamwelliae* G. Taylor, a *Labiatae* shrub, is occasionally used as a substitute for palmarosa oil. It is grown commercially in Malawi. *Cymbopogon densiflorus* (Steudel) Stapf from Angola produces an essential oil very similar to gingergrass oil, but this oil is not produced commercially. Palmarosa oil has been used as an adulterant of Turkish rose attars. The names 'Geranium palmarosa' and 'Geranium palmarosa Turkish' were used for the adulterated product. Palmarosa oil is sometimes adulterated with ginger oil, with geraniol obtained from citronella oil and with synthetic geraniol.

Description Perennial, tufted, aromatic grass with numerous erect culms arising from a short, stout, woody rhizome. Culm (stem) terete, up to 2(–3) m tall, smooth, glabrous, lower nodes often swollen. Leaves sheathing; sheath shorter than internode, tightly embracing the culm, striate, auriculate, glabrous, basal ones looser and breaking up into fibres; ligule oblong, 1.5–4 mm long, membrano-chartaceous; blade linear-lanceolate with long filiform tip, up to about 50 cm × 3 cm, cordate at base, often amplexicaul, margins often scabrid, glabrous, lower surface glaucous or pruinose, both surfaces smooth. Inflorescence an erect, narrow, loose to dense, repeatedly branched panicle, up to 30 cm × 5 cm, the primary axis carrying 2–3 branches at each node, each of these ending in a

Cymbopogon martini (Roxb.) J.F. Watson – 1, base of culm; 2, leafy shoot; 3, part of inflorescence; 4, pair of spikelets.

spatheole which carries a peduncle crowned with a pair of racemes; spatheole elliptical-acute when flattened, up to 4 cm long, orange-red, smooth or rough; peduncle filiform, 1–6 mm long; raceme 1.5–2 cm long, consisting of 4–7 pairs of spikelets, 1 of each pair sessile, the other pedicellate, terminated by 1 sessile and 2 pedicellate spikelets; rachis, internodes and pedicels slender, flattened on 1 side, pilose along the margins; sessile spikelet cylindrical-acute, 3.5–4.5 mm long, glabrous; lower glume shape and size of the spikelet, 2-keeled in upper half, winged on the keels, apex emarginate; upper glume boat-shaped, as long as the spikelet, with a broad wing on the keel; lower floret reduced to empty lemma; upper floret hermaphrodite, with 3 mm long, narrow lemma bearing a 12–18 mm long awn, palea absent, 3 stamens, 2 styles with plumose stigma; pedicellate spikelet elliptical-acute, 3.5–4 mm long, male, lower glume many-veined, upper glume 3-veined, florets reduced to a hyaline oblong scale wrapped round 3 stamens. Fruit a cylindrical to subglobose caryopsis, with basal hilum; the fruiting panicle often turns bright red at maturity.

Growth and development *C. martini* grows naturally in round clumps or tussocks. In var. *martini* the clumps remain separate, but they grow much closer together in var. *sofia*, sometimes forming continuous closed stands of several ha. *C. martini* is strongly cross-pollinated and wild stands are highly variable. Oil yield and geraniol content are highest under long days. Flowering in India occurs in November–December. The colour of the inflorescence changes from greenish before anthesis to red.

Other botanical information Traditionally two forms of *C. martini*, motia and sofia, were distinguished in India. Much later these were given the status of botanical varieties: var. *martini*, which is palmarosa grass or motia and var. *sofia* Bruno, which is gingergrass or sofia. They are almost indistinguishable morphologically. Reported differences include:

- var. *martini*: diploid; the upper surface of the culm leaves make a right or obtuse angle with culm; few radical leaves present; it grows in scattered patches; habitat dry and sunny; oil with a floral rosy smell and geraniol content up to 95%.
- var. *sofia*: tetraploid; the upper surface of culm leaves makes an acute angle with the culm; many radical leaves present; the grass grows in dense masses; habitat wetter and less sunny; oil with a turpentine-like odour and geraniol content up to 65%.

A practical method to distinguish the 2 varieties is to move an inflorescence leaf between the fingers from base to tip: var. *sofia* feels rough and sticky, var. *martini* smooth and clean. Spontaneous hybrids are common where their natural habitats overlap. Several cultivars of var. *martini* yielding high quality oil have been developed.

C. caesius (Nees ex Hook. & Arnott) Stapf from Madras (India) slightly resembles *C. martini* and produces an oil similar to gingergrass, but is hardly exploited. It is glaucous with narrow leaves rounded at the base and the panicle remains yellow-green at maturity.

Ecology *C. martini* occurs naturally and in cultivation in India from 12–32°N and is also grown commercially from about 5°S in Java and the Seychelles to 20°S in Madagascar. It is cultivated from 150–800(–1200) m altitude. Although under natural conditions it is often found on hillsides with an annual rainfall below 600 mm, it requires about 750 mm annual rainfall for a reasonable single harvest. If it is to be harvested several times per year, it requires at least 1500 mm annual rainfall and supplementary irrigation during periods of drought. *C. martini* prefers warm and sunny conditions with average daily temperatures of 20–25°C; temperatures of 25–30°C for extended periods can significantly reduce yields and suppress flowering. Frost causes damage at all growth stages and at higher elevations aboveground plant parts may die back during the cool season. Even slight frost at harvesting can be devastating and may reduce yields by half. Long days seem to favour oil production, both in quantity and in geraniol content.

In its natural habitat *C. martini* grows on poor, often slightly alkaline soils (pH 7.5–8.5) of sandy-loamy to loamy texture. Soils rich in organic matter and nitrogen are reported to yield high quality oil. In Orissa, India it is found on slightly saline soils. In cultivation, fertile well-drained soils of pH 6–7 are considered optimum. On alkaline soils (pH 8.5 or higher) growth and yields are reduced, but oil quality is not affected. Palmarosa grass does not tolerate acid soils or waterlogging. Gingergrass is more tolerant of prolonged periods of heavy rain that saturate the soil and also of imperfectly drained soils.

Propagation and planting *C. martini* is generally propagated by seed. Propagation by offshoots and cuttings is also possible, but there are indications that seedlings yield more herbage and oil. Care should be taken to use pure seed of var. *martini*, in particular in India and Pakistan where natural stands often are mixtures of var. *martini* and var. *sofia*. Seed is sown in nursery beds; 2.5 kg of clean seed is used for 100 m^2 nursery, providing enough seedlings for a field of 1 ha. The tiny seeds are often mixed with fine sand to obtain even distribution, and the mixture is then beaten to detach the glumes and improve germination. Healthy seed germinates 10–20 days after sowing and seedlings are ready for transplanting in 6–8 weeks when 15–20 cm tall. In India, planting is done on flat land or on ridges. When irrigated, beds with several rows per bed are also suitable. As *C. martini* grows vigorously, seedlings should be planted singly. On small farms, spacings of 80–90 cm × 80–90 cm are common; for larger plantations where adequate amounts of fertilizer and irrigation are applied 30 cm × 30–45 cm or twin rows with a wider spacing between alternate rows is recommended. Planting is done after irrigation or after the onset of the monsoon. Planting at the end of the rainy season results in slow crop growth but less competition from weeds. Its vigorous growth makes *C. martini* unsuitable for use in intercropping systems. However, the Indian Forest Department recommends planting it in forest plantations as a cash crop, since it is unpalatable to livestock and discourages grazing in young plantations.

Husbandry New plantations of *C. martini* should be weeded several times, but an established crop quickly smothers most weeds after being harvested. Fertilizer requirements are not well documented. A crop producing 11 t dry matter in India removed 32 kg N, 7.5 kg P, 21 kg K, 35 kg Ca, 21 kg Mg and 21 kg S. Yields tend to decline rapidly if no fertilizer is applied: in India herbage yields fell from 11.5 t/ha in the first and second year to 8.4 t/ha in the 4th year and 4.1 t/ha in the 7th year, while oil content fell from 1.5 g to 0.8 g per 100 g fresh matter. An annual application of 40 kg N, preferably in a compound NPK fertilizer (40-40-20 or 40-20-20), is a general recommendation, but is probably the minimum for sustained production. Var. *martini* has a life span in cultivation of 10–15 years, but many plantations become unprofitable after 6–7 years.

Diseases and pests A blight caused by *Ellisiella caudata* (*Curvularia andropogonis*) may cause severe damage in *C. martini* during the rainy season throughout India. It causes greyish-brown spots on the leaves that coalesce to form large lesions. *Colletotrichum caudatum* leaf spot may also affect the crop. Serious pests are not known for *C. martini*.

Harvesting *C. martini* should be harvested when plants are flowering, the oil content of the flowers is highest after opening and drops dramatically after flowering. The harvesting period can be extended by planting early- and late-flowering strains. The first harvest can be taken about 6 months after planting; the number of subsequent harvests per year depends on temperature and water availability. In northern India, where frost is common, only 1 harvest per year is possible, but irrigated crops in Java can produce up to 4 harvests per year. The time of harvesting affects oil yield and quality. Harvesting during the rainy season gives high herbage and oil yields, but low geraniol content, while during the dry season herbage and oil yield are lower and geraniol content higher. Harvesting is done by hand or mechanically. Hand harvesting requires about 6 man-days per ha. Mechanical harvesters that cut, chop and load the crop for direct transport to the still are available and can harvest about 1 ha per hour. The height of cutting is generally 20 cm above the ground. Cutting high leaves a substantial stubble, so reducing the cost of harvesting and distillation, but cutting low stimulates regrowth of the crop.

Handling after harvest After harvesting, the crop is often spread out in the field for 4–6 hours to lose moisture. It can then be kept in a shady cool place for several days without much loss of oil. Poor storage conditions, however, can seriously reduce the oil content. Grass from wild stands in India is stored for up to 3 weeks before being distilled. In India, traditional stills are widely used, many of them employing a water distillation process. In Java and Madagascar, however, modern steam distillation equipment is employed.

Yield Well managed plantations of *C. martini* var. *martini* in India produce annual herbage yields of 10–15 t/ha, giving 50–100 kg oil. Improved cultivars may yield up to 25 t/ha of herbage producing 150 kg oil. Little is known about yields in other countries.

Genetic resources Several institutions in South and South-East Asia are involved in germplasm collection and conservation of aromatic grasses. Systematic collection of germplasm of *Cymbopogon* was initiated at the Lemongrass Breeding Station, Odakkali, Kerala, India as early as 1951. The collection now has over 450 accessions. Other major institutions include: the Research Institute for Spice and Medicinal Crops

(RISMC), Bogor, Indonesia; the Thailand Institute of Scientific and Technological Research (TISTR), Bangkok, Thailand; the University of the Philippines, Los Baños, the Philippines; the Central Institute of Medicinal and Aromatic Plants, Lucknow, India and the National Board of Genetic Resources, New Delhi, India.

Breeding Most of the little breeding work done on *C. martini* is carried out in India. The first high-yielding selections were made by the Amravati Forest Division in Maharashtra. Many commercial cultivars have been developed from these selections. From germplasm collected in Madhya Pradesh and Maharashtra selection IW-31245 was chosen to be released as a cultivar. It has a high yield potential (10–11 t/ha), high oil yield (about 100 kg) with a high geraniol content (90%). Other cultivars released in India are 'RH-49' and 'Trishna'. Breeding work in India aims at strong tillering, large inflorescences, thin culm, long leaves, a high herbage and oil yield and a high geraniol content.

Prospects Palmarosa oil has gradually lost importance in the world market, being replaced by low-cost synthetic or natural geraniol. The natural oil is still preferred in high quality perfumes, however, especially in the Middle East. Gingergrass oil will probably remain mainly of local importance only in India. Production of palmarosa oil in South-East Asia is very feasible and will be of interest as soon as world prices for natural geraniol rise.

Literature |1| Boelens, M.H., 1994. Sensory and chemical evaluation of tropical grass oils. Perfumer and Flavorist 19: 29–45. |2| Duke, J.A. & duCellier, J.L., 1993. CRC handbook of alternative cash crops. CRC Press Inc., Boca Raton, Florida, United States. pp. 214–215. |3| Gupta, R., Pareek, S.K. & Maheshwari, M.L., 1995. Palmarosa. In: Chadha, K.L. & Gupta, R. (Editors): Advances in Horticulture. Vol. 11. Medicinal and aromatic plants. Malhotra Publishing House, New Delhi, India. pp. 735–749. |4| Soenarko, S., 1977. The genus Cymbopogon Sprengel (Gramineae). Reinwardtia 9: 225–375. |5| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 103–117.

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Cymbopogon winterianus Jowitt

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GRAMINEAE
$2n = 20, 40$

Synonyms *Cymbopogon nardus* (L.) Rendle var. *mahapangiri* auct.

Vernacular names Java citronella grass, winter's grass, old citronella grass (En). Herbe citron de Java (Fr). Indonesia: serai wangi (general), sere wangi (Javanese), sereh wangi (Sundanese). Malaysia: serai wangi. Thailand: takhrai ma-khu-ut (northern), takhrai-hom (central), takhrai-daeng (peninsular). Vietnam: s[ar] Java, s[ar] d[or].

Origin and geographic distribution *C. winterianus* is only known from cultivation and most probably originated in southern India or Sri Lanka. *C. winterianus* was brought to Java at an early date and was taken into cultivation before 1900. Large-scale production and the use of improved selections and distillation equipment in Java started around 1900. At present *C. winterianus* is cultivated throughout the tropics. In South-East Asia it is important in Indonesia and Vietnam and elsewhere in Brazil, China, Ghana, Guatemala, Haiti, Honduras and India.

Uses Java citronella oil distilled from the leaves of *C. winterianus* is a very widely used aroma material in perfumery and cosmetics, either directly or as a starting material for the production of other aroma compounds. The complete oil is mainly used as an insect repellent for humans and pets and is applied in soaps, detergents, household insecticides and technical products. d-Citronellal from the oil, which has few direct perfumery uses, is often converted into l-menthol or hydroxycitronellol. The latter is used in floral and non-floral fragrances (odour of lily of the valley). Geraniol from citronella oil is sometimes converted into citronellol and its esters, which are respectively major components and modifiers of floral fragrances. In traditional medicine, poultices of the leaves are applied to treat minor cuts and bruises, while extracts are used against internal disorders and as a vermifuge. The extracts are also mildly astringent and stomachic. In Thailand a preparation of crude citronella oil mixed with leaves of *Azadirachta indica* A.H.L. Juss. and rhizomes of *Alpinia galanga* (L.) Willd. is applied as a bio-insecticide in vegetable production and in citrus orchards. *C. winterianus* is sometimes planted to control erosion or to provide mulch.

Production and international trade The annual world production of citronella oil is estimated at 5000 t, valued at about 19 million US$ (1997). Most citronella oil is Java citronella oil; production of Ceylon citronella oil is restricted to Sri Lanka and is only 200 t/year. After *C. winterianus* was introduced into Java, Java citronella oil gained an excellent reputation in the world market. Later, the planting of mixtures and hybrids of *C. winterianus* and *C. nardus* (L.) Rendle and the marketing of adulterated oil spoiled the good name of Java citronella oil. Through strict control of production and marketing between the First and Second World Wars, Java regained its reputation for quality and dependability and average exports between 1989–1995 ranged from 560–650 t. *C. winterianus* was taken to Taiwan, where a large industry developed, mainly exporting to Japan. However, after a peak of 3000 t in 1965, production fell rapidly due to industrialization, and by 1984 it had all but ceased. Production in China is concentrated in Hainan Island; it reached a peak in 1957, but citronella production was subsequently partly replaced by more profitable essential-oil crops. In Central America, Guatemala is the main producer. It started citronella production at the end of the 19th Century with a boom during the second World War, but production rapidly declined when oil from Java became available again. Later, production recovered. Other countries producing and exporting citronella oil are Brazil, Guatemala, Ghana, Honduras, India and Vietnam.

Properties The leaves of *C. winterianus* contain 0.25–1.3% citronella oil, which is an almost colourless or pale yellow liquid, with a fresh and sweet rosy top note, a body with notes of rose and lemon and a sweet, somewhat woody dry-out. It is free of the camphene-borneol notes characteristic of Ceylon citronella oil. The major chemical components of Java citronella oil are citronellal, geraniol, elemol, geranyl acetate, limonene, β-elemene, citronellyl acetate and eugenol. The composition of the oil changes with leaf age. Comparison of citronella oils originating from Java, China and Latin America indicated a remarkable similarity in chemical composition; only oil from Sri Lanka and Burma (Myanmar) showed much lower citronellal content. Contrary to the uniformity in major components, there is considerable variation in minor constituents in oils from different origins, and in perfumery they are differentiated accordingly.

Citronella oil has been approved for food use by the Food and Drug Administration of the United States under paragraph 182.20 and has been 'generally recognized as safe' (GRAS No 2308); it is registered by the Council of Europe under No 39n. A monograph on its physiological properties has been published by the Research Institute for Fragrance Materials (RIFM). See also: Composition of essential-oil samples and the Table on standard physical properties.

Adulterations and substitutes Java citronella oil is not often adulterated as its price is lower than that of most other aroma materials. The oil of *Corymbia citriodora* (Hook.) K.D. Hill & L.A.S. Johnson (synonym: *Eucalyptus citriodora* Hook.), which also contains a high proportion of citronellal (about 80%), is used as an alternative source of citronellal for industrial purposes.

Description Perennial, tufted, aromatic grass with numerous erect culms arising from a short rhizome. Culm (stem) up to 2.5 m tall, terete, smooth, glabrous. Leaves sheathing; sheath striate, glabrous, smooth, yellowish or turning purplish-red, those of the culm tightly clasping and shorter than the internodes, those at the base

Cymbopogon winterianus Jowitt – 1, habit of one leafy culm; 2, part of inflorescence; 3, pair of spikelets.

very short, loose, slipping from the culm; ligule chartaceous, about 1 mm long, ciliate; blade linear with long filiform tip, up to 1 m × 1.5(–5) cm, drooping for 2/3 of their length, smooth and glabrous, light green on upper surface, glaucous below, margins often scabrid-serrate. Inflorescence a large, repeatedly branched panicle, 60–100 cm long, axis zigzag, branches of the highest order ending in a spatheole subtending a pair of racemes; spatheole linear-lanceolate, 1–2.5 cm long, many veined, dull reddish; racemes 1–2 cm long, ciliate, one subsessile, the other one stalked, consisting of 4–7 pairs of spikelets, 1 of each pair sessile, the other pedicellate, terminated by 1 sessile and 2 pedicellate spikelets; sessile spikelet oblong-ellipsoidal, 4–5 mm long, with 2 florets; lower glume oblong-lanceolate, shape and size of the spikelet, usually flat, narrowly winged, 2-keeled, 0–3-veined; upper glume boat-shaped, keeled in the upper half, 3-veined; lower floret reduced to empty lemma; upper floret hermaphrodite, lemma 3 mm long, hyaline, 2-lobed, awn up to 5 mm long if present, palea absent, lodicules 2, stamens 3, styles 2 with plumose stigmas; pedicellate spikelet narrowly oblong-ellipsoidal, up to 5 mm long, male or sterile; lower glume shape and size of the spikelet, 7–9-veined; upper glume equal in size, 3-veined; florets represented by a single hyaline scale 3 mm long, wrapped round 3 stamens and 2 lodicules. Fruit a cylindrical to subglobose caryopsis, with basal hilum.

Growth and development Splits of a clump of *C. winterianus* root easily, usually within 3 weeks after planting and tillering starts after the 4th week. Clumps of *C. winterianus* can become up to 0.5 m in diameter and economic lifetime is about 6 years. Flowering starts about 8 months after planting, but plants are cut preferably just prior to flowering. Many cultivars of *C. winterianus*, if allowed to flower, do not produce viable seed. Viviparous formation of plantlets has been observed in inflorescences that had flowered before the start of the rainy season. The plantlets appear to arise from the nodes or the axil of the spatheoles. They sometimes produce their own inflorescence while still attached to the mother plant. The oil content of leaves can differ considerably, depending on age, time of cutting and soil fertility (0.25–1.3%); essential oil content is highest in young leaves.

Other botanical information The name citronella grass refers mainly to 2 grasses producing citronella oil: *C. nardus* (L.) Rendle (Ceylon citronella grass or lenabatu) and *C. winterianus*. Both are morphologically very similar, probably closely related and sometimes even considered as one species. However, *C. winterianus* differs in its wider, shorter and less harsh leaves, its much looser inflorescence, and its distinct venation of the lower glume of the hermaphrodite spikelets. Moreover, the oil of *C. winterianus* differs so much in composition, characteristics and odour that the two oils are neither substitutes nor alternatives to each other. The oil of *C. nardus* is of poorer quality, but because the plant is better adapted to local circumstances (e.g. poor soils and periods of drought) it is preferred for cultivation in Sri Lanka. Occasionally, *C. nardus* is also grown outside Sri Lanka for its essential oil, e.g. in Java, especially var. *confertiflorus* (Steudel) Bor (synonym: *C. confertiflorus* (Steudel) Stapf). Commercially, however, this taxon has no importance. *C. winterianus* also closely resembles *C. flexuosus* (Nees ex Steudel) J.F. Watson (East Indian lemongrass), but the essential oil of the latter is different, being characterized by neral and geranial.

Several high-yielding cultivars have been developed in India. In 1987, 'Mandakini', suitable for the foothills of the Himalayas, and 'Manjusha', suitable for the North Indian Plains were released. They outyield the best older cultivars by 60% and 30%, respectively. Later, a new cultivar, named 'Bio-13', was developed through tissue culture. It is superior in yield to 'Mandakini' and 'Manjusha' and its essential oil has a very high citronellol and geraniol content.

Ecology *C. winterianus* is grown throughout the tropics and warm subtropics, provided moisture is amply available. A total annual rainfall of 2000–2500 mm evenly distributed over the year is needed for good, sustained yields. Where there is a pronounced dry season, irrigation is required if *C. winterianus* is to persist. The oil from leaves harvested after a dry period tends to have an increased aldehyde content. Generally, *C. winterianus* is found below 500 m altitude. However, in India, cultivars adapted to higher altitudes have been selected that yield well up to at least 1200 m, e.g. in tea-growing areas in Assam. Average daytime temperatures of 22–27°C are optimal for growth. Low temperatures retard growth and may reduce leaf-oil content. Even light frost causes severe damage and serious frost is often lethal. Hail storms can severely damage young plantations and cause damage to the leaves in older plantations reducing the oil content. *C. winterianus* requires more fertile soils than the other *Cymbopogon* grasses and on poor soils its economic life is short. It prefers neutral to slightly acid, well-drained, loamy soils with an adequate supply of moisture and nutrients. It tolerates only short periods of waterlogging and is intolerant of salinity.

Propagation and planting *C. winterianus* is generally propagated vegetatively, as propagation by seed takes a long time and carries the risk of including hybrids of *C. winterianus* and *C. nardus*. Offshoots for planting are obtained by division of clumps. Clumps 1 year old give 50–60 rooted splits and 1 ha of clumps is normally adequate to plant 7–8 ha. Hormones or fungicides are rarely applied, as offshoots strike root easily and it is simple and cheap to replace dead plants. Plantlets are placed about 10 cm deep in a hole which is filled in gradually to prevent the crown from rising above ground level. Soil should be well compacted around the young plants. Planting is usually in a square arrangement at a spacing of 60–90 cm × 60–90 cm. Close spacing is most common and generally results in less weed growth and higher yield. *C. winterianus* is sometimes intercropped with young rubber, cocoa, pepper or vanilla or underplanted in tall tree plantations. The degree of canopy shade determines the reduction in herbage yield.

Husbandry Weeds can be controlled by hand or mechanically, manual weeding being generally more effective. Special care is needed to remove lalang grass (*Imperata cylindrica* (L.) Raeuschel). Cultivation should be superficial to avoid damaging the shallow root system or uprooting young plants. No herbicides are recommended for use in *C. winterianus*, but 2,4-D is sometimes applied 2 weeks before planting and several herbicides have been used for spot-spraying after harvesting.

As large amounts of nutrients are removed with the leaves, regular application of fertilizer is essential for sustained production. In experiments, N applications of up to 400 kg/ha per year have given the highest yields. A general recommendation is to apply annually per ha 80–120 kg N, 40 kg P_2O_5 and 40 kg K_2O. In areas where the crop grows actively throughout the year, the recommendation is double these amounts. N applications are always split and are given after harvest. Many small farmers, however, rarely apply any fertilizer at all and abandon the crop when yield drops to an uneconomic level. Larger oil producers in Java have adopted a rotation of 4 years of *C. winterianus* alternating with 2 years of a green manure crop, often a *Tephrosia* or *Mimosa* species.

Diseases and pests Leaf blight caused by *Curvularia andropogonis* may cause serious reductions in leaf and oil production of Java citronella grass. Initial symptoms consist of brownish patches on the tips and margins of leaves, which may dry out later. Prophylactic spraying with dithiocarbamates at intervals of 10–15 days can effectively control the disease. Anthracnose caused by *Colletotrichum graminicola* may also cause damage and is controlled similarly. In Latin America, sugar cane mosaic virus is the most important disease. No serious pests have been reported.

Harvesting The first harvest of *C. winterianus* is usually taken 6–12 months after planting and subsequently 3–4 times per year, depending on the rate of regrowth. In Indonesia, up to 6 cuts per year are sometimes possible, but 4 annual harvests give the highest oil yield. In northern India, the timing of harvesting is related to the onset and duration of the monsoon. In Assam, crops planted in April–May are first harvested after 3–4 months and subsequently every 2 months. During the dry winter season (November–February), only 2 harvests are taken. Many farmers use plant height as an indicator of the best time for harvesting. In Guatemala a crop 140 cm tall is considered ready for harvesting. *C. winterianus* can be harvested for up to 5–6 years, but it is generally more economical to replace a crop after 4 years.

Yield Annual herbage yield of Java citronella grass varies greatly, and may range from 10–30 t/ha. Oil yield also varies considerably between the dry and wet seasons. In India, it ranges from 0.5–0.6% (dry season) to 0.3–0.35% (wet season), in Java from 1.2% (dry season) to 0.5% (wet season), Guatemala and Honduras from 1.8% (dry season) to 0.75% (wet season). Average annual oil yield in Java is estimated at 45–80 kg/ha, in Guatemala at 110 kg/ha. The yield of citronella oil also depends on the distillation procedure.

Handling after harvest After harvesting, the crop is first left in the field to wilt and dry. In Indonesia, drying in the sun for 3–4 hours is usual, except when the grass is very wet after a rainy period. In Sri Lanka and India the crop may be left to dry for 1–2 days. In the Philippines, lowest moisture and highest oil yield were found after drying for 7 days; elsewhere the crop is sometimes left for up to 1 month without much loss in yield. Rapid withering in the sun may slightly increase the monoterpene content. Steam distillation is used to extract the oil from the leaves. Steam pressure varies per country; in Thailand a steam pressure of 150 kPa is recommended, in Sri Lanka

100–200 kPa. In Honduras an initial pressure of 650 kPa is applied, reduced to 250 kPa when condensation begins and raised to 1000 kPa when the condensate flows evenly. The duration of distillation varies with steam pressure and the capacity of the still; a load of 500–600 kg is distilled for about 2 hours. Spent grass is sometimes spread over the field as mulch or used to fuel the still.

Genetic resources Several institutions in South and South-East Asia are involved in germplasm collection and conservation of aromatic grasses. Systematic collection of germplasm of *Cymbopogon* was initiated at the Lemongrass Breeding Station, Odakkali, Kerala, India as early as 1951. The collection now has over 450 accessions. Other major institutions include: the Research Institute for Spice and Medicinal Crops (RISMC), Bogor, Indonesia; the Thailand Institute of Scientific and Technological Research (TISTR), Bangkok, Thailand; the University of the Philippines, Los Baños, the Philippines; the Central Institute of Medicinal and Aromatic Plants, Lucknow, India and the National Board of Genetic Resources, New Delhi, India.

Breeding In India, cultivars of *C. winterianus* adapted to North Indian and South Indian conditions have been developed. Mutation breeding techniques using irradiated plant material have been tried. This resulted in genetic divergence including changes in oil composition, but has not resulted in improved cultivars.

Prospects In spite of its very low price, Java citronella oil is still one of the most widely produced essential oils. Most of the oil is used for industrial purposes and has to compete with synthetic products. Any increase in production cost may lead to an increase in selling price and a reduction in demand and to the cultivation of alternative crops.

Literature |**1**| Boelens, M.H., 1994. Sensory and chemical evaluation of tropical grass oils. Perfumer and Flavorist 19: 29–45. |**2**| Bor, N.L., 1953, 1954. The genus Cymbopogon Spreng. in India, Burma and Ceylon. Journal of the Bombay Natural History Society 51: 890–916 (Part 1, 1953); 52: 149–183 (Part 2, 1954). |**3**| Husain, A., 1993. Present and future of agrotechnology of essential oil plants in India. In: Dhar, K.L., Thappa, R.K. & Agarwal, S.G. (Editors): Newer trends in essential oils and flavours. Tata McGraw-Hill Publishing, New Delhi, India. pp. 174–193. |**4**| Ng, T.T., 1972. Growth performance and production potential of some aromatic grasses in Sarawak – a preliminary assessment. Tropical Science 14: 47–58. |**5**| Sahoo, S. & Debata, B.K., 1995. Recent advances in breeding and biotechnology of aromatic plants: Cymbopogon species. Plant Breeding Abstracts 65: 1721–1731. |**6**| Sharma, J.R., 1993. Trends in genetic degradation of aromatic plants. In: Dhar, K.L., Thappa, R.K. & Agarwal, S.G. (Editors): Newer trends in essential oils and flavours. Tata McGraw-Hill Publishing, New Delhi, India. pp. 249–268. |**7**| Singh, M., Ganesha Rao, S., Prakasa Rao, E.V.S., 1996. Effect of depth and method of irrigation on herb and oil yields of Java citronella (Cymbopogon winterianus Jowitt) under semi-arid tropical conditions. Journal of Agronomy and Crop Science 177: 61–64. |**8**| Soenarko, S., 1977. The genus Cymbopogon Sprengel (Gramineae). Reinwardtia 9: 225–375. |**9**| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 67–86.

C.C. de Guzman & R.A. Reglos

Gaultheria L.

Sp. pl.: 395 (1753); Gen. pl., ed. 5: 187 (1754).

ERICACEAE

x = 11, 12, 13; *G. leucocarpa*: $2n$ = 44

Major species and synonyms

- *Gaultheria leucocarpa* Blume, Bijdr.: 856 (1826), synonyms: *G. crenulata* Kurz (1873) (for var. *leucocarpa* f. *cumingiana*), *G. cumingiana* Vidal (1885) (for var. *leucocarpa* f. *cumingiana*), *Brossaea leucocarpa* (Blume) O. Kuntze (1891).
- *Gaultheria punctata* Blume, Bijdr.: 856 (1826), synonyms: *G. fragrantissima* auct., non Wallich (1820), *Brossaea fragrantissima* (auct.) O. Kuntze (1891), *G. fragrantissima* Wallich var. *punctata* (Blume) J.J. Smith (1914).

Vernacular names General: wintergreen (En). Petit thé des pois (Fr). Vietnam: ch[aa]u th[uj].

- *G. leucocarpa*: Indonesia: gondopuro (Javanese), kering, cantigi bodas (Sundanese). Philippines: logaway (Bagóbo). Thailand: chamayomdoi (Chiang Mai).
- *G. punctata*: Indonesia: gondopura (Javanese), gandarasa, cantigi seungit (Sundanese).

Origin and geographic distribution *Gaultheria* occurs in the Americas, Asia and Australia. The largest number of species is found in Central and South America (about 85), followed by eastern Asia (about 30 species). There are 24 species in Malesia. *G. leucocarpa* is commonly found from Burma (Myanmar) and southern and south-western China through Malaysia, Sumatra, Java, to the Philippines. *G. punctata* is less common and its distribution is restricted to Indonesia (Sumatra, Java and Bali).

Uses The leaves and flowers of several *Gaultheria* species yield wintergreen oil, which has an intensely sweet-aromatic, medicinal fragrance and flavour with a creamy-fruity top note and a sweet-woody dry-out. The oil was formerly used extensively to flavour drinks, in perfumes and in medicine. Its best known use is in root beers and cola drinks, while herbal tea is made from fermented leaves. Other products flavoured with wintergreen oil are candies, chewing gum and toothpaste. Only minute quantities (0.2–0.5 mg per 100 g) should be used, as the taste is prominent. In perfumery, traces of wintergreen oil may add natural notes to e.g. ylang-ylang, tuberose, narcissus, lily and gardenia. It is now rarely used in perfumery, however, because a cheap synthetic form of its main chemical component, methyl salicylate, is available. Isolated natural methyl salicylate is still used in the flavour industry.

Gaultheria is used medicinally against rheumatism, neuralgia, sciata and cancer and also for its carminative and anthelminthic properties. It is a mild antiseptic in mouth care products, e.g. against toothache and sore throat. It is applied in ointments and liniments for its anti-irritant properties. The oil is also a component of insecticidal and insect repellant preparations.

Wintergreen oil from *G. punctata* is used in Indonesia to enhance the smell of finely cut leaves of *Pandanus amaryllifolius* Roxb. (rampeh) and to perfume clothes. Leaf paste is applied externally to ease chest complaints, while in concoctions it is occasionally used as a prophylactic before and after childbirth. The oil is applied in hair oils to control loss of hair. The leaves of *G. punctata* are occasionally chewed together with those of *Piper betle* L. and are used in herbal teas. *G. leucocarpa* is used similarly, but yields much less wintergreen oil. The leaves are used in traditional medicine to treat coughing, tuberculosis, fever and pain. The seeds of both species are used in handicrafts.

Several *Gaultheria* species are grown as ornamentals.

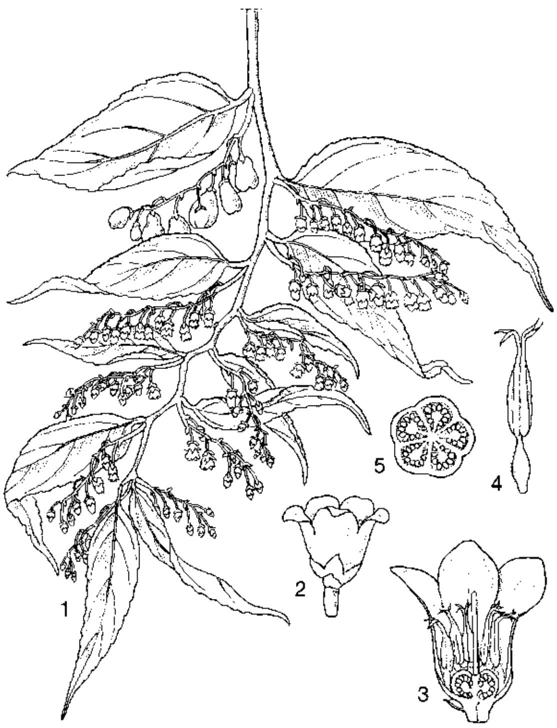
Production and international trade In South-East Asia, *Gaultheria* is only processed for essential oil on a local scale, for flavouring and medicinal purposes. The well-established production of wintergreen oil from *G. procumbens* L. in North America and especially the production of synthetic methyl salicylate make large-scale steam distillation in South-East Asia uneconomical.

Properties The main constituent of wintergreen oil is methyl salicylate. Oil from *G. leucocarpa* from Malaysia contains 96% methyl salicylate. The content of methyl salicylate in some other species is even higher. Most plant parts contain methyl salicylate or its precursors. Fresh leaves and flowers have hardly any odour, but the characteristic odour becomes apparent when they are crushed and stored for a short time. Methyl salicylate is then formed by hydrolysis of glycosides. The oil contains minute quantities of alcohols and ketones. See also: Composition of essential-oil samples.

In the United States wintergreen oil is 'generally recognized as safe' (GRAS No 3113). It is included in the Food Chemical Codex. The maximum use level in food products is 0.04% (in candies). When taken in large amounts methyl salicylate is toxic and causes problems similar to those caused by high doses of aspirin. The acute oral lethal dose (LD50) is about 1 g/kg body weight in the rat. It is a severe eye irritant, but reports on its irritating effect on the human skin are contradictory.

Adulterations and substitutes For application in perfumery methyl salicylate is almost exclusively produced synthetically. Natural products are sometimes adulterated with the synthetic product for this purpose. Only the natural product is used for flavouring, however.

Description Evergreen shrubs or half-shrubs, rarely epiphytic, erect or rarely procumbent, prostrate, creeping or climbing. Leaves arranged spirally or very rarely opposite, mostly serrate. Inflorescence a terminal or axillary raceme or a terminal panicle, sometimes reduced to a few-flowered fascicle or a solitary flower; flowers rather small; pedicel subtended by a large basal bract and 2(–3) higher inserted, mostly small bracteoles; calyx 5-lobed, lobes imbricate, persistent, becoming enlarged, swollen and succulent in fruit, mostly dark purple or almost black; corolla campanulate or urceolate, shortly 5-lobed, lobes imbricate, spreading or recurved; stamens (8–)10, included, attached around the disk to the base of the corolla; filaments mostly dilated at or above the base; anthers dorsifixed, introrse, with 2 apical teeth; disk about 10-lobed, glabrous; ovary superior or semi-inferior, 5-ribbed, 5-locular; style simple, columnar; stigma small, obtuse. Fruit a thin to thick walled, 5-celled capsule, subglobose, enclosed in the fleshy calyx, loculicidally dehiscent from the apex into 5 valves, many-seeded. Seed minute, subglobose to angled-depressed; testa thin, reticulate. Seedling with epigeal germination.



Gaultheria leucocarpa Blume – 1, flowering and fruiting branch; 2, flower; 3, longitudinal section through flower; 4, stamen; 5, cross-section through ovary.

- *G. leucocarpa*. Slender shrub, 0.25–2(–3) m tall, climbing or somewhat decumbent. Branches flexuous, often pendulous; branchlets reddish or purplish. Leaves arranged spirally; petiole 3–9 mm long, purplish; blade ovate to lanceolate-ovate, 3.5–14 cm × 2–6.5 cm, base mostly subcordate, margin regularly, obtusely crenate-serrate with glandular, orange teeth, apex long acuminate to subcaudate, with a small terminal gland, firmly coriaceous, dull dark green above, paler beneath, glabrous or pubescent beneath. Inflorescence a simple, axillary, lax raceme, up to 10 cm long, many-flowered, glabrous or densely pubescent; pedicel recurved, 3–10 mm long; bracts and bracteoles ovate-lanceolate, ciliate; calyx about 2.5 mm long, deeply 5-partite, glabrous on both sides or puberulous inside, lobes ciliate and pale green or red; corolla campanulate, 3–4 mm long, usually glabrous, whitish. Fruit 6–9 mm in diameter, white, rose-tinged or red to black-purple. Seed triangular-obovoid, 0.5 mm long, brown.
- *G. punctata*. Treelet or large shrub, (0.25–) 2–3(–5) m tall, erect or decumbent-scandent. Branchlets stout, sharply trigonous or winged by the decurrent petioles. Leaves alternate; petiole 1–8 mm long, flattened, grooved above, red; blade elliptical-oblong, (2–)4.5–8.5 (–10) cm × 0.8–3(–4) cm, base cuneate, often decurrent into the petiole, margin regularly, coarsely glandular-serrate, teeth rather blunt, apex gradually acuminate, obtuse by a terminal gland, subcoriaceous to coriaceous, glossy dark green and glabrous above, dull greenish-whitish and glandular-punctate beneath. Inflorescence an axillary panicle composed of many, erect, single racemes, (5–)7–10(–12.5) cm long; rachis trigonous, greenish; pedicel 2–9 mm long, white or pink; bract ovate-acuminate; bracteoles inserted immediately below the calyx, opposite, ovate-acute, 1.5 mm long; calyx 3–3.5 mm long, tube white, lobes ovate-acute, reddish, ciliate; corolla subovate-urceolate, 5–7 mm × 4–5 mm, lobes broadly triangular, recurved, white to pinkish-white, glabrous. Fruit 8–10 mm in diameter, dull red to dark red or blackish-purple. Seed obliquely obovoid-triangular, about 0.5 mm long.

Growth and development In South-East Asia, *G. leucocarpa* and *G. punctata* flower throughout the year and self-pollination and self-fertilization seem to be the rule. Some flowers are protandrous with the stamens ripening on the first day and the stigma attaining maturity on the next day, but insect pollinators have seldom been observed. Practically all flowers set fruit. Flowering alternates more or less with fruiting. Plants that are fruiting abundantly generally bear few flowers at the same time.

Other botanical information At present *Gaultheria* comprises about 135(–150) species, including species formerly described as *Pernettya* Gaud. The number of species for South-East Asia may increase considerably as a result of new discoveries in the partially explored mountainous regions of Borneo and New Guinea which are rich in *Ericaceae*.

The very widely distributed *G. leucocarpa* is rather variable and 3 botanical varieties have been distinguished in South-East Asia based on differences in fruit colour and hairiness (in China there are several more):
- var. *hirta* Valeton ex J.J. Smith: leaves, inflorescence and corolla pubescent; fruit unknown; only once collected in Sumatra.
- var. *leucocarpa*: leaves and corolla glabrous, ovary densely pubescent; distributed as the species. It is subdivided into 4 formas which geographically do not overlap: forma *cumin-*

giana (Vidal) Sleumer: fruit deep red to black-purple, inflorescence glabrous, occurring in Burma (Myanmar), Thailand, Indo-China, China, Taiwan, Peninsular Malaysia, Sumatra, Java and the Philippines; forma *leucocarpa*: fruit white or rose-tinged, inflorescence glabrous, occurring in Sumatra and Java; forma *melanocarpa* J.J. Smith ex Amshoff: fruit black-purple, inflorescence densely pubescent, occurring in Peninsular Malaysia, Sumatra and Java; and forma *scandens* Hochr.: fruit white or rose-tinged, inflorescence densely pubescent, occurring in Java and Sumatra.

- var. *psilocarpa* (H. Copel.) Sleumer (syn. *G. psilocarpa* H. Copel.): all parts glabrous; fruit dark red to black-purple; only known from the Philippines.

G. punctata has occasionally been regarded as belonging to *G. fragrantissima* Wallich. The latter, however, has very short, recurved inflorescences and much smaller flowers and is restricted to the Eastern Himalayas and the Khasia Hills.

Although no definite *Gaultheria* hybrids have been described from Asia, it is possible that *G. intermedia* J.J. Smith (collected from an unknown mountain in Java or Sumatra) is a hybrid between *G. leucocarpa* and *G. punctata*. *Gaultheria* hybrids are more common in New Zealand and South America.

The best known species yielding wintergreen oil is *G. procumbens* (Indian wintergreen), occurring naturally in the north-western United States and the adjacent part of Canada; it is also widely grown as an ornamental. *G. malayana* Airy Shaw from Peninsular Malaysia and *G. nummularioides* D. Don, occurring from the Himalayas to Burma (Myanmar), and in Indonesia (Sumatra, Java, Bali) are occasionally used for their wintergreen oil. Several other Malesian *Gaultheria* spp. also have a strong methyl salicylate odour but there are no indications of their use.

Ecology *Gaultheria* species are mostly found in the lowest stratum of montane forest or as open country montane shrubs. *G. leucocarpa* occurs in montane forest and in open, exposed places among brushwood or shrubs at 1300–3300 m altitude. It is fairly common on the margins of craters, steep slopes, on stony, volcanic or sometimes peaty and generally poor soils. It is mostly terrestrial, but occasionally found growing as an epiphyte. *G. punctata* is locally common at higher elevations, mostly in open country on rocky, stony or volcanic soils. In Sumatra it occurs at 1000–3700 m altitude, in Java up to 3100 m.

Agronomy In South-East Asia, *Gaultheria* material is mainly collected from the wild. The fruits, which are sweet with a slightly bitter after-taste, are eaten by birds and rodents, which are believed to be involved in seed dispersal.

Handling after harvest The essential oil from *Gaultheria* is derived by steam distillation of the leaves. Prior to distillation the leaves are steeped in warm water to promote the enzymatic hydrolysis of glycosides to form methyl salicylate.

Genetic resources and breeding No germplasm collections or breeding programmes of South-East Asian *Gaultheria* species are known to exist.

Prospects Since wintergreen oil contains only one major component, and as additional components do not make an important contribution to the quality of the oil, it is unlikely that South-East Asian *Gaultheria* will again become an important source of methyl salicylate. The American *G. procumbens* can satisfy the demand for natural wintergreen oil.

Literature |1| Arctander, S., 1960. Perfume and flavor materials of natural origin. S. Arctander, Elizabeth, N.J., United States. pp. 658–659. |2| Hsu, Ting-zhi, 1981. Preliminary classification of Chinese Gaultheria. Acta Botanica Yunnanica 3: 417–434. |3| Ibrahim, J., Abu Said, A., Abdul Rashih, A., Nor Azah, M.A., Mohd. Zaki & Azizol A.K., 1995. Essential oils of selected Malaysian plants and their potential uses. In: Norhara, H., Bacon, P.S. & Khoo, K.C. (Editors): Proceedings of the third Conference on Forestry and Forest Products Research. Forest Research Institute of Malaysia, Kuala Lumpur, Malaysia. pp. 97–103. |4| Middleton, D.J., 1991. Ecology, reproductive biology and hybridization in Gaultheria L. Edinburgh Journal of Botany 48: 81–89. |5| Middleton, D.J., 1992. A chemotaxonomic survey of flavonoids and simple phenols in the leaves of Gaultheria L. and related genera (Ericaceae). Botanical Journal of the Linnean Society 110: 313–324. |6| Nor Azah, M.A., Abdul Rashih A., Ibrahim J., Abu Said A. & Noorsiha A., 1996. Metil salisilat daripada genus Gaultheria Linn. [Methyl salicylate from the genus Gaultheria Linn.]. In: Azizol, A.K., Khozirah, S., Ibrahim, J., Jamaluddin, I. & Nik Musa'adah, M. (Editors): Prosiding Konvensyen Kebangsaan Tumbuhan Ubatan [Proceedings of the National Cenvention on Medicinal Plants]. Forest Research Institute Malaysia, Kuala Lumpur, Malaysia. pp. 175–179. |7| Perry, L.M., 1980. Medicinal plants of South-East Asia: Attributed properties and uses. MIT Press, Cambridge, United States. p. 133. [8] Sleumer, H., 1966. Ericaceae. In: van Steenis, C.G.G.J. (Editor): Flora Malesiana, Series 1. Vol. 6. Wolters-Noordhoff Publishing, Groningen, the Netherlands. pp. 677–696.

L.S.L. Chua & S. Sunarti

Jasminum grandiflorum L.

Sp. pl., ed. 2: 9 (1762).

OLEACEAE

$2n = 26$

Synonyms *Jasminum officinale* L. var. *grandiflorum* (L.) Stokes (1830), *J. floribundum* R. Br. ex Fresen. (1837), *J. officinale* L. forma *grandiflorum* (L.) Kobuski (1932).

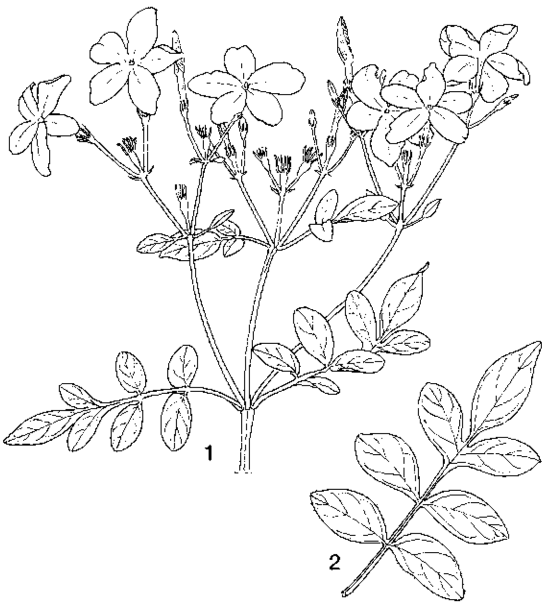
Vernacular names Jasmine, Spanish jasmine, French jasmine (En). Jasmin odorant (Fr). Indonesia: melati gambir (Java). Thailand: chakhaan, sa thaan (northern). Vietnam: chi-nh[af]i.

Origin and geographic distribution The exact origin of *J. grandiflorum* is not known; wild populations occur from China, Burma (Myanmar), Nepal and Bhutan through India, Pakistan and Arabia (Saudi Arabia, Oman, Yemen) to eastern Africa (Egypt, Sudan, Ethiopia, Eritrea, Somalia, Uganda and Kenya). Arabia and the foothills of the western Himalayas have been mentioned as possible areas for its origin. *J. grandiflorum* is widely cultivated in warm temperate, subtropical and tropical climates all over the world for its scented flowers, as an ornamental and as a source of oil. There used to be important plantations in France (Grasse), but when labour became expensive, the major areas of cultivation became Algeria, Morocco, Italy (Calabria and Sicily), Spain and Egypt. In India and China, jasmine has been cultivated for local use since antiquity. In South-East Asia *J. grandiflorum* is mainly cultivated as an ornamental and for its fragrant flowers (e.g. in Indonesia, the Philippines and Thailand). It was introduced into Indonesia from Taiwan and has been cultivated there since 1930; since the 1970s it has also been grown as an industrial crop by smallholders.

Uses In practically all countries in which jasmine occurs its fragrant flowers have been used since antiquity for personal adornment, in religious ceremonies, strewn at feasts and added to baths. Fresh flower production and distribution is a big industry, especially in the Middle East and the Mediterranean, but also in parts of South-East Asia. Jasmine absolute is the major product of *J. grandiflorum* flowers. It has a powerful and tenacious odour and is common in all kinds of perfumes. The residue of the concrete after extraction of the absolute (e.g. wax) can be used in soaps and is an excellent perfume fixative. Attar of jasmine or East Indian jasmine oil is prepared by water distillion of flowers and collecting the distillate in a base oil e.g. sandalwood oil. Perfumed oils are produced by extracting flowers with hot sesame or groundnut oil or by mixing flowers with boiled sesame seed and subsequently expressing the seed oil. Jasmine absolute and concrete are used as additives in food and tobacco. In China and Indonesia, jasmine flowers are popular to flavour tea. Jasmine oil or essence is used medicinally. It is said to stimulate the reproductive system as an aphrodisiac and as a muscle relaxant, by warming and softening nerves and tendons.

Production and international trade In 1994 the United States imported about 10 t jasmine oil valued at about 200 US$ per kg. The export trade in fresh jasmine flowers by air from Bombay to the Middle East and Gulf States totalled 30 t in 1995. Egypt is one of the major suppliers of concrete to the world market. An Indo-French joint venture in Coimbatore processed 500 t flowers in 1995. China consumes much of its production domestically. The area of jasmine cultivation in Central Java was about 580 ha in 1976/1977.

Properties Jasmine concrete, the major jasmine product traded, is obtained by solvent extraction (using petroleum ether, hexane or liquid carbon dioxide) of fresh flowers. It is normally a yellowish to reddish orange-brown waxy solid, only partially soluble in 95% alcohol with an odour like jasmine absolute. Jasmine absolute is a dark orange-brown viscous liquid, darkening with age to red-brown or even deep red. Its odour is intense floral, warm, rich, highly diffusive, with a peculiar waxy-herbaceous oily-fruity and tea-like undertone. Light may reduce the quality of the absolute, especially degrading the benzyl acetate and benzyl benzoate it contains. The major components from jasmine absolute (Egyptian samples) include: benzyl acetate, benzyl benzoate, isophytol, phytol, phytol acetate, linalool and methyl jamonate. Composition varies due to many factors, e.g. cultivar, time of day the flowers were plucked, flower age, weather conditions, season of plucking, time between plucking and extraction, extraction method and extraction solvent. In the United States, jasmine concrete and absolute are 'generally recognized as safe' (GRAS Nos 2599, 2600 respectively). See also: Composition of essential-oil samples.



Jasminum grandiflorum L. – 1, flowering branch; 2, leaf.

Description Evergreen or deciduous shrub, often scandent, 2–3(–5) m tall or long; branches stiff, erect, angular, subglabrous to finely pilose. Leaves opposite, imparipinnately compound, glabrous or finely pilose, coriaceous, glossy-green; rachis flattened or winged; petiole 7–10 mm long; leaflets 3–11; petiolule 0–5 mm long; lateral leaflet blade ovate-elliptical, 0.5–3.5 cm × 0.3–2 cm, base rounded to obtuse, margin entire, ciliolate, apex acute to rounded; terminal leaflet ovate-lanceolate, 1–5 cm × 0.4–2.2 cm, base attenuate and decurrent onto the rachis, margin entire, ciliolate, apex acute-acuminate. Inflorescence cymose, 3–many-flowered; flowers very fragrant, 4–5 cm in diameter; pedicel 3–20 mm long, the central cymose pedicels much shorter than the laterals; calyx tubular, tube up to 2 mm long, lobes 5–7, filiform, 3–10 mm long, glabrous; corolla tubular, tube 15–22 mm long, 4–6-lobed, lobes ovate to narrowly lanceolate, 8–17 mm × 4–8 mm, white, usually reddish tinged or streaked outside; stamens 2, filaments 0.5 mm long, attached at about the middle of the corolla tube, anther 5–5.5 mm long, connective a short acute appendage; pistil with 2-locular ovary, style as long as corolla tube or 6 mm long in short-styled flowers, stigma about 4 mm long, slightly 2-grooved. Fruit a 2-lobed berry, lobes ellipsoid, 10 mm × 8 mm, black when ripe.

Growth and development *J. grandiflorum* grows slowly the first 2 years after planting, but first flowering starts at the age of 6 months. In the 3rd and following years flowering is profuse. *J. grandiflorum* is day-neutral, and floral initiation is promoted by high day and low night temperatures. Mature plants flower for 7–9 months per year in warm regions, 4–6 months in temperate regions. In Europe, Egypt and northern India the main flowering period is usually July–October, in southern India from May to December. Seed set is usually very low and pollen sterility frequently above 75%. Flowers open early in the morning and oil content decreases considerably after 10 a.m. In Europe, flowers contain substantially more essential oil in August and September than in July and October. Jasmine plantations usually remain productive for 10–15 years but perhaps much longer if well-managed.

Other botanical information *J. grandiflorum* is a complex species with wild and cultivated populations. The cultivated plants can best be classified as a cultivar group, here proposed as cv. group Grandiflorum (synonym: subsp. *grandiflorum*) with the following distinctive characteristics: leaflets (5–)7–9(–11), lower petiolules 0–1(–1.5) mm long, terminal leaflet (1–)1.5–3.5(–4) cm long. The wild plants have been classified as subsp. *floribundum* (R. Br. ex Fresen.) P.S. Green and are characterized by: leaflets 3–5(–7), lower petiolules 1–3(–5) mm long, terminal leaflet (1.2–)2.5–3(–5) cm long. *J. grandiflorum* was long considered to be conspecific with *J. officinale* L., a native of the Sino-Himalayan region that is an old, popular jasmine widely grown in temperate climates for its fragrant flowers (common or poet's jasmine). It is much hardier than *J. grandiflorum* for which it has also served as a budding rootstock in temperate climates. *J. officinale* is best distinguished from *J. grandiflorum* by its subumbellate inflorescence with all pedicels almost equally long while in *J. grandiflorum* the inflorescence is cymose and the central pedicels are much shorter than the lateral ones. Confusingly, one of the cultivars of *J. officinale* is called 'Grandiflorum' (synonym: *J. grandiflorum* hort.).

In addition to *J. grandiflorum*, two species – *J. auriculatum* Vahl and *J. sambac* (L.) Aiton – are also commercially cultivated for their essential oil. *J. auriculatum* is widely cultivated in India and Thailand and has simple (unifoliolate) or trifoliolate leaves. *J. sambac*, also with simple leaves, is the most common cultivated species in India and South-East Asia, where it is a major medicinal plant (it relieves headache, rheumatism and other afflictions of the joints). Its flowers and those of *J. multiflorum* (Burm.f.) Andrews are also used to flavour tea. Many other species are cultivated on a small scale for their fragrant flowers and as ornamentals. About 50 *Jasminum* species occur in South-East Asia; they deserve better investigation for their commercial prospects.

Ecology *J. grandiflorum* prefers warm sunny conditions and with adequate soil moisture it can withstand short periods of very high temperatures. Growth and flowering are depressed by shade, low daytime temperatures and cool wet conditions. Some cultivars are drought and frost resistant. *J. grandiflorum* is fairly drought tolerant but flowering is strongly reduced by moisture stress. Plantations are usually below 500 m altitude. Almost any well-drained soil is suitable, but sandy clays or loams (pH 6–8) are preferred. Marshy, waterlogged or very stony soils should be avoided, as should saline soils.

Propagation and planting Since jasmine is very susceptible to root diseases spread from pathogens residing in soil debris, it is necessary to deep plough and to collect and burn plant residues before planting. Jasmine can be propagated by seed, but seed production is usually low, seed viability is seldom above 50% and seed remains viable for 6 months only. Propagation is normally by cuttings, layering or grafting on a selected rootstock, depending on the cultivar. Cuttings 12–20 cm long should be taken from terminal shoots; treatment with a root stimulator increases the strike rate. Layering in the field is done with one-year-old shoots; a slanting cut is made approximately half-way through the shoot some 50 cm from the end; the cut is buried about 10–15 cm deep with the top remaining aboveground. After about 4–6 months the rooted layers can be separated from the parent plant and transplanted. Cuttings taken from shoot tips have given better results than semi-ripe cuttings. They are usually treated with a fungicide, placed in prepared planting holes and watered. A spacing of 2 m × 1.5–2 m is common, requiring some 4000 cuttings per ha, but much closer planting is also practised (up to 30 000 plants per ha). In southern France *J. grandiflorum* is grafted on 2–3-year-old rootstocks of *J. officinale* to give protection against frost. In warmer regions grafting is not needed. Jasmine requires support, ranging from individual stakes and trellises to the post and wire systems used in vineyards. To lower plantation establishment costs it is common to intercrop in the first 2 years, as is done in India. In southern Italy intercropping is done in bergamot orange plantations which start producing after 10–15 years.

Husbandry After planting, jasmine must be weeded regularly, but care must be taken to prevent root damage. Jasmine responds well to fertilizers which are normally applied manually and hoed-in during weeding. An annual application of 15 kg farmyard manure, 60 g N, 120 g P_2O_5 and 120 g K_2O per plant split into 12 monthly doses is usually sufficient. Where farmyard manure or plant residues are not utilized, NPK 10-15-10 is usually applied at planting, but exact amounts should be determined by soil analysis. Irrigation is important when natural rainfall limits flower production. Annual pruning is necessary to ensure that flowers are within reach of pickers, to provide new growth and to remove dead or diseased shoots. Most growers cut back plants to about half their size after flowering (usually to 90 cm) and sometimes leaves are stripped to reduce disease carry-over. Prunings should preferably be burnt. After jasmine cultivation, crop rotation for several years is necessary before jasmine can be planted again on the same field.

Diseases and pests Major root and stem rots in jasmine are caused by *Phytophthora* spp., *Pythium* spp. and *Fusarium* spp. Leaf spots are common on jasmine and may be caused by *Alternaria* spp., *Cercospora* spp., *Puccinia* spp., *Septoria* spp. and in India by *Uromyces hobsoni*. Bud rot caused by *Botrytis* spp. can be extremely damaging in excessively damp or humid conditions. All diseases can be prevented or greatly reduced by burning prunings and plant debris. Jasmine can suffer from many pests, but only few are economically important: the cockchafer *Melolontha melolontha* in Europe and the Middle East and *Cetonia aurata* in warmer areas. Cutworms, especially *Agrotis* spp., damage young plants. Caterpillars that damage foliage in Europe and the Middle East are often *Acherontia atropos*, in warmer Asia they are particularly the army worm (*Spodoptera exempta*) and bud worm (*S. littoralis*). Spider mites (*Tetranychus* spp.) can cause severe defoliation. Nematodes have often been reported, but the extent of their damage is not known.

Harvesting Jasmine flowers are picked manually between dawn and 10 a.m., during the hot season in India even between 3–8 a.m. Preferably only half-opened and fresh fully opened flowers must be picked, not buds or old (yellowish) flowers, as these will depress the quality of the absolute. Although rain makes flowers almost useless, picking flowers in the rain should continue, to promote further flowering. An experienced picker can harvest 0.5 kg flowers per hour, but the pickers are usually young women and children, who achieve 2 kg in 5 hours.

Yield Annual flower yield of jasmine varies from 5.5–12.5 t/ha, on average 5–8 t/ha. Modern commercial plantations average 8–10 t/ha. In Java, production is highest during the rainy season (30 kg/ha per day), and lowest during the dry season (4 kg/ha per day). Concrete yield is about 0.1%; up to 0.3% is reported from India. As an approximate guide, 1000 kg flowers yield 1 kg concrete when solvent extracted, half of this as absolute. The annual average flower yield for *J. auriculatum* in India ranges from 2–9 t/ha, with average concrete yield of 0.3–0.4%. The average annual flower yield for *J. sambac* is 1–7 t/ha and the concrete yield is 0.1–0.2%.

Handling after harvest Jasmine flowers must be quickly processed, since delay substantially reduces essential oil content. Flowers should be kept shaded and cool between picking and processing and the processing facility should be close to the plantation. Freshly picked flowers can be stored in polythene bags at −15°C without loss of yield, quality or odour. Jasmine oil can be obtained from flowers by steam distillation but the yield is very low. Jasmine concrete is obtained from flowers, formerly by enfleurage, currently by solvent extraction. In solvent extraction, flowers are washed up to 3 times with petroleum ether or, preferably, with hydrocarbon-free food-grade hexane; the extract is then distilled to remove the solvent, resulting in the concrete. Concrete is usually produced at the plantation, but absolute is produced where convenient, often in another country.

Genetic resources No substantial germplasm collections of *Jasminum* species are known of. In the countries with commercial jasmine plantations (e.g. India, Egypt, France, Italy, Thailand, the Philippines, Taiwan) working collections are available for breeding but statistics are lacking. In India germplasm of 13 cultivars is present in the Indian Institute of Horticultural Research, Bangalore and at the Tamil Nadu Agricultural University, Coimbatore.

Breeding Variability in jasmines is limited within the Grandiflorum cv. group. There are triploid and tetraploid forms as well as diploid forms. The usual poor seed production is due to abnormal meiosis, cytomixis, defective gene functions and persistent tapetal cells; however, abundant seed-producing clones exist as well. Prospects for breeding, e.g. for disease resistance and higher flower and oil yields seem bright, because variability is large in wild forms of *J. grandiflorum* and there are many other *Jasminum* species. Breeding programmes are in progress in all countries with commercial jasmine plantations, particularly in India.

Prospects Jasmine is interesting in many ways: for its essential oil, as an ornamental, for its fragrant fresh flowers for which there is a considerable market, and for its medicinal properties. The major cultivated species in South-East Asia is *J. sambac*, but it seems worthwhile to investigate the commercial prospects of producing *J. grandiflorum* and other *Jasminum* species as well.

Literature |**1**| Green, P.S., 1965. Studies in the genus Jasminum 3. The species in cultivation in North America. Baileya 13: 137–172. |**2**| Green, P.S., 1986. Jasminum in Arabia. Studies in the genus Jasminum L. (Oleaceae) 10. Kew Bulletin 41: 413–418. |**3**| Green, P.S., 1997. A revision of the pinnate-leaved species of Jasminum. Studies in the genus Jasminum (Oleaceae) 15. Kew Bulletin 52: 933–947. |**4**| Guenther, E., 1952. The essential oils. Vol. 5. Concrete and absolute of jasmine. D. van Nostrand Company, New York, United States. pp. 319–338. |**5**| Musalam, Y., Kobayashi, A. & Yamanishi, T., 1988. Aroma of Indonesian jasmine tea. In: Lawrence, B.M., Mookherjee, B.D. & Willis, B.J. (Editors): Flavors and fragrances: a world perspective. Proceedings of the 10th International Congress of Essential Oils, Fragrances and Flavours, Washington, DC, United States, 16–20 November 1986. Elsevier Science Publishers B.V., Amsterdam, the Netherlands. pp. 659–668. |**6**| Srivastava, H.C., 1995. French jasmine. In: Chadha, K.L. & Rajendra Gupta (Editors): Advances in horticulture. Vol. 11. Medicinal and aromatic plants. Malhotra Publishing House, New Delhi, India. pp. 805–823. |**7**| Tobroni, M., 1981. Tanaman melati di Jawa Tengah dan Yogyakarta [Jasminum cultivation in Central Java and Yogyakarta]. Warta BPTK 7 (3/4): 343–353. |**8**| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 342–361.

P.C.M. Jansen

Lavandula L.

Sp. pl.: 572 (1753); Gen. pl., ed. 5: 249 (1754).

LABIATAE

$x = 6$. *L. angustifolia*: $2n = 48, 54$; *L. latifolia*: $2n = 50$; *L. stoechas*: $2n = 30$

Major species and synonyms

- *Lavandula angustifolia* Miller, Gard. dict. ed. 8, No 2 (1768), synonyms: *L. spica* L. (1753, p.p., nomen ambig.), *L. officinalis* Chaix (1786), *L. vera* DC. (1815).
- *Lavandula latifolia* Medikus, Bot. Beobacht. (Mannheim) 1783: 135 (1784), synonyms: *L. spica* auct., non L.
- *Lavandula stoechas* L., Sp. pl.: 573 (1753).
- *Lavandula ×intermedia* Emeric ex Loisel., Fl. gall. ed. 2, 2: 19 (1828), synonym: *L. ×burnati* Briquet (1895).

Vernacular names General: Lavender (En). Lavande (Fr).
- *L. angustifolia*: common lavender, English lavender (En). Lavande véritable, lavande vraie, lavande femelle (Fr).
- *L. latifolia*: spike lavender (En). Aspic, grande lavande, lavande mâle (Fr).
- *L. stoechas*: French lavender, Spanish lavender, Arabian lavender (En). Lavande maritime, lavande stéchas, queirelet (Fr).
- *L. ×intermedia*: lavandin, Dutch lavender (En). Lavandin, lavande bâtarde (Fr).

Origin and geographic distribution *Lavandula* comprises about 30 species and occurs naturally from the Canary Islands to India through the Mediterranean region where it has its greatest diversity. *L. angustifolia* and *L. latifolia* are found throughout the northern Mediterranean from Portugal to Greece; *L. stoechas* occurs in the same region and also in northern Africa and the Middle East; *L. angustifolia* and *L. ×intermedia* are grown commercially for their essential oil in Bulgaria and the Mediterranean, mainly in south-eastern France, Italy, Spain and also in Russia, United Kingdom, Australia and on a small scale in many parts of the world. The 4 taxa are also cultivated worldwide as ornamentals.

Until the beginning of the 20th Century *L. angustifolia* was only rarely cultivated for the essential oils and was mainly collected from wild stands. The depopulation of southern France during the 19th Century led to a wide and rapid colonization of abandoned fields by *L. angustifolia* and *L. latifolia*, especially in places where they were extensively grazed. This expansion led first to intensified collection of lavender from the wild and the building of a trading network for the upcoming perfume industry and later to the introduction of crop husbandry practices in the wild stands. Only since about the 1920s has lavender been cultivated. The first plantations were of *L. angustifolia*; from 1923 experimental plantations of *L. ×intermedia*, which had to be multiplied vegetatively, proved very successful. Cultivation spread rapidly, as crop husbandry methods and marketing had already been developed. *L. stoechas* and *L. latifolia* are occasionally collected from wild stands for their essential oils. Lavenders are only occasionally cultivated in South-East Asia, mostly as ornamentals.

Uses Lavender (all parts, but particularly flowering branches) is of ancient use as an aromatic and medicinal plant. It was used in Roman times to perfume bath water. Today, the lavender oils combined rank economically among the 10 most important essential oils of the world after citrus, rose and mint oils. *L. angustifolia* yields true lavender oil, which is an important component in luxury perfumery, while *L. ×intermedia* yielding the less costly lavandin oil is used to scent cosmetic products, detergents and soaps and to impart aroma to various foods. Lavender oil has been applied in painting, as preservative in egg-based distemper and as an additive to oil paints. The oil from *L. latifolia* is of limited interest as an aroma material. *L. stoechas* has been grown since the Middle Ages in England and the Mediterranean for its scent. In western India it is still a medicinal plant. Sachets filled with dried flowers, leaves and stalks of several *Lavandula* spp. are placed between clothes and linen to impart a pleasant smell and to repel moths. Lavender is also used to flavour tea, salad oil and vinegar, drinks, sweets and food. The flowers are a source of honey. Malay people pour out lavender water at grave sites in libation ceremonies.

Lavandula has played an important role in medicine since antiquity and its effectiveness as bactericide and astringent has been confirmed experimentally. Large amounts of lavender were burnt in France until the 18th Century during plague epidemics to ward off the disease. Infusions of the flowers are taken against throat complaints, the oil is employed as insect repellent, to treat insect bites, to heal burns and wounds and as vermifuge. The aroma has a calming effect and can soothe headaches and help treat insomnia.

Production and international trade Annual world production of lavender oil is about 250 t (1995–1998), that of lavandin oil is over 1000 t and is still increasing. The main producers of lavender oil are Bulgaria (over 100 t per year) and France (nearly 100 t), while France is the main producer of lavandin oil with over 800 t per annum of which 500 t are from cv. Grosso. The value of lavender oil is about US$ 30 per kg, that of lavandin oil about US$ 11.5 per kg (1998). Spike lavender oil and cantueso oil are of minor importance. Spike lavender oil is mainly produced in Spain and Portugal. Its production is declining gradually, from a maximum of over 200 t per year to about 50 t at present. The total quantity of cantueso oil produced is less than 100 kg per year.

Properties The essential oil steam-distilled from the flowering branches of *L. angustifolia* is a colourless or pale yellow liquid. Its aroma has a sweet, fresh-fruity top note, a sweet, floral-herbaceous, refreshing body and a pleasant, herbal, balsamic-woody undertone. Its main chemical components are: linalool, linalyl acetate, 1,8-cineole, limonene, pinenes, caryophyllene and lavandulyl acetate. Linalyl butyrate and N compounds, present in traces only, are said to add a characteristic aromatic note. In perfumery, lavender oil from clonal plantings is considered less rich and consequently of poorer quality than the oil from more variable crops grown from seed. English lavender oil, which is distilled exclusively from the flowers of cultivars selected in the United Kingdom, has a somewhat different character. It is richer in linalool and rather poor in linalyl esters, but lacks the harshness of spike lavender and lavandin oil.

Each cultivar of *L. ×intermedia* yields an oil with its own characteristics, but in general their odour is close to that of lavender oil but harsher and often with a camphorous note inherited from *L. latifolia*. The oil has a fresh, strongly herbaceous, cineolic top note that should not be distinctly camphorous, a rich, herbaceous, woody body and a delicate herbal dry-out lasting 24 hours. Its chemical composition is similar to lavender oil, the camphor content may be as low as 0.7% and as high as 8%.

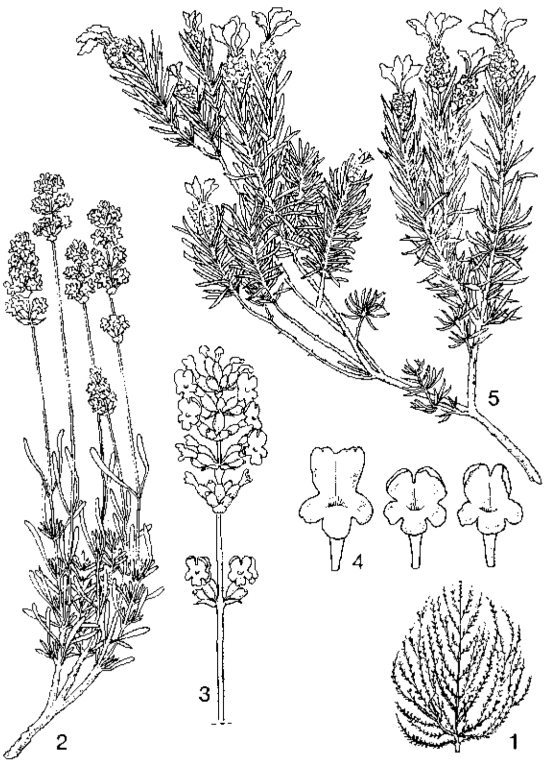
Spike lavender oil obtained by steam distillation (mostly in France) or by water and steam distillation (mostly in Spain) of flowering branches of *L. latifolia* is a pale yellow to water-white, mobile liquid with a cineolic top note, a fresh, herbaceous body and a somewhat dry-woody undertone. Its main chemical components are linalool, camphor, camphene and 1,8-cineole. The oil is considered inferior to true lavender oil and lavandin oil.

The essential oil from *L. stoechas*, cantueso oil, is only used medicinally and contains the following chemical components: fenchone, camphor, pinocarvyl acetate and smaller amounts of fenchol, myrtenal, myrtenol, cis-verbenol, p-cymen-8-ol, trans-carveol, cadinene and ledol.

Lavender oil and lavandin oil have been approved for food use by the Food and Drug Administration of the United States under paragraph 182.20. The maximum use level in food products is about 0.004% (in baked goods). The oils are 'generally recognized as safe' (GRAS Nos 2622 and 2618, respectively). The same is true for spike lavender oil (GRAS No 3033). See also: Composition of essential-oil samples and the Table on standard physical properties.

Adulterations and substitutes True lavender oil may be adulterated with oil from other *Lavandula* spp., but rigorous inspection and the use of standard qualities in perfumery has limited the practice. As a source of linalool lavandin oil can be replaced in most applications by linalool from several other sources, the price of the oil often being the main consideration. Spike lavender oil is more often adulterated because of its relatively high price and the easy availability of adulterants such as sage oil, lavandin oil and eucalyptus oil.

Description Aromatic shrubs or rarely perennial herbs, erect or ascending, often much branched, with stellate indumentum; root system superficial. Leaves opposite, simple, exstipulate, usually entire. Inflorescence terminal, lax or crowded spike-like, composed of axillary, 1–10-



Lavandula angustifolia Miller – 1, habit; 2, flowering branch; 3, inflorescence; 4, 3 corolla types. L. stoechas L. – 5, flowering branch.

flowered verticillasters; bracts distinct from leaves; bracteoles usually absent or indistinct; flowers with short pedicel or subsessile; calyx ovoid-tubular to tubular, slightly dilated in fruit, straight, 2-lipped, upper lip not lobed, protracted into an appendage, lower lip equally (2–)4-toothed, teeth narrower than in upper lip; corolla sympetalous, usually blue or purple, sometimes white or pink; tube exserted, throat somewhat dilated; limb 2-lipped, upper lip 2-lobed, lower one 3-lobed; stamens 4, didynamous, anterior 2 longest, included in corolla tube; ovary superior, deeply 4-partite, glabrous; style inserted at ovary base, apex bifid with flattened lobes. Fruit a conglomerate of 4, 1-seeded, smooth, shiny nutlets, with a basal-dorsal areole.

- *L. angustifolia*: Shrub, 1–2 m tall. Branches grey-brown to dark brown with long flowering and short leafy shoots, bark longitudinally peeling. Leaves clustered on leafy shoots, widely spaced on flowering shoots; petiole very short; blade linear-lanceolate to linear, 17 mm × 2 mm on leafy shoots, 2–6 cm × 3–6 mm on flowering shoots, grey stellate tomentose, base attenuate, margin entire, revolute, apex obtuse. Inflorescence a crowded, interrupted or nearly continuous spike, 2–8 cm long; verticillasters numerous, 6–10-flowered, upper ones densely crowded; peduncle about 3 times longer than the spike; bracts papery, rhombic-ovate, 3–8 mm long, length/width ratio 0.8–2.2, rust-coloured when dry; bracteoles absent or up to 2.5 mm long; pedicel 1–1.5 mm long; calyx 4–7 mm long, densely grey stellate tomentose outside, with 13 longitudinal ribs, upper lip entire, appendage obcordate, lower one 4-toothed; corolla 10–12 mm long, blue, densely tomentose outside, base subglabrous, throat and limb glandular hairy, upper lip straight, its lobes circular, slightly overlapping, lower lip spreading. Nutlets narrowly cylindrical.
- *L. latifolia*: Half-shrub, 1–2 m tall. Leaves clustered at branch bases, widely spaced apically, oblong-lanceolate, 2–6 cm × 0.5–1 cm, densely grey-green stellate tomentose, base attenuate, margin entire, apex obtuse to acute. Inflorescence interrupted and often branched, 15–25 cm long; peduncle 17–30 cm long; bracts linear, almost 1 cm long; bracteoles linear, up to 3 mm long; verticillasters 7–8, 4–6-flowered, lax; calyx tubular, straight, 5–6 mm long, densely stellate tomentose, 13-veined, 5-toothed, posterior tooth largest; corolla 8–10 mm long, purple, densely tomentose, upper lip straight, lobes divaricate almost at a right angle, ovate, apex obtuse, lobes of lower lip subcircular. Nutlet cylindrical.
- *L. stoechas*: A very variable shrub up to 1 m tall, grey-tomentose. Leaves linear to oblong-lanceolate, 10–40 mm long, sessile, usually grey-tomentose. Spike very dense, usually 2–3 cm long; peduncle length very variable; fertile bracts rhombic-cordate, 4–8 mm long, tomentose; upper sterile bracts oblong-obovate, 10–50 mm long, usually purple, often forming a coma on top of the spike; verticillasters 6–10-flowered; calyx 4–6 mm long, 13-veined, upper tooth with an apical, obcordate appendage 1–1.5 mm wide; corolla 6–8 mm long, usually dark purple, rarely white to pink.
- *L. ×intermedia*: variably intermediate between its parents *L. angustifolia* and *L. latifolia*.

Growth and development Lavenders are short-lived perennials. After establishment in the field a first small harvest of flowers is possible after 1 year. Real production starts in the 2nd year, peaks in the 3rd and 4th years and can continue for 10–15 years, depending on soil conditions and diseases. Essential oil content starts declining from the 5th year onwards. In France, flowering and harvesting is between mid-July and mid-September depending on species and cultivar. In France, *L. latifolia* flowers 2–3 weeks later than *L. angustifolia*. Best harvest time is when 60–80% of the crop is in flower. Pollination is mainly effected by insects, in France by commercially exploited honeybees. Nectar extraction by bees is said to raise the return of the oil by 10–15% too.

Other botanical information In *L. angustifolia* 2 subspecies and many cultivars (mostly ornamentals) are distinguished:

- subsp. *angustifolia*: bracts usually shorter than the calyx; calyx 4–6 mm long, appendage of upper lip obscure. Occurring throughout the range of the species. Several cultivar groups can be distinguished on the basis of flower colour:
  - Blue-flowered cultivars, e.g.: 'Backhouse Purple', flowering plants up to 90 cm tall; 'Maillette', flowering plants up to 45 cm tall, in France important in clonal plantations; 'Munstead', flowering plants up to 40 cm tall, spikes loose; 'Super Bleue', most important cultivar for the production of dried flowers in France.
  - Pink-flowered cultivars, e.g.: 'Rosea', vegetatively up to 25 cm, flowering up to 45 cm tall, used in eau-de-Cologne; 'Hidcote Pink', dwarf and dense, up to 30 cm tall; 'Loddon Pink', up to 45 cm tall, flowers soft pink.

- Purple-flowered cultivars, e.g.: 'Atropurpurea', very dark purple; 'Hidcote Giant', up to 1 m tall, flowers deep purple; 'Middachten', flowering plants up to 45 cm tall, plants are weak and strike root poorly; 'Royal Purple'; 'Summerland Supreme'.
- White-flowered cultivars, e.g.: 'Alba', dwarf, vegetatively up to 35 cm, flowering up to 45 cm tall; 'Dutch White', tall with leaves up to 7 cm long; 'Nana Alba', dwarf, vegetatively 10 cm and flowering up to 25 cm tall.

Based on robustness there is a group of cultivars called Dauphiné Lavender (classified as var. *delphinensis* Rouy & Foucaud). This group has flowering stems up to 50 cm long, with leaves sometimes slightly revolute and widely interrupted spikes. It is said to grow in valleys and to be less fragrant than dwarf cultivars.

- subsp. *pyrenaica* (DC.) Guinea: bracts usually exceeding calyx; calyx 6–7 mm long, appendage of upper lip distinct, hairs on calyx confined to the ribs. Occurring in the Pyrenees and northern Spain.

L. angustifolia grown for the essential oil is usually propagated from seed and although many cultivars are known, most are rarely used at present. More important are the cultivars that can be propagated vegetatively as clones. In France 'Maillette' and 'Matheronne' are most popular. The quality of their essential oil is inferior to that of oil from plantations raised from seed, but clonal plantations are uniform and more easily managed.

L. latifolia develops a shorter wood base than *L. angustifolia*, but its annual stems are as long as or longer than its ally. Its inflorescence is more slender and more often branched. It is not much cultivated.

L. stoechas is a very variable species. Mainly based on differences in length of peduncles, bracts, and spikes, and on differences in the calyx appendage, 6 subspecies have been distinguished. *L. stoechas* is not much cultivated for its essential oil, it has more value as an ornamental. Well known cultivars include: 'Alba', flowers white; 'James Compton', erect, up to 1 m tall with fragrant leaves, deep purple flowers and large pale purple bracts; 'Papillon', sterile bracts very long and narrow, bright purple.

L. ×*intermedia* is a sterile hybrid between *L. angustifolia* and *L. latifolia* and is intermediate in many characteristics, but is taller than both parents. The hybrids occur naturally in the altitudinal zone where the habitat of the parents overlap. The tall, sterile plants were noted already when lavender was only collected from wild stands and were first taken into cultivation in France in the 1920s. The major cultivars grown in France are: lavandin abrial ('Abrialii'), lavandin super ('Super') and lavandin grosso ('Grosso'). Lavandin abrial was the first cultivar developed, but due to its susceptibility to 'lavender decline' has been almost completely replaced by lavandin grosso. 'Grosso' is by far the most widely grown, planted on about 80% of the lavandin area. The essential-oil content of its flowers is only reasonable, but this is compensated by its very strong growth.

Ecology *Lavandula* occurs naturally on dry, exposed, stony slopes. In their natural habitat *L. angustifolia* and *L. latifolia* are separated by altitude. In southern France the former occurs from 600–1400 m, the latter from 200–500(–600) m altitude. They are fairly tolerant of drought, tolerant of high temperatures during summer and frost in winter. *L. angustifolia* occasionally occurs below 600 m altitude and then often hybridizes with *L. longifolia*. In cultivation, *L. angustifolia* is found at lower altitudes than when growing wild, and mainly up to 800 m. It requires a well-drained soil. In their natural habitat *L. angustifolia* and to a lesser extent *L.* ×*intermedia* and *L. latifolia* prefer calcareous soils, while *L. stoechas* is found on siliceous soils.

Propagation and planting *L. angustifolia* is mostly propagated by seed, sown either in autumn or in spring, depending on the severity of the winter. Sowing was formerly often done directly into the field, but the use of nurseries has become common practice. Plants remain in the nursery for at least a year. Clonal plantings of *L. angustifolia* and *L.* ×*intermedia* are made from cuttings. Healthy mother plants are cut near ground level; the branches can be stored for several months in a cool damp place until labour is available to divide them into cuttings of 10–15 cm long with 1–2 branches. Cuttings are planted out in a nursery in spring. They should be planted deep, about two-thirds of the cutting should be in the ground. They are ready for transplanting after about one year. Cuttings from green branches can also be used, provided they are treated with growth hormones and kept in a greenhouse under mist. Recently, in vitro methods have been developed for the multiplication of lavender.

Planting out in the field is done in autumn, except where low winter temperatures might cause damage to the young plants. Planting is either in rows 1.5 m apart with 0.4 m within the row, or in a square arrangement at a wide spacing allowing each plant to grow out fully, using 10 000 plants/ ha for *L. angustifolia* or 4000–5000 plants/ha for *L. ×intermedia*.

Husbandry Many spontaneous fields of lavenders in the north-western Mediterranean, especially in France, have been improved by husbandry methods. Clearing of stones and application of ash as fertilizer were among the first measures taken. Fields were also ploughed to uproot old plants and stimulate the growth of young ones. Natural stands should be grazed, as otherwise broom (*Cytisus* sp.) may replace lavender as the dominant vegetation.

In cultivated lavender, the soil is loosened superficially 2–3 times during spring to maintain a soil mulch and to control weeds. Care should be taken to avoid damaging the superficial root system. Weeding can also be done with herbicides. Where weeding is neglected, dodder (*Cuscuta* sp.) can become a serious problem. Regular applications of fertilizers are recommended; in France, N fertilizer is recommended after harvesting and in spring.

In *L. angustifolia*, selections from high elevations and north-facing slopes giving the best quality oil were often used. These selections were then planted at lower elevations on south-facing slopes and on very poor soils. Higher plant densities often used in row plantings increased the risk of moisture stress. Mechanized maintenance caused damage to the root system, further aggravating the situation. Under such conditions crops survive for only a few years, making them very susceptible to 'lavender decline'. *L. ×intermedia*, although adapted to lower altitudes, also suffered from being planted on poor, drought-prone soils, too high planting densities and root damage due to mechanical weeding. Many selections that inherited a poor adaptation to calcareous soils from *L. latifolia*, suffered when planted on soils suitable for plantings of *L. angustifolia*. Under such conditions the life of *L. ×intermedia* was also reduced to about 3 years. The robust 'Grosso' is more tolerant of the conditions leading to 'lavender decline' and has become the dominant cultivar in south-eastern France.

Diseases and pests Since the 1950s 'lavender decline' ('dépérissement') has caused serious losses in lavender in France and neighbouring countries mainly by reducing the economic life of plantations from 15–20 years to as little as 3 years, rendering the crop uneconomic. The disease is probably caused by a combination of unfavourable growing conditions and mycoplasmas. Root rot caused by *Armillaria mellea* is the most serious fungal disease in lavenders. There is no economic method of control, and prevention by cleaning fields before planting and rogueing of infected plants are the only possible measures. *Thomasiniana lavandulae* is the most important of the various insects attacking lavenders. Its larvae feed under the bark, causing the tops of branches to dry out and break.

Harvesting Lavenders are harvested when in full bloom; in France from 15 July to 15 September for *L. angustifolia* and *L. ×intermedia*. Formerly, harvesting was done by hand using a sickle, but mechanical harvesters have been developed. When harvesting by hand, a very productive labourer can cut 500–600 kg lavender stalks per day, mechanical harvesters 3–4 ha or 7500 kg.

Yield In France, the yield of lavender oil is about 40 kg/ha, that of lavandin oil up to 120 kg/ha, while the yield of spike lavender oil is about 50 kg/ha.

Handling after harvest After harvesting, stalks of lavender are left to dry in the field for a few days. They are then steam-distilled, either in small field stills or in large factories. Small modern stills can distil about 1000 kg stalks in 30 minutes.

For the production of dried flowers, stalks are dried for several days turning them 2–3 times per day. When fully dry, a tractor is passed over the stalks to free the flowers. They are then collected and carefully cleaned.

Genetic resources Germplasm collections of *Lavandula* are maintained by the Institut National de la Recherche Agronomique (INRA) in Antibes, France and smaller ones in the Western Regional Plant Introduction Station, Pullman, Washington, United States.

Breeding Interest in breeding work of lavender has declined since the development of *L. ×intermedia* 'Grosso' and of clonal selection of *L. angustifolia*. The high costs and long time required to develop new cultivars limit interest in breeding work.

Prospects Although the fragrance of lavender is currently less in vogue than in the first half of the 20th Century, lavender remains one of the most widely used natural fragrance materials. In luxury perfumes, the essential oil from plantings of *L. angustifolia* grown from seed will remain a component that can hardly be replaced by synthetic aroma compounds. In South-East Asia the main use of lavender will probably remain as an ornamental, but the potential of lavender as an essential oil crop in the region should be considered seriously.

Literature |1| Boelens, M.H., 1995. Chemical and sensory evaluation of Lavandula oils. Perfume and Flavorist 20(3): 23–51. |2| Chaytor, D.A., 1937. A taxonomic study of the genus Lavandula. Journal of the Linnean Society, Botany 51: 153–204. |3| Gras, R. & Montarone, M., 1993. Le dépérissement des plantes arbustives à parfum. 1ère partie: la mise en culture; 2ème partie: l'évolution des techniques [Decline of perfume shrub-plants. part 1: domestication; part 2: evolution of techniques]. PHM Revue Horticole 335: 17–20; 336: 19–24. |4| Guinea, E., 1972. Lavandula. In: Tutin, T.G. et al. (Editors): Flora Europaea. Vol. 3. University Press, Cambridge, United Kingdom. pp. 187–188. |5| Kokkalou, E., 1988. The constituents of the essential oil from Lavandula stoechas growing wild in Greece. Planta Medica 54: 58–59. |6| Lawrence, B., 1996. Progress in essential oils. Perfumer and Flavorist 21: 55–68. |7| Meunier, C., 1992. Lavandes et lavandins [Lavenders and bastard lavenders]. Édisud, Aix en Provence, France. 224 pp. |8| Peracino, V., Caramiello, R. & Maffei, R., 1994. Essential oils from some Lavandula hybrids growing spontaneously in north west Italy. Flavour and Fragrance Journal 9: 11–17. |9| Segura, J. & Calvo, M.C., 1991. Lavandula spp. (Lavender): in vitro culture, regeneration of plants, and the formation of essential oils and pigments. In: Bajaj, Y.P.S. (Editor): Biotechnology in agriculture and forestry. Vol. 15. Medicinal and poisonous plants. Springer Verlag, Berlin, Germany. pp. 283–310. |10| Tucker, A.O. & Hensen, K.J.W., 1985. The cultivars of lavender and lavandin (Labiatae). Baileya 22: 168–177.

H.C. Ong

Litsea cubeba (Lour.) Persoon

Syn. pl. 2: 4 (1807).

LAURACEAE

$2n = 24$

Synonyms *Laurus cubeba* Lour. (1790), *Litsea citrata* Blume (1826), *Tetranthera polyantha* Wallich ex Nees var. *citrata* Meissner (1864).

Vernacular names May chang (originally Chinese), pheasant pepper tree (En). Indonesia: krangean (Javanese), lado-lado (Sumatra), baleng la (East Kalimantan). Malaysia: medang ayer, medang melukut. Thailand: chakhai-ton (northern), takhrai (south-western), takhrai-ton (north-eastern). Vietnam: c[aa]y m[af]ng tang.

Origin and geographic distribution *L. cubeba* occurs wild from the eastern Himalayas to continental South-East Asia, Malaysia, Indonesia (Java, Kalimantan, Sumatra), southern China (up to the Yangtze river) and Taiwan. It is cultivated for its essential oil mainly in Japan, China and Taiwan. In Java it is grown on a small scale.

Uses Essential oils are steam-distilled from the fruits and from the leaves of *L. cubeba*. The essential oil obtained from the fruits is called 'may chang' oil. It is a commercial source of citral which is used for the production of ionones and formerly vitamin A and in essences for cosmetics, foodstuffs and tobacco products. Because of its pleasant citrus-like smell and taste it is a modifier for lemon and lime flavours and a general freshener in fruit flavours. In perfumery may chang oil is used as an alternative for verbena oil and lemongrass oil in colognes, household sprays, soaps and air-fresheners.

In Java, 2 slightly different essential oils are steam-distilled from the leaves. The oil produced in West Java is called trawas oil, that from Central Java krangean oil. Both oils are used medicinally and in soap perfumes.

In Indonesia, the fruits are eaten as a vegetable side dish and are a common substitute for the spice *Piper cubeba* L.f., while in northern Vietnam tea is sometimes flavoured with the flowers.

All plant parts of *L. cubeba* are applied medicinally and have antiparalytic, anticephalalgic, antihysteric, carminative, spasmolytic and diuretic properties. The fruit is used in decoction for the treatment of vertigo, paralysis and in post-partum preparations; the leaves for treating skin diseases. Traditionally the Dayak Kenyah people of East Kalimantan use the fruits and bark as oral and topical medicine for babies as well as for adults. It is applied in cases of fever, stomach-ache, chest pain and as a tonic. It is also an antidote to treat drunkenness. In aromatherapy the oil is applied as a cooling agent against acne and dermatitis, and to relieve anxiety and stress. Recent studies found that the essential oil may be useful in the treatment of cardiac arrhythmia. *L. cubeba* oil has in vitro antifungal properties against several pathogens such as *Alternaria alternata*, *Aspergillus niger*, *Candida albicans*, *Fusarium* spp., *Helminthosporium* spp.

In China *L. cubeba* is planted as a wind-break in tea plantations and the wood has some value as timber. In Nepal the leaves serve as a source of fodder, while in Assam (India) muga silkworms (*Antheraea assama*) are sometimes reared on the leaves.

Production and international trade China is the major producer of may chang oil, with an annual production of about 2000 t, of which more than 50% is exported. *L. cubeba* oils fetch a price per kg of US$ 4 (1994), thus competing strongly with lemongrass oil. Trawas oil and krangean oil are produced on a small scale only and are not traded internationally.

Properties All parts of *L. cubeba* contain essential oil, but only may chang oil steam disilled from the fruit is of major commercial importance. The essential oil content of the fruit ranges from 0.3–5.0% (dry weight). May chang oil is pale yellow with a fresh lemon-like and sweet-fruity smell and a soft, sweet-fruity dry-out. It is almost free of the fatty-grassy notes of lemongrass oil, but lacks the tenacity of the latter. In perfumery it blends well with many other natural and synthetic aroma materials. The main chemical component is citral, which is a mixture of the stereoisomers geranial and neral. Other components are limonene, methyl-heptenone, α-pinene and linalool. The oil has been approved for food use by the Food and Drug Administration of the United States in paragraph 182.20. See also: Composition of essential-oil samples and the Table on standard physical properties.

The leaves of *L. cubeba* contain up to 7% essential oil (dry weight). The chemical composition of the oil is variable. Krangean oil from Central Java contains mainly 1,8-cineole (about 50%), and smaller amounts of citral (10%), citronellal (1%), linalool, α-pinene and β-pinene; in trawas oil, from West Java, the main components are 1,8-cineole and citronellal (both 25%). Analysis of a leaf oil from China indicated 1,8-cineole (50%) and sabinene (17%) as the main components, while linalool (78%) was the primary component of a leaf oil from India. Analysis of a flower oil in China indicated sabinene as the main component (62%). A sample of bark oil from India contained citronellol (41%), linalool (22%) and citronellal (18%). Several alkaloids have also been isolated from various parts of *L. cubeba*. Among those recently isolated and identified are laurotetanine, O-methyloblongine, oblongine, xanthoplanine and magnocararineu. Bioassay studies have indicated termicidal, antiasthmatic and antianaphylactic activities. The seed contains a fatty oil, from which lauric acid and capric acid are produced.

Adulterations and substitutes Because of its lower market price, may chang oil is often used as a substitute for lemongrass oil, but synthetic citral is even cheaper. May chang oil is sometimes adulterated with synthetic citral.

Description Small, dioecious, deciduous tree or shrub, 5–10(–15) m tall; trunk terete, up to 6(–20) cm in diameter; bark 1 mm thick, very tough, green outside, yellow inside, smooth, with large lenticels, lemon-like scent and pungent taste; branchlets slender, glabrous but apical parts ferrugineous-villose. Leaves alternate, simple, aromatic; petiole 8–18 mm long; blade lanceolate to oblong, 7–15 cm × 1.5–3 cm, base acute, apex long-acuminate, membranaceous or chartaceous, finely pellucid-dotted, brownish-green when young, shiny dark-green above, glaucous below, lateral veins slender, in 8–12 pairs. Inflorescence an axillary, 4–5-flowered, umbelliform raceme, about 1 cm long; primary peduncle accrescent, up to 1 cm long; secondary peduncle thin, 5–8 mm long, with basal, lanceolate bract and apically a globose involucre of 4 decussate bracts surrounding the umbel like a flower bud; pedicel minutely puberulous, 3–4 mm long; flower 3–4 mm in diameter, yellowish-white; tepals 5–6, broadly ovate, 1.5–2.5 mm long, outside glabrous; male flowers with 9 sta-

Litsea cubeba (Lour.) Persoon – 1, flowering branch; 2, umbel; 3, longitudinal section through flower; 4, stamen without glands; 5, fruiting branch.

mens in 3 whorls, filaments sparsely hairy, those of 3rd whorl with 2 basal subsessile glands, anthers quadrangular; female flowers with 9 staminodes, a large, glabrous ovary with very short style and a large, multi-lobed stigma. Fruit a globose berry, 5–6 mm across, apiculate when young, blackish when mature, seated on a pedicel 3–5 mm long which is slightly thickened at the apex into a cup-shaped receptacle. Seed spherical, white.

Growth and development *L. cubeba* flowers on both long and short shoots, with flowering on the short shoots dominating. Under strongly seasonal conditions, flowering occurs before the unfolding of the leaves, with male trees blooming earlier than the female ones. In natural stands, female plants may outnumber male ones by 5:3 to 5:4. In Indonesia flowering and fruiting is throughout the year, in Taiwan, however, flowering is from February–May, fruiting in September–October. Clonal trees of *L. cubeba* bear fruit after 2-3 years.

Other botanical information Several other *Litsea* species produce essential oils, e.g. *L. elliptica* Blume (synonym: *L. odorifera* Valeton) and *L. glutinosa* (Lour.) C.B. Robinson. *L. elliptica* leaf oil contains besides safrole (used as a substitute of sassafras) the ketones and alcohols 12-tridecen-2-one, 10-undecen-2-one and undecen-2-ol. The oil (and sawdust) can also be used as an insect repellent. The fruit of *L. glutinosa* contains about 0.3% essential oil with (E)-β-ocimene (70–84%) as the main constituent.

Litsea diversifolia Blume (vernacular names: huru kisereh (Sundanese), nangka-an (Javanese)) is a small tree (3–12 m tall, trunk up to 25 cm in diameter but usually much smaller) of mixed mountain forest in Java (1000–2500 m altitude). The wood is occasionally used in house building but it is said to have a pleasant cinnamon smell and a decoction of shredded wood is drunk like tea.

Ecology *L. cubeba* is found in hilly areas and grows well at altitudes of 700–2300 m; in East Kalimantan it occurs at 400–600 m. In Java it is found on fertile loams and also near sulphur lakes.

Agronomy *L. cubeba* is propagated by wildlings or nursery-grown seedlings. Seed loses its viability rapidly. After collection, the fruit flesh is removed and cleaned seeds are sown in containers. Shade is not necessary, but protection against heavy rain is required, to prevent the seeds from being washed out. Germination starts 6–8 weeks after sowing and continues for about 5 months. The first seedlings are ready for transplanting after 9 months; slower ones take up to 20 months. Although *L. cubeba* is grown on a fairly large scale in China, Japan and Taiwan, and as a smallholder crop in Java, very little is known about its husbandry. *L. cubeba* is affected by the papillionid *Chilasa slateri* which feeds on the leaves. It can be controlled by spraying insecticides (e.g. dichlorvos). Fruits are harvested when the citral content is highest, i.e. just before it turns red and becomes fully ripe. Fruits are often dried at room temperature for 1–2 weeks, traditionally in bamboo containers. The essential oil is extracted by steam distillation. About 100 kg fruit may yield up to 1–5 kg essential oil.

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

Prospects *L. cubeba* is a promising essential-oil crop, mainly as a cheap source of citral for industrial use, but also as a medicinal plant used in aromatherapy. To reach its potential, however, selection of the best chemotypes and research on the husbandry of the crop are urgently required.

Literature |1| Bao Yipei, 1995. Progress and status of research on Chinese Litsea cubeba oil. Chemistry and Industry of Forest Products 15(2): 71–77. |**2**| Coppen, J.J.W., 1995. Flavours and fragrances of plant origin. Non-wood Forest Products No 1. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 61–64. |**3**| Gogoi, P., Baruah P. & Nath, S.C., 1997. Antifungal activity of the essential oil of L. cubeba Pers. Journal of Essential Oil Research 9: 213–215. |**4**| Khanh, H.C., 1988. Evaluation and status of the essential oils production in the provinces of central Vietnam. Proceedings of the Seminar on Technology of Essential Oils, Hanoi, Vietnam, December, 6–9, 1988. pp. 53–60. |**5**| Lawrence, B.M., 1996. Progress in essential oils: Litsea cubeba. Perfumer and Flavorist 21(5): 62. |**6**| Lee, S.S., Lin, Y.J., Chen, C.K., Liu, K.C. & Chen, C.H., 1993. Quaternary alkaloids from Litsea cubeba and Cryptocarya konishii. Journal of Natural Products 56: 1971-1976. |**7**| Li, Hui-Lin et al., 1976. Flora of Taiwan. Vol. 2. Epoch Publishing Company, Taipei, Taiwan. pp. 434–448. |**8**| Lin, T.S. & Yin, H.W., 1995. Effects of Litsea cubeba press oils on the control of termite Coptotermes formosanus Shiraki. Bulletin of the Taiwan Forestry Research Institute 10(1): 59–63. |**9**| Nath, S.C., Hazarika, A.K., Baruah, A. & Sharma, K.K., 1996. Essential oils of Litsea cubeba Pers. – An additional chemotype of potential industrial value from northern India. Journal of Essential Oil Research 8: 575–576. |10| Susiarti, S., 1995. Peran baleng la (Litsea cubeba) sebagai tumbuhan obat dan aroma pada masyarakat Dayak Kenyah di Pujungan, Kalimantan Timur [The role of baleng la (Litsea cubeba) as a medicinal and aromatic plant in the Dayak Kenyah community at Pujungan, East Kalimantan]. Paper presented at the Symposium Nasional I Tumbuhan Obat Dan Aromatik (Apinmap Simposium), Bogor, Indonesia, 10–12 October 1995.

M.A. Nor Azah & S. Susiarti

Melaleuca cajuputi Powell

Pharm. Lond. Transl.: 22 (1809).
MYRTACEAE
$2n = 22$

Synonyms *Myrtus saligna* Burm.f. (1768), *Melaleuca minor* Smith (1812), *M. leucadendron* (L.) L. var. *minor* (Smith) Duthie (1878).

Vernacular names Cajeput (also spelt 'cajaput' or 'cajuput'), swamp tea-tree (En). Punk tree (Am). Indonesia: kayu putih (general), galam (Sundanese), gelam (Javanese, Madurese). Malaysia: kayu putih, gelam. Cambodia: smach chanlos. Thailand: samet-khao. Vietnam: c[aa]y tr[af]m.

Origin and geographic distribution The exact limits of the natural range of *M. cajuputi* are not known, as it has been cultivated in Asia for several centuries. The approximate boundaries cover a latitudinal range from 18°S to 12°N from tropical, northern Australia (Queensland, Northern Territory, Western Australia) through south-western Papua New Guinea, Indonesia, Malaysia to Thailand and Vietnam.
Natural populations of *M. cajuputi* in eastern Indonesia occur on the Moluccan Islands of Buru, Seram and Ambon. *M. cajuputi* has been planted since 1926 in central Java for oil production, using seed from Buru. It is also planted in Malaysia.

Uses The leaves of *M. cajuputi* possess antibacterial, anti-inflammatory and anodyne properties and are used traditionally against pain, burns, colds, influenza and dyspepsia. Cajeput oil is produced from the leaves by steam distillation. The oil is a common household medicine, especially in South-East Asia, used internally for the treatment of coughs and colds, against stomach cramps, colic and asthma. It is used externally for the relief of neuralgia and rheumatism, often in the form of ointments and liniments, and for the relief of toothache and earache. It is also applied in treating indolent tumours. The oil is reputed to have insect-repellent properties; it is a sedative and relaxant and is useful in treating worms, particularly roundworm, and infections of the genito-urinary system. It is used as a flavouring in cooking and as a fragrance and freshening agent in soaps, cosmetics, detergents and perfumes.
The wood of *M. cajuputi* is hard and fairly heavy and makes good fuelwood. Of limited interest for sawmilling, it is generally used in the round or roughly fashioned and is suitable for posts, poles and piles. The timber tends to check and warp, but when carefully seasoned it is suitable for general construction and flooring. The soft bark is used as a packing material, in boat building, filling mattresses or pillows and for insulation. *M. cajuputi* is an important honey tree and often plays an important role in estuarine environments where it provides habitat for birds, fish and shrimps. It makes an excellent shade and shelter tree and is one of the few trees that can be grown successfully to reforest exposed locations on brackish soils and acid sulphate soils.

Production and international trade The two principal centres of production of cajeput oil are Indonesia and Vietnam. In Indonesia, commercial oils are produced both from natural stands in the Moluccas and from plantations in Java. Estimates of production from the natural stands (about 200 000 ha) suggest that a total of some 90 t of oil are produced annually on Buru, Seram, Ambon and adjacent islands. Production from an estimated 9000 ha of government-owned plantations in Java amounted to approximately 280 t in 1993. Production in southern Vietnam is estimated to be in the order of 100 t per year, from about 120 000 ha natural *Melaleuca* forest. Smaller amounts of oil are also exported from Malaysia.
Annual world production of cajeput oil is very difficult to quantify accurately, but appears to be in excess of 600 t. In 1985 it was valued at US$ 500 000. With a 1997 distillery-gate price in Indonesia of about US$ 9.4 per kg of oil of 55% cineole, the value of the industry may now exceed US$ 5.6 million before further processing.
The oil is often exported as crude oil, mainly to Europe. There is no internationally accepted quality standard for cajeput oil. As a result, there may be major differences between batches. Cajeput oil is purchased and sold by traders in three grades in the Moluccas. Grading depends on where the trees are grown, which appears to affect the proportion of 1,8-cineole in the oil. Grade 1 oil of

55–65% cineole content comes from hillside trees and fetched US$ 8.8–9.6 per kg at the farm gate in 1995. Grade 2 oil of 20–55% cineole content comes from trees on lower sites and is priced at about US$ 7.2 per kg. Grade 3 oil presumably comes from locations that produce oils of very low cineole content, such as Gogoria and Wai Geren on Buru Island.

Properties There is wide variation in the chemical composition of cajeput oil. It appears that different chemical forms predominate in different parts of the natural range of *M. cajuputi* and that their occurrence partly parallels the morphological variation in the species. Commercial cajeput oil is derived mostly from the cineole-rich form, *M. cajuputi* subsp. *cajuputi*. The other subspecies produce oils of generally low cineole content.

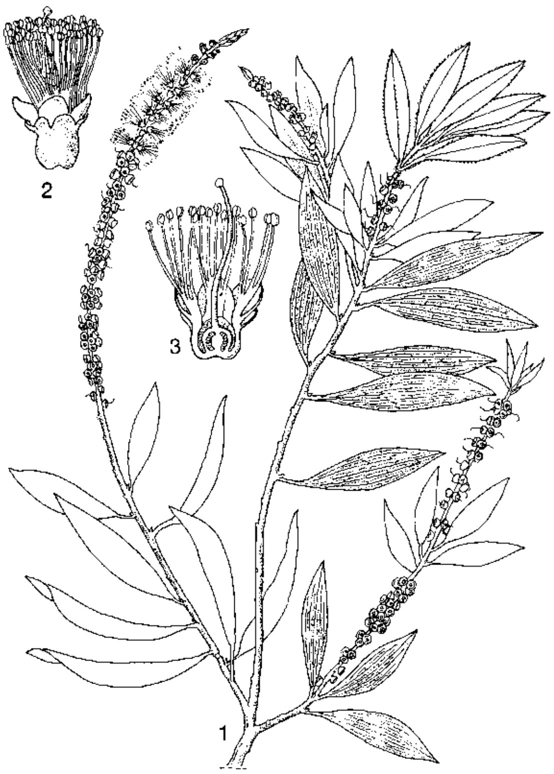
The oil of *M. cajuputi* subsp. *cajuputi* usually contains substantial amounts of 1,8-cineole (3–60%), and the sesquiterpene alcohols globulol, viridiflorol and spathulenol. Other compounds present, usually in quantifiable amounts, are limonene, β-caryophyllene, α-humulene, viridiflorene, α-terpineol, α- and β-selinene and caryophyllene oxide. The oil yield of fresh leaves ranges from 0.4–1.2%. Cajeput oil is mainly a pale yellow mobile liquid sometimes with a greenish-blueish tint. The green-blue coloration may be a function of the presence of azulene compounds in the fractions of the oil that have a higher boiling point, but has also been attributed to chlorophyll or small amounts of copper in the oil. The green colour mostly disappears in storage. Some cajeput oils with significant amounts of eudesmol isomers solidify into a whitish paste after extraction. The odour of commercial oils is rather penetrating, with a camphoraceous-medicinal aroma, similar to cineole-rich eucalypt oil but milder and more fruity. The almost fruity-sweet body notes and the soft tones in the dry-out are very characteristic. The taste is aromatic; the initial burning sensation on the tongue is followed by a cooling sensation. Cajeput oil is classified as non-toxic (rodent LD_{50} of 2–5 g/kg) and non-sensitizing, although skin irritation may occur at high concentrations. It has been approved for food use by the Food and Drug Administration (FDA) of the United States. See also: Composition of essential-oil samples.

The wood of *M. cajuputi* has a yellowish sapwood, merging gradually into pinkish-grey heartwood. It has a high silica content (0.2–0.95%) which blunts saws. Generally used in the round or roughly fashioned, cajeput timber is durable in ground or water. It is hard and heavy, with a green density of about 1070 kg/m^3 and an air-dry density of about 750 kg/m^3. Careful drying is necessary to minimize checking and warping. Collapse is slight, shrinkage about 3.5% radially and 7% tangentially. It is difficult to plane and mortise due to interlocking grain, but glues well and is a good jointing timber.

On average there are 2 700 000 viable seeds per kg.

Adulterations and substitutes The large variation found in the chemical composition of commercial cajeput oil is partly a reflection of the substantial natural variation in *M. cajuputi*, but is also due to the admixture of similar oils from other species; adulteration with synthetic compounds is also common. Cajeput oil is sometimes adulterated with kerosene or fatty oils, its odour being so strong that moderate addition of kerosene is hardly noticeable. Foam formation on violent shaking indicates such adulteration. Substitute oils often marketed as cajeput oil come from the liniment tree (*Asteromyrtus symphyocarpa* (F. Muell.) L.A. Craven (synonym *Melaleuca symphyocarpa* F. Muell.)) and the broad-leaved paperbark (*Melaleuca quinquenervia*). In western markets cajeput oil is often replaced by the less expensive eucalypt oil.

Description Evergreen shrub or usually single-stemmed tree up to 25(–40) m tall with an extensive root system, sometimes with aerial adventitious roots. Bark layered, fibrous and papery, grey to white. Crown fairly dense and wide, somewhat silvery in appearance; smaller branches and twigs slender but not drooping, young shoots densely silky hairy with spreading fine hairs up to 2 mm long. Leaves alternate, flat, silky hairy to glabrescent; petiole compressed to concave-convex, 3–7(–11) mm × 1.1–2.3 mm, straight or curved; blade elliptical to lanceolate-elliptical, sometimes obliquely so, 5–10(–12) cm × 1–2.5(–6) cm, 2–10 times longer than wide, attenuated or sometimes abruptly rounded at base, apex acute or narrowly obtuse, often apiculate, thinly coriaceous, dull green, finely but obscurely dotted with oil glands, with 5–7 prominent veins and prominent reticulation. Inflorescence a terminal or upper-axillary spike, single or 2–3 together; spike fairly densely flowered, 3.5–9 cm × 2–2.5 cm; rachis 1–1.3 mm thick, enlarging at anthesis, densely pilose; bracts ovate, striate, villous, caducous; bracteoles absent; flowers in triads, white, greenish-white or creamy; calyx tubular, 2.5–3 mm long, pubescent, tube subcylindrical, 1.2–1.9 mm × 1.5–2 mm, at base adnate to ovary (persistent in fruit), with 4 trian-



Melaleuca cajuputi Powell – 1, flowering and fruiting branch; 2, flower; 3, longitudinal section through flower.

gular to semicircular lobes 0.7–0.9 mm × 1.2–2 mm with thin margin; petals 5, broadly obovate-spatulate with a short claw, 2–2.7 mm × 1.8–2.3 mm, blade suborbicular with 7 slender branched veins and streaked with glands; stamens numerous, 7–10 mm long, white, glabrous, arranged in bundles with a claw 1–3.5 mm long; per bundle 7–10 filaments, attached to the upper margin of the claw, free part up to 8 mm long; anthers 0.4–0.55 mm long; pistil with 3-celled ovary about 1 mm long, style 6–9 mm long and a small stigma. Fruit a cup-shaped to globose, many-seeded capsule, 3–3.5 mm × 3.5–4 mm, orifice 1.5–2 mm in diameter with thin valves. Seed linear, minute.

Growth and development *M. cajuputi* is a long-lived, moderately fast-growing tropical tree adapted to both waterlogged and well drained soils. On soils subject to prolonged waterlogging it develops aerial adventitious roots, which can form buttresses on the lower trunk. Like all melaleucas, it does not develop dormant buds and grows whenever conditions are favourable. After bush fires, it will regenerate by seed, coppicing and from root suckers. Young trees may grow 2.3 m in height and 7 cm in diameter per year and set their first flower buds when only 13–14 months old. Melaleucas appear to be obligate outcrossers and pollination is mainly by insects, but also by birds and small mammals. In Java *M. cajuputi* flowers throughout the year; in Australia it flowers from March–June and from August–December. Mature seeds have been collected in Australia in October–November. The very small seeds are orthodox and germinate readily in moist, warm conditions with no pretreatment.

Other botanical information *M. cajuputi* is one of the 10 species that together form the *M. leucadendra* (L.) L. (also often named *M. leucadendron*) complex. Many early references to *M. leucadendra* or *M. leucadendron* yielding cajeput oil from Indonesia and Vietnam in fact refer to *M. cajuputi*. It is often difficult to distinguish species within the complex, especially in areas where they overlap, because distinctive characteristics also overlap. Within the complex, *M. cajuputi* is most closely related to *M. viridiflora* Sol. ex Gaertner and *M. quinquenervia* (Cav.) S.T. Blake. Distinctive characteristics are: *M. cajuputi* has leaves with petiole 3–11 mm long, blade mostly longer than 5 cm and less than 2.5 cm wide, old leaves densely dotted with glands, rather thin in texture, with reticulations almost as prominent as the main veins and young shoots with spreading hairs. *M. viridiflora* has leaves with petioles 1–2 cm long, blades wider than 2.5 cm, very thick, young shoots with appressed silky hairs. *M. quinquenervia* is like *M. cajuputi* but its old leaves are not conspicuously dotted with glands, not thin-textured and have obscure reticulations.

Differences in genetic structure between populations east and west of Wallace's line based on allozyme variation led to the hypothesis that *M. cajuputi* has spread naturally from Australia into South-East Asia, aided by its propensity for invading disturbed sites. *M. cajuputi* is the only species out of about 250 in *Melaleuca* L. to occur naturally west of Wallace's Line. *M. cajuputi* is rather variable and based on differences in morphology, chemical content and geographic distribution 3 subspecies are distinguished:

- subsp. *cajuputi*. Leaf width (6–)10–16(–26) mm; leaf length/width ratio 2.8–9.7; stamens per budle (6–)8–11(–14); stamen bundle claw length 1–1.6 mm. Distribution: Indonesia (Buru, Ceram, Tanimbar Islands, Timor) and Australia (Western Australia, Northern Territory). This is the main source of cajuput oil and is often cultivated. Purely cultivated forms could better be classified as cultivars.

- subsp. *cumingiana* (Turcz.) Barlow. Leaf width (15–)19–28(–39) mm; leaf length/width ratio 2.2–2.9; stamens per bundle (4–)6–8(–10); stamen bundle claw length 2.1–3 mm. Distribution: Burma (Myanmar), Thailand, Vietnam, Peninsular Malaysia, Indonesia (Sumatra, western Java, south-western Kalimantan). Within the natural range of this subspecies, cultivars of subsp. *cajuputi* occur in plantations sometimes with characteristics intermediate between the 2 subspecies.
- subsp. *platyphylla* Barlow. Leaf width (17–)25–50(–60) mm; leaf length/width ratio 1.3–6.5; stamens per bundle (8–)9–12(–15); stamen bundle claw length 1.1–3.5 mm. Distribution: Indonesia (southern Irian Jaya), Papua New Guinea (southern) and Australia (Queensland).

Ecology *M. cajuputi* is primarily found in coastal areas of the hot humid tropics. In its natural habitat the mean maximum temperature of the hottest month is usually 31–33°C and the mean minimum of the coolest month 17–22°C. The area has up to 230 days over 32°C, but few days exceed 38°C. The area is frost-free. Mean annual rainfall is 1300–1750 mm with a strong monsoonal pattern. *M. cajuputi* grows in a wide range of conditions, but most stands are found on low swampy coastal plains, sometimes immediately behind mangroves that may be flooded to a depth of over one metre during the wet season. The soils are often highly organic alluvial clays with poor drainage and very low fertility, and may be potentially acid sulphate (e.g. the Mekong Delta, Vietnam). It is resistant to fire, tolerates exposure to salt-laden winds, but not to saline waterlogged conditions. In swamps *M. cajuputi* forms pure forest, mixed open-forest or woodland associated with *M. leucadendra* (L.) L., *Barringtonia acutangula* (L.) Gaertn., *Lophostemon suaveolens* (Sol. ex Gaertn.) Peter G. Wilson & J.T. Waterh. and *Nauclea orientalis* (L.) L. On less swampy sites it grows with a wide range of eucalypts, acacias and other melaleucas including *M. dealbata* S.T. Blake, *M. saligna* Schau. and *M. viridiflora* Sol. ex Gaertn. Its altitudinal range in Australia is 5–150(–250) m.

By contrast, populations in the Moluccas consist of extensive and mostly pure stands that extend inland on infertile, gravelly ridges with a subsoil of red-brown clay. These sites are often colonized by *Imperata* grassland. Most ridges and slopes of the northern coastline of Buru and those along the Wai Apu River (which drains to the east coast) have sparse vegetation comprising open woodland and low shrubland of *M. cajuputi* at 30–400 m altitude, covering some 100 000 ha. In western Seram, *M. cajuputi* occurs as an almost pure, continuous stand of some 150 000 ha along the Hoamoal Peninsula. Scattered populations occur on lowland plains and low undulating ridges at 30–150 m above sea-level elsewhere in Seram and also on the smaller islands between Seram and Buru. Only a few scattered stands of *M. cajuputi* have been recorded on Ambon. In Vietnam, *M. cajuputi* forests once occupied most of the seasonally inundated acid sulphate soils (1.5 million ha) of the Mekong Delta, principally on Ca Mau Peninsula, in the Long Xuyen Quadrangle and on the Plain of Reeds. It is estimated that today only 120 000 ha of natural melaleuca forest remain in the Delta.

Propagation and planting Propagation of cajeput is usually by seed. Viable seed germinates readily, but the tiny seedlings are easily damaged by overhead watering or rain, or may be killed if the sowing mix dries out. In Vietnam the 'bog' technique of watering has been adopted to avoid these problems. This involves standing the germination tray permanently in water so that moisture rises to the surface by capillary action, keeping it constantly moist but not flooded. Seed is sown evenly at a density of about 7000 seeds/m^2. An inflated plastic bag is fitted over the container to maintain a moist environment. After about 4 weeks the seedlings are sturdy enough to withstand overhead watering and the container is removed from the water and handled normally. The risk of fungal disease is high, so good hygiene is essential. After germination the tiny seedlings can be slow to develop, but once under way they grow quickly and their total nursery period is 3(–6) months. Plantations have also been established with small stump plants. *M. cajuputi* can also be reproduced vegetatively from stem and branch cuttings.

In Java, plantations are usually established on degraded land using seedlings of unselected stock at an initial density of 5000 stems per ha. During the first two years plantations may be intercropped with cassava, maize and groundnuts.

Husbandry On seasonally inundated, acid sulphate soils of the Mekong Delta of Vietnam, weeds are a major problem hampering the establishment of *M. cajuputi*. If left unchecked the prodigious weed growth becomes a major fire hazard during the dry season. Intercropping ensures adequate weed control. There is some small-scale mulching of plants with the spent leaves left after oil extraction; this practice merits more widespread application. No artificial fertilizers are applied.

Diseases and pests Young cajeput trees in Java, especially West Java, are attacked by subterranean termites (*Macrotermes gilvus*, *M. inspera-tus* and *Odontotermes grandiceps*) which attack the bark and wood, causing the trunk to split. Trees whose roots have been attacked may die. Newly planted stumps are most seriously affected. Up to 50% of the trees may be damaged before they are 2 years old. Often as many as 5–6 replantings are needed to replace all dead trees.

Harvesting In plantations of cajeput in Indonesia trees are allowed to grow for 4 years after planting and are then cut off at about 1 m above the ground at the first harvest of leaves. Thereafter the trees are visited annually and coppice shoots thicker than 1 cm are selectively harvested and leaves and twigs stripped into gunny bags for transport to the distillery. In Central Java some harvesting for oil production takes place throughout the year. However, peak production is during the period June–October which coincides with the best months for oil recovery from leaves and twigs. It is estimated that oil can be economically produced from cajeput plantations for 25 years.

In natural stands in Indonesia harvesting of leaves is a family operation, with groups of 2–6 people involved in the sequential harvesting of family holdings of some 200 ha of *M. cajuputi*. Coppice growth 1–2 m tall (6–12 months old) is cut by machete and leaves are stripped to fill 20 kg baskets. A skilled cutter can harvest seven baskets per day. The dry season months of May–August are the preferred time of harvest because of reputedly better yield, but harvesting may take place throughout the year.

Yield On the most productive sites, 1 ha of cajeput plantation in Central Java produces about 7.5 t of cajeput leaves annually which gives about 60–65 kg of oil, or a recovery rate of about 0.85%. This yield is reasonable given the extensive management practised. It is widely recognized that yields could be increased dramatically by using genetically superior seed sources and more intensive management practices.

Handling after harvest The Indonesian State Forest Corporation operates 12 distilleries in Java. There are 4 major and 8 minor factories producing about 280 t of cajeput oil per year from government-run plantations. The industry is labour intensive. In one operation in Central Java based on 3200 ha of plantation, 300 workers are engaged seasonally in the harvesting of leaves and a further 70 people are employed at the distillery. The distillery for this operation comprises 8 stills of 0.9 t capacity each, fed by a steam boiler fuelled by spent leaves of earlier distillations. A 3.5 hour distillation time is standard using a modern, high pressure boiler.

In the Moluccas distillation is done in small traditional stills. The family still is usually a permanent fixture made from mostly local materials. Still capacity is usually about 160 kg of dried leaves and distillation time extends for 8 hours, resulting in 3 kg of oil. Estimates suggest that there are about 100 family stills operating on Buru, 10–12 on Seram and 1–2 operating on each of the islands of Boano, Kelang, Manipa and Ambon.

Once the oil has been separated it should be cleaned of extraneous matter by filtering. Cajeput oil is relatively stable. However, if it is to be stored for any length of time, some of the dissolved water should be removed from the oil by filtering through a bed of anhydrous sodium sulphate. Storage in a cool location away from light is recommended. Oils are best stored in nearly full, glass or stainless steel containers. Head space should be minimal, to reduce oxidation during storage. As it is often impractical to use glass or stainless steel containers for storage and transport, clean drums or cans approved for oil storage are commonly used. Heavily galvanized or epon-lined drums are preferable.

Genetic resources As cajeput is still relatively common throughout its wide geographical range, there are no current conservation concerns, apart from the situation in the Mekong Delta of Vietnam. In this region it is estimated that every year 5000 ha of the 120 000 ha remaining of the once vast *Melaleuca* forests, are lost through illicit cutting and burning. The wastelands that are created by this process are a priority for reforestation and melaleucas are favoured because they can tolerate the very harsh conditions for tree establishment and growth without expensive mounding.

Breeding The wide range of variation in morphology and oil traits of cajeput indicates considerable scope for genetic improvement. Careful selection of well-adapted and fast-growing seed sources of the high-cineole chemotype will be paramount for plantation development aimed at cajeput oil production. In collaboration with the Indonesian Forest Tree Improvement Research and Development Institute, the Australian Tree Seed Centre of CSIRO Forestry and Forest Products is assembling seed collections of *M. cajuputi* suitable for this purpose. These seedlots will provide the basis for selecting and breeding trees with faster growth rates, higher oil content and higher proportions of 1,8-cineole in the oil than are currently available to the industry.

Prospects The immediate future for the cajeput oil industry looks bright, especially in Indonesia where demand for the oil consistently exceeds supply. In Western markets it is likely to remain of minor importance as it is mostly replaced by cheaper eucalypt oil. Major constraints include lack of official quality standards leading to blended and adulterated oils of variable composition, few efficacy or clinical trials to support claims of medicinal benefits, and low yields and quality variation in oils from natural stands and plantations. If plantations are to be more productive on a sustainable basis, tree improvement programmes are needed to enhance biomass production and oil traits. Research is also needed to determine optimal silvicultural methods for oil production without depleting soil nutrients.

Literature |1| Blake, S.T., 1968. A revision of Melaleuca leucadendron and its allies. Contributions from the Queensland Herbarium No 1. Queensland Herbarium, Department of Primary Industries. Brisbane, Australia. 113 pp. |2| Brophy, J.J. & Doran, J.C., 1997. Essential oils of tropical Asteromyrtus, Callistemon and Melaleuca species: In search of interesting oils with commercial potential. ACIAR Monograph No 40. Australian Centre for International Agricultural Research, Canberra, Australia. pp. 10–22, 62–65. |3| Craven, L.A. & Barlow, B.A., 1997. New taxa and new combinations in Melaleuca (Myrtaceae). Novon 7: 113–119. |4| Doran, J.C., 1998. Cajuput oil. In: Southwell, I.A. & Lowe, B. (Editors): Medicinal and aromatic plants – Industrial profiles – . Tea tree, the genus Melaleuca. Harwood Academic Publishers, Amsterdam, the Netherlands. (in press). |5| Doran, J.C. & Gunn, B.V., 1994. Exploring the genetic resources of tropical melaleucas. FAO Forest Genetic Resources Information 22: 12–24. |6| Lassak, E.V. & McCarthy, T., 1983. Australian medicinal plants. Methuen, Sydney, Australia. pp. 37–38. |7| Lowry, J.B., 1973. A new constituent of biogenetic, pharmacological and historical interest from Melaleuca cajuputi oil. Nature 241: 61–62. |8| Motl, O., Hodačová, J. & Ubik, K., 1990. Composition of Vietnamese cajuput essential oil. Flavour and Fragrance Journal 5: 39–42. |9| Nyuyen Duy Cuong, Truong Thi Xuyen, Motl, 0., Stránsky, K., Presslová, J., Jedlicková, Z. & Serý, V., 1994. Antibacterial properties of Vietnamese cajuput oil. Journal Essential Oil Research 6: 63–67. |10| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 302–319.

J.C. Doran

Melaleuca quinquenervia (Cav.) S.T. Blake

Proc. Roy. Soc. Queensl. 69: 76 (1958).

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Synonyms *Metrosideros quinquenervia* Cav. (1797), *Melaleuca viridiflora* Sol. ex Gaertner var. *rubriflora* Brong. & Gris (1864), *M. viridiflora* Sol. ex Gaertner var. *angustifolia* (L.f.) N.B. Byrnes (1984), non Blume (1826).

Vernacular names Broad-leaved paperbark, broad-leaved tea tree, belbowrie (En). Punk tree, melaleuca (Am). Niaouli (Fr). Indonesia: kayu putih.

Origin and geographic distribution *M. quinquenervia* is native to the coastal region of eastern Australia, from near Sydney in New South Wales to Cape York in northern Queensland. It also occurs in southern New Guinea and has an extensive distribution in New Caledonia, especially in the north-western part of the island. The latitudinal range of the natural occurrence is 8–34°S. *M. quinquenervia* has been planted in the tropical lowlands of the Philippines, India, the West Indies, Guyana and in the United States (Hawaii and Florida) and probably in Madagascar. In southern Florida, it has escaped cultivation and has become weedy in seasonally wet locations.

Uses The leaves of *M. quinquenervia* are a source of a cineole-rich essential oil called niaouli oil or gomen oil used in pharmaceutical preparations e.g. to flavour cough drops, gargles and toothpastes and in aromatherapy. In France, where its pharmaceutical use has a long tradition, it sometimes replaces cajeput oil and eucalypt oil in the treatment of coughs including whooping cough, rheumatism, neuralgia and chronic catarrhs of the pulmonary membrane. *M. quinquenervia* is often grown as a wind-break and as an ornamental. A strong flavoured, low density honey is produced from the abundant flowers. The wood is an excellent fuel and makes good quality charcoal. As timber it is suitable for pit props, fence posts and rails, flooring, house timbers and pulp. The bark may be used as mulch in potting mixes, for packaging and insulation.

Production and international trade Production statistics of niaouli oil are very scarce and incomplete. The world production of niaouli oil in 1997 had an estimated value of US$ 67 000. Production in New Caledonia was estimated at 2–2.5 t in 1980, 4 t in 1985 and 7–10 t in 1998, down from an average of 20 t/year prior to the Second World War and during the early 1950s. No statistics are available on the area of the world planted to *M. quinquenervia*. Two million trees have been planted on State Forest Reserve land in Hawaii. The largest area planted to it, however, is in Florida, where it has naturalized and is dominant over almost 200 000 ha, with pure stands covering 16 000 ha.

Properties The leaf oils of *M. quinquenervia* fall into 2 classes based on their chemical composition. One chemotype is rich in nerolidol (90%), while the other is rich in 1,8-cineole (30–70%) and sometimes in viridiflorol (0–60%). The cineole-rich chemotype is the source of niaouli oil produced in New Caledonia. Niaouli oil is a pale yellow to greenish-yellow or almost colourless liquid with a strong, fresh, sweet-camphoraceous, but cooling odour, reminiscent of cajeput oil, eucalypt oil and cardamom oil, though less spicy than the latter. It has a slight off-taste of bitter almonds. The flavour is warm, only slightly astringent, aromatic and somewhat sweet. Its sweetness in odour and flavour is quite characteristic and different from eucalypt oil and cajeput oil. The odour of bitter almonds is attributed to the presence of benzaldehyde. Besides cineole and viridiflorol, it contains α-terpineol and several of its esters, α-pinene and β-caryophyllene. See also: Composition of essential-oil samples. There are reports from Florida that exudates from the flowers cause respiratory irritation in sensitive persons.

The sapwood is pale yellow to pink. The heartwood is pink to reddish brown, rippled with light and dark tones, hard, fine-textured and diffuse, porous, tending to warp and difficult to season. It can produce a nice finish. It contains silica. The basic density of the heartwood is generally 490–550 kg/m^3, and air-dry density 700–750 kg/m^3. The energy values of the wood and bark are 18 400 and 25 800 kJ/kg, respectively. The wood is an excellent fuel, but the bark of old trees has to be peeled off because only the outer layers burn. Problems caused by the dust from the bark of mature trees and the low density of the bark can be overcome by adapted burning systems. The bark of young trees has a greater energy value than the wood. Durability of untreated posts in contact with the ground is poor; posts must be replaced after about 3 years. Silica in the wood rapidly blunts saws and planes. To minimize checking and warping, the wood must be dried carefully. Collapse is slight. Shrinkage is about 3.5% radially and 7% tangentially.

There are 1.5–5 million viable seeds per kg of seed and chaff mix.

Adulterations and substitutes Niaouli oil is occasionally adulterated with kerosene or fatty acids. A very high cineole content may indicate adulteration with cheaper eucalypt oil. Eucalypt oil with small amounts of admixtures is commonly used as a substitute for niaouli oil.

Description A small to medium-sized tree, (4–)8–12(–25) m tall. Trunk moderately straight to crooked; bark thick, made up of many papery layers that split and peel, rough and shaggy on large trunks; crown narrow and open, or fairly dense, dull green or slightly yellowish-green; twigs pendulous, densely hairy when young. Leaves alternate, scattered, glabrescent; petiole compressed, 4–10 mm × 1.5–2.4 mm; blade lanceolate to oblanceolate, 5–9 cm × 0.6–2.4 cm, mostly 4–6 times longer than wide, straight or oblique, rarely

Melaleuca quinquenervia (Cav.) S.T. Blake – flowering and fruiting branch.

slightly falcate, dull green, coriaceous, stiff, base narrowly attenuate, margin entire, apex acute or obtuse, sometimes apiculate, main veins 5, rarely 3 or 7, prominent, parallel from base to tip, reticulation indistinct, oil glands usually obscure. Inflorescence a many-flowered, terminal or sometimes upper-axillary, dense to moderately open spike, often 2–4 together, 4–8.5 cm × 2.5–3.5 cm; rachis 1–1.8 mm wide, glabrous to hairy; flowers in triads, usually white or creamy white, rarely greenish or reddish; calyx tubular, 3–4 mm long; tube subcylindrical, 2–2.5 mm long, persistent, with 4 semi-circular lobes, 1–1.8 mm long, margins hyaline; petals 5, obovate-spatulate, deeply concave, 3–3.5 mm × 2–2.5 mm, with a short claw, white or red; stamens in 5 bundles of 6–9 each, conspicuous, 11–20 mm long, anthers 0.6–0.8 mm long, claw 1.5–2 mm long. Fruit a broadly cylindrical, thick-walled capsule, 3.5–4 mm × 4–5 mm, grey-brown, persistent; orifice 2.5–4 mm in diameter. Seed tapering from the dorsal end, about 1.0 mm × 0.3 mm, pale-brown.

Growth and development Seedling plants of *M. quinquenervia* can grow 0.9–1.8 m/year. In Florida, they may grow throughout the year, but growth is most rapid in spring to early summer, and in late summer to early autumn. In trial plantings on two locations in south-eastern Queensland (Australia) a provenance from northern Queensland averaged 4.3 m in height and 15 cm in diameter at ground level at 4.5 years. In Hawaii, trees in plantations on good sites may reach 18 m in height and 50 cm in diameter in 40 years. Formation of vesicular-arbuscular mycorrhizae and ectomycorrhizae has been found in Australia. Flowering commences as early as 3 years after sowing. *M. quinquenervia* coppices readily, but root suckers are not commonly produced. The usual flowering time in Australia is autumn and winter, but flowers may be present at other times or throughout the year. Pollination is by insects and a high rate of outcrossing is assumed. Seed ripens in spring and summer. They are shed through 3–4 slits positioned horizontally below the capsule rim. The spike, which produces 30–70 densely packed woody, stalkless capsules, grows out into a leafy twig beyond the fruits.

Other botanical information *M. quinquenervia* belongs to the *Melaleuca leucadendra* (L.) L. (also named *Melaleuca leucadendron*) species complex: a group of 10 closely related species. It is often difficult to distinguish the individual species within the complex, especially in areas where the species overlap, because distinctive characteristics overlap as well and sometimes intermediate forms occur. Within the complex *M. quinquenervia* is most closely related to *M. cajuputi* Powell and *M. viridiflora* Sol. ex Gaertner. Distinctive characteristics are: *M. cajuputi* has leaves with 3–11 mm long petiole, blade mostly longer than 5 cm and less than 2.5 cm wide, old ones dotted with fine glands, rather thin, reticulations are about as prominent as the main veins and young shoots have spreading hairs. *M. quinquenervia* is like *M. cajuputi* but its old leaves are not dotted with conspicuous glands, not thin and have relatively obscure reticulations. *M. viridiflora* has leaves with 1–2 cm long petiole, blade wider than 2.5 cm, very thick, young shoots with appressed silky hairs. Some authors consider *M. quinquenervia* to be a variety of *M. viridiflora* Sol. ex Gaertner (var. *rubriflora* Brong. & Gris), but this reduction is rarely followed.

Ecology In Australia and Papua New Guinea, *M. quinquenervia* is generally confined to the lowlands, below 100 m, but in New Caledonia it forms extensive stands up to an altitude of 900–1000 m. It occurs in the warm subhumid and humid zones. In Australia, the mean maximum temperature of the hottest month ranges from 26°C in the south to 34°C in the north. The corresponding mean minimum temperatures of the coolest month are 4°C and 20°C. A few frosts may occur in its habitat in southern Australia. Average annual rainfall is about 900–1250 mm; the seasonal distribution pattern varies from a moderate summer-autumn maximum in southern Australia to a strong monsoonal pattern in the north.

In Australia, *M. quinquenervia* generally grows on level or gently undulating coastal lowlands. It grows along streams, fringing tidal estuaries, and frequently forms pure stands in freshwater swamps. It often occurs close to the beach and will tolerate wind-blown salt. Trees are highly fire-tolerant during all but the early seedling stages. The soils are often peaty humic gleys, sandy at the surface but silty or clayey below and with a high organic matter content. The water table is near or above the surface for most of the year. *M. quinquenervia* appears to tolerate a low level of groundwater salinity, although this reduces growth. In Papua New Guinea it occurs on coastal, non-tidal, highly organic, alluvial clay plains with poor drainage and very low fertility. The plains may be flooded to more than 1 m deep during the wet season. In New Caledonia *M. quinquenervia* occurs extensively on well-drained slopes and ridges in the uplands. It grows on all soil types but is rarely found on soils derived from ultrabasic rock.

M. quinquenervia is usually dominant and frequently occurs in almost pure stands. The best-developed stands on favourable sites occur as open forest and woodland, but elsewhere stands are reduced to low woodland or tall scrub.

M. quinquenervia was first introduced to Florida as an ornamental and for afforestation of the grassy plains of the Everglades in the early 1900s. It is now regarded as a noxious weed there. Seed disperses naturally and establishes readily in wetlands. Unmanaged stands may have a density of 7 000–20 000 stems/ha thus crowding out native vegetation and wildlife habitats and reducing native biodiversity by 60–80% in wet prairie and marsh communities of the Everglades.

Propagation and planting Propagation of *M. quinquenervia* is by seed which can be sown either in seedbeds or directly into nursery containers. Mature seed germinates readily and does not require pretreatment. Seeds are very small, so care is needed to ensure that the sowing mix does not dry out, any diseases are avoided or controlled and that seeds and small seedlings are not damaged or washed away by careless watering. Watering from below instead of from above may be used to avoid the latter problem. Conventional nursery procedures will produce healthy, vigorous seedlings suitable for planting in about 4–7 months from sowing. When seedlings are 2–3 cm tall (4–8 weeks after sowing), they are either transplanted or thinned, depending on the method used. Many *Melaleuca* species are propagated vegetatively from cuttings or by micropropagation, and these techniques might also be successful with *M. quinquenervia*. Planting out at routine plantation spacings (e.g. 2–3 m × 2 m) is appropriate for most purposes.

Husbandry *M. quinquenervia* can successfully compete with weeds but early weed control will improve growth rates. The fungus *Botryosphaeria ribis* holds promise as a biological control agent of weedy *M. quinquenervia* in Florida.

Diseases and pests A large number of insects feed on *M. quinquenervia* in Australia but damage remains localized. The heartwood lacks resistance to damage by fungi, termites and marine borers. As an exotic, it is relatively free of diseases and pests.

Harvesting Leaves for niaouli oil production are collected from natural stands only, by slashing branches and stripping the leaves. One man can collect 300–500 kg leaves per day.

When grown for its wood, *M. quinquenervia* is most commonly grown on relatively short coppice rotations that maximize the production of small-sized logs suitable for fuelwood, posts, piles and poles.

Yield No information is available on the yield of leaves of *M. quinquenervia*. Logs of 45 cm in diameter can be produced in 10–12 years. First-year coppice yields from established stands in Florida have averaged 3–4 t/ha of dry wood.

Handling after harvest Niaouli oil is obtained by steam distillation of the leaves. In New Caledonia only a few, traditional, direct-fired stills remain in use today.

Genetic resources *M. quinquenervia* remains relatively common throughout its wide geographical range. Given the variation in its natural habitat, genetic differences in growth and adaptation are likely to be found and careful selection of seed sources for specific environments may lead to improved performance. The Australian Tree Seed Centre, CSIRO Division of Forestry in Canberra is assembling range-wide seed collections of tropical *Melaleuca* species, including *M. quinquenervia*.

Breeding There are no known selection and breeding programmes at the present time. *M. quinquenervia* has recently been introduced to Vietnam for provenance trials.

Prospects The production of niaouli oil has declined mainly because of the high cost of local labour. As a very similar oil can be produced from cheap eucalypt oil, the production of niaouli oil is unlikely to recover in the near future. The best prospects for widespread use of *M. quinquenervia* in forestry are on swampy sites, as more productive species are already available for better-drained habitats. It has a demonstrated ability to establish and grow moderately rapidly in areas of the humid and subhumid tropics that may be inundated for months. Its use will be limited by the extent of swampy environments available for reforestation and its relative performance in comparison with some closely related, similarly-adapted *Melaleuca* species like *M. leucadendra* and *M. cajuputi*.

The introduction of *M. quinquenervia* and its close relatives should always be carefully considered and proceed with caution, in view of its potential to become a weed.

Literature |1| Blake, S.T., 1968. A revision of Melaleuca leucadendron and its allies (Myrtaceae). Contributions from the Queensland Herbarium No 1. Queensland Herbarium, Department of Primary Industries, Brisbane, Australia.

113 pp. |2| Boland, D.J., Brooker, M.I.H. & Chippendale, G.M., 1992. Forest trees of Australia. 4th edition. Commonwealth Scientific and Industrial Research Organization, East Melbourne, Australia. pp. 568–570. |3| Byrnes, N.B., 1986. A revision of Melaleuca L. (Myrtaceae) in northern and eastern Australia. 1–3. Austrobaileya 2: 65–76, 131–146, 254–273. |4| Cherrier, J.F., 1981. Le niaouli en Nouvelle-Calédonie (Melaleuca quinquenervia S.T. Blake) [Broad-leaved paperbark in New Caledonia]. Revue Forestière Française 33: 297–311. |5| Geiger, R.K. (Editor), 1981. Proceedings of Melaleuca Symposium, September 23–24, 1980. Florida Department of Agriculture and Consumer Services, Division of Forestry, Tallahassee, Florida, United States. 140 pp. |6| Ramanoelina, P.A.R., Bianchini, J.P., Andriantsiferana, M., Viano, J. & Gaydou, E.M., 1992. Chemical composition of niaouli essential oils from Madagascar. Journal of Essential Oil Research 4: 657–658. |7| Ramanoelina, P.A.R., Viano, J., Bianchini, J.P. & Gaydou, E.M., 1994. Occurrence of various chemotypes in niaouli (M. quinquenervia) essential oils from Madagascar. Journal of Agricultural and Food Chemistry 42: 1177–1182. |8| Rayachhetry, M.B., Blakeslee, G.M. & Center, T.D., 1996. Predisposition of melaleuca (Melaleuca quinquenervia) to invasion by the potential biological control agent Botryosphaeria ribis. Weed Science 44: 603–608. |9| Wang, S., Huffman, J.B. & Littel, R.C., 1981. Characterization of Melaleuca biomass as fuel for direct combustion. Wood Science 13: 216–219. |10| Trilles, B., Bouraïma-Madjebi, S. & Valet, G., 1998. Melaleuca quinquenervia (Cavanilles) S.T. Blake, Niaouli. In: Southwell, I.A. & Lowe, B. (Editors): Medicinal and aromatic plants –Industrial profiles– Tea tree, the genus Melaleuca. Harwood Academic Publishers, Amsterdam, the Netherlands (in press).

J.C. Doran & J.W. Turnbull

Michelia L.

Sp. pl.: 536 (1753); Gen. pl., ed. 5: 240 (1754).

MAGNOLIACEAE

$x = 19$; *M. ×alba*, *M. champaca*, and *M. figo*: $2n = 38$

Major species and synonyms

- *Michelia ×alba* DC., Syst. nat.: 449 (1817), synonyms: *M. longifolia* Blume (1823).
- *Michelia champaca* L., Sp. pl.: 536 (1753), synonyms: *M. pubinervia* Blume (1829), *M. velutina* Blume (1829), *M. pilifera* Bakh.f. (1963).
- *Michelia figo* (Lour.) Sprengel, Syst. veg. 2, ed. 16: 643 (1825), synonyms: *Liriodendron figo* Lour. (1790), *Magnolia fuscata* Andr. (1802), *Magnolia parviflora* Delessert (1821).

Vernacular names

- *M. ×alba*: White champaca (En). Indonesia: cempaka putih (general), kantil (Javanese), campaka bodas (Sundanese). Malaysia: chempaka puteh, chempaka gading. Philippines: champakang-puti. Laos: champi. Thailand: champi. Vietnam: ng[oj]c lan tr[aws]ng.
- *M. champaca*: Orange champaca, golden champa (En). Champac (Fr). Indonesia: cempaka kuning (general), cempaka (Javanese), campa (Sumatra). Malaysia: chempaka, chempaka merah (Peninsular), champaka (Sabah). Philippines: champaka, sampaka (Tagalog), champaka-laag (Sulu). Burma (Myanmar): laran, mawk-sam-lung, sagah. Laos: champa. Thailand: champa (general), champa-khao, champapa (peninsular). Vietnam: ng[oj]c lan, hoa su nam.
- *M. figo*: Banana shrub, chenille copperleaf (En). Foula figo (Fr). Indonesia: cempaka ambon, cempaka telor (general), cempaka gondok (Javanese). Malaysia: chempaka ambon, pisang-pisang. Thailand: champi khaek (central), champa khaek (south-eastern). Vietnam: tu-tieu.

Origin and geographic distribution *Michelia* comprises about 30 species and is distributed in East and South-East Asia from India and Sri Lanka eastwards to southern Japan and Taiwan and south-eastwards into Indonesia (not in Sulawesi and New Guinea). *M. ×alba* is not known in the wild, but is commonly cultivated in tropical and subtropical countries, including South-East Asia. *M. champaca* probably originated in India, where it is still planted in the grounds of Hindu and Jain temples, and is distributed from India to south-western China, Indo-China, Peninsular Malaysia, Sumatra, Java and the Lesser Sunda Islands. It is now commonly cultivated throughout the tropics. *M. figo* originates from south-eastern China; in South-East Asia it is frequently and widely cultivated mainly as ornamental shrub, but it is not known to be naturalized.

Uses *M. ×alba*, *M. champaca* and *M. figo* are commonly cultivated for their fragrant flowers and as ornamentals. The flowers of *M. ×alba* and *M. champaca* are marketed for their scent, used in making garlands, placed between stored clothes, sprinkled in bridal beds and used in the preparation of scented hair lotions. In Thailand an infusion of the flowers is applied as a cosmetic after bathing. The flowers of *M. figo* are also used in hair lotions. The extraction of fresh flowers and distillation of the leaves yield 2 different fragrant essential oils which are used in high-quality perfumes. In China scented yulan tea is prepared with the flowers of *M. ×alba* and *M. figo*.

In Java, flowers of *M. ×alba* and *M. champaca* mixed with flowers of other plants and with leaves of *Pandanus amaryllifolius* Roxb. are used in traditional ceremonies and in Bali in the 'Ngaben' cremation ceremony. In Java and Peninsular Malaysia, the flower buds of *M. ×alba* are applied medicinally and put into infusions given to women as an antiseptic after delivery or following miscarriage. In Indonesia an infusion made by steeping the bitter bark in water is given against fever. In Burma (Myanmar), the aromatic bitter bark of *M. champaca* is used to treat intermittent fever, the flowers to treat leprosy and the leaves to treat colic. In Peninsular Malaysia the bark is considered to be febrifuge. In India, a dye is extracted from the flowers of *M. champaca*.

Several *Michelia* species, including *M. ×alba* and *M. champaca*, yield a timber of minor economic importance, used for light construction, vehicle bodies, packing cases and for the production of veneer, plywood, wood-wool board and as fuel. The nicely structured wood of *M. champaca* is sought after for furniture and cabinet work, carvings, turnery and pattern making.

In West Java *M. champaca* is used for reforestation of eroded areas. *M. ×alba* and *M. champaca* are widely planted as roadside trees in low-traffic areas.

Production and international trade In South-East Asia *Michelia* flowers are highly praised and marketed fresh in most local markets. Essential oil from flowers, leaves and fruits is also produced and traded locally but no statistics are available. Although the wood of *Michelia* species (trade name: chempaka) is valuable and considered equal to or better than teak wood, most trees and shrubs are cultivated for their fragrant flowers and only cut down when they become too old or diseased. In 1992 about 900 m^3 of chempaka timber with a value of US$ 87 000 was exported from Sabah to Japan.

Properties Few analyses of *Michelia* essential oils have been published, so the chemical compositions given here do not give a balanced representation of the oils. Both the flowers and leaves of *M. ×alba* contain essential oil. Solvent extraction of the flowers of *M. ×alba* yields 0.2% concrete, which on simultaneous steam distillation and extraction yields 0.05 g absolute per 100 g flowers. The absolute has an intensely sweet, almost nauseating odour. The essential oil from the leaves of *M. ×alba* is a pale yellow to greenish-yellow liquid with a sweet oily-grassy rather delicate top note reminiscent of perilla oil or freshly cut tulip leaves. After the top note the odour changes into a delicately sweet, tea-like or hay-like fragrance with an undertone of sage-clary or rose absolute.

Analysis of an absolute obtained from *M. ×alba* flowers collected in Fukien (China) showed over 100 chemical components, the most important being: linalool, 2-phenyl ethanol, 9,12-octadecadienal, methyl eugenol, methyl hexanoate. Methyl 2-methylbutyrate, methyl butyrate and p-cymene are the most important components in the headspace of the flowers. Steam distillation of leaves of *M. ×alba* also collected in Fukien (China) yielded about 0.2% of an essential oil consisting mainly of linalool, with small amounts of (E)-nerolidol and 2-phenylethyl isobutyrate. The linalool in *M. ×alba* essential oils is mainly the dextro-rotatory stereoisomer (leaf oil 95%, flower oil 75%). Characteristic minor components of the flower oil and leaf oil are theaspirine A and B and 3,7-dimethyl-1,5,7-octatrien-3-ol.

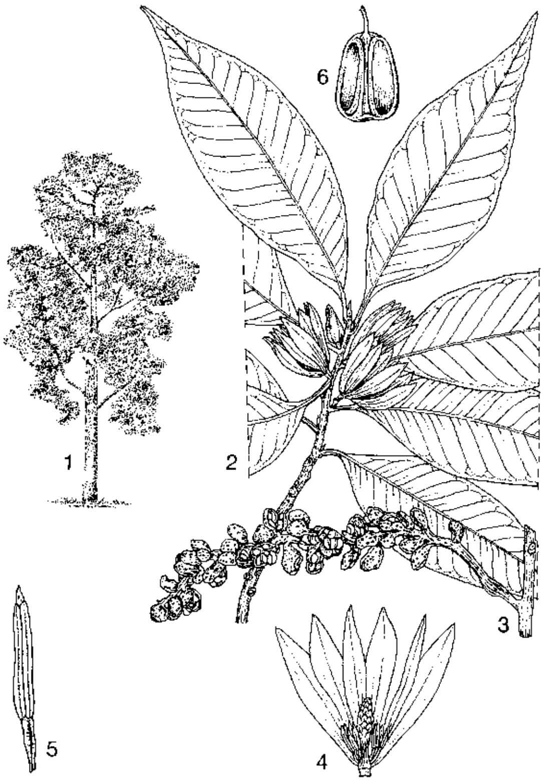
Concrete from *M. champaca* flowers is a solid waxy substance; the absolute is a dark yellow or brownish-orange, somewhat viscous liquid with a very characteristic, delicately dry-floral fragrance, simultaneously reminiscent of ylang-ylang, carnation, and tea rose. The richness of the fragrance corresponds with the complex composition of the absolute, which contains 2-phenylethanol, methyl linoleate, methyl anthranilate, benzyl acetate, β-ionone, methyl palmitate, indole, linalool, ionone oximes, 2-phenylethyl acetate, (E,E)-α-farnesene, α-ionone. Analysis of the headspace of the flowers adsorbed by resin indicated as main components: heptanal, methyl linoleate, indole, methyl anthranilate, linalool, methyl myristate, 2-phenylethanol. The essential oil is not distilled from the flowers, as its fragrance would not justly represent the odour of the flowers. The effect of champaca concrete and absolute in fragrance materials is rather weak and has to be reinforced by blenders and modifiers. Sandalwood oil, isoeugenol and benzyl salicylate are excellent fixatives for the champaca fragrance. Unfortunately, there are so many poorly constituted champaca products on the market that interest in the oil is greatly impaired.

The absolute from the flowers of *M. figo* has a fruity, banana-like fragrance quite unusual

among flower aromas. The most volatile fraction (15%) of the flower absolute is composed mainly of isobutyl acetate, ethyl isobutyrate, β-caryophyllene, methylcyclohexane, ethyl acetate, β-elemene, n-hexane, ethyl 2-methylbutyrate. Analysis of the headspace of flowers collected in Guangzhou, China indicated the main components to be butyl acetate, ethyl hexanoate, ethyl butyrate, 2-methylbutyl acetate, ethyl isobutyrate and ethyl 2-methylbutyrate.
Several other *Michelia* species yield essential oils, e.g. *M. glabra* Parment., *M. yunannensis* Franch. ex Finet & Gagnep. and *M. balansae* (A. DC.) Dandy. The essential oil from the leaves of *M. glabra* from India is characterized by safrole, the bark oil by sarisan. The flower headspace of *M. yunannensis* from southern China mainly contains pentadecane, α-cedrene and bornyl acetate, whereas the headspace of *M. balansae* from that region mainly contains ethyl hexanoate and limonene. See also: Composition of essential-oil samples.
The bark of *M. champaca* contains sesquiterpene lactones of the guiane type which are of interest in the treatment of cancer. The presence of the anticancer substances parthenolide, costunolide, β-sitosterol and liriodemine has been demonstrated in the bark of *M. ×alba*. The seeds contain about 30% of an edible, semi-solid oil. The main fatty acid components of refined oil are oleic, palmitic, linoleic and stearic acid.
The weight of 1000 seeds of *M. champaca* is 35–100 g.

Adulterations and substitutes As champaca oil is produced in the same areas as ylang-ylang oil, it is not surprising that champaca oil is frequently adulterated with the latter, sometimes by co-extraction of the 2 kinds of flowers.

Description Evergreen or semi-deciduous trees or shrubs; bole cylindrical, not buttressed; bark surface smooth, grey to greyish- white, inner bark fibrous, yellow to brown; crown conical to cylindrical. Leaves simple, entire; stipules adnate to or free from the petiole, early caducous leaving a circular scar. Flowers bisexual, axillary or subaxillary on short, small-leaved shoots (brachyblasts), solitary or rarely in pairs, large, fleshy, fragrant; tepals 6–21, in 3–6 subequal whorls, white, yellow or intermediate; receptacle elongate, columnar; stamens free, spirally arranged, 20 or more, filaments very short and fleshy, anthers with an elongated connective; gynoecium stipitate, carpels few to many, arranged spirally, free or connate, separated from the stamens by naked part of receptacle, ovules 2–many. Fruiting carpels (follicles) dehiscent along the dorsal suture when free or concrescent and forming a fleshy or woody syncarp. Seeds protruding from the fruit hanging from elastic funicles. Seedling with epigeal germination; cotyledons emergent, leafy; hypocotyl elongated; first leaves also arranged spirally.



Michelia champaca L. – *1, tree habit; 2, flowering twig; 3, infructescence; 4, sectioned flower; 5, stamen; 6, seed.*

- *M. ×alba*. Tree, 10–30 m tall, with greyish pubescent twigs. Leaves arranged spirally; stipules up to 2.5 cm long, adnate to the base of the petiole, pubescent; petiole 1.5–5 cm long, stipular scar 3–25 mm long but usually short; blade ovate-lanceolate to oblong-lanceolate, 15–35 cm × 5.5–16 cm, base attenuate with 2 ridges decurrent on the petiole, apex with an acumen up to 3 cm long, veins in 12–18 pairs, reticulation fine but prominent, glabrous to sparsely puberulous. Brachyblast 10–17 mm long, with 2–3 evenly distributed scars, densely greyish pubescent; pedicel 0–2 cm long. Flowers usually numerous, white, fragrant; tepals (8–)12, oblong, all subequal, 3–5.5 cm long; stamens 20–32, about 1 cm long, connective appendage 1 mm long; carpels 10–13, glabrous or greyish puberulous, gynophore 5 mm long. Fruit never formed, plant is sterile.

- *M. champaca*. Huge forest tree, up to 50 m tall and 1.8 m in trunk diameter, with glabrescent twigs. Leaves arranged spirally; stipules up to 3(–6.5) cm long, adnate to the petiole for at least one third of their length, pubescent; petiole 1–4 cm long, pubescent, bearing a long stipular scar; blade ovate-lanceolate to oblong-lanceolate, 10–30 cm × 4–10 cm, base rounded to cuneate-attenuate, apex with acumen 1–2.5 cm long, veins in 14–23 pairs meeting in an only slightly prominent intramarginal vein, reticulation fine, pubescent on underside, especially on midrib and veins, glabrescent. Brachyblast 0.5–2.5 cm long, with 2(–3) nodes, densely pubescent; pedicel 0–2 cm long, pubescent; bracts spathaceous, pubescent, covering the fusiform, 3–4 cm long flower buds. Flowers light yellow when young, turning dark orange, fragrant; tepals (12–)15(–20), in several inconspicuous whorls, obovate, 2–4.5 cm long, membranaceous; stamens 6–8 mm long, connective appendage 1 mm long; carpels about 30, gynophore 3 mm long and densely pubescent. Fruiting carpels (follicles) free, basally adnate to the axis or shortly stipitate, 3–20 laxly arranged in a cluster 6–9 cm long; follicle flattened ovoid to subglobose, 1.5–3.5 cm × 1–2.5 cm, subwoody, pale brown with white warts, containing 2–6 seeds. Seed ovoid, red-brown, in open follicle hanging on thin funicle.
- *M. figo*. Shrub, 1–2 m tall, often profusely branched; twigs often zigzag, with brown hairs. Leaves usually distichously arranged, glabrous; stipules adnate to the petiole for nearly their whole length, with long brown hairs; petiole 3–5 mm long with long stipular scars; blade elliptical to oblong, 3–6.5(–11) cm × 2–5 cm, base attenuate, apex with short acumen of 0–5 mm, veins in 9–12 pairs, reticulation fine and prominent. Brachyblast 0.5–20 cm long, woolly pubescent; pedicel very short; bracts spathaceous, pubescent, covering the broadly ellipsoid to globose flower buds. Flowers dirty white, fragrant; tepals 6, about 2 cm long, with purple spot at base; stamens about 1 cm long, filaments purple, connective appendage very short; carpels 20–30, glabrous, on gynophore 2 mm long, ovules usually 2, stigma purple. Fruiting carpels (follicles) 1-several, subglobose, 8 mm in diameter, often containing only 1 seed.

Growth and development The growth form of *Michelia* is according to Roux's architectural tree model, which is characterized by a continuously growing monopodial orthotropic trunk with plagiotropic branches. *M. champaca* grows well in cultivation and can reach a height of 27 m with a trunk diameter of 55 cm in 27 years; the mean annual increment is 1–1.8 m in height and 1.5–2 cm in diameter. Flowering starts when the tree is 4–5 years old. In intensive cultivation, *M. ×alba* starts flowering 1 year after planting. In Indonesia *M. ×alba*, *M. champaca* and *M. figo* flower year-round; in India *M. champaca* flowers during hot, rainy weather, and bears seed in August. *Michelia* flowers are protogynous and are pollinated by beetles which feed on the stigmas, pollen, nectar and secretion of the petals. Natural regeneration is usually abundant. Vesicular-arbuscular mycorrhizae have been observed on *M. champaca* roots in India.

Other botanical information *M. ×alba* is only known from cultivation and does not produce fruits. It is thought that it has arisen by hybridization between *M. champaca* and *M. montana* Blume because morphologically it is intermediate between those 2 species. As *M. montana* is confined to Malesia, *M. ×alba* most probably originated in Malesia, possibly in Java where *M. montana* and *M. champaca* are common species with wild and cultivated representatives.

As a result of its wide distribution and its long history of cultivation throughout the tropics, *M. champaca* is very variable. It is subdivided into 2 varieties:

- var. *champaca*: tree, up to 30 m tall and 50 cm in trunk diameter; petiole with a long stipular scar, at least up to half its length, sometimes over its whole length; leaf blade ovate with cuneate-attenuate base and usually a long acumen at apex. It is cultivated throughout the tropics, possibly originating from India where it is cultivated on the temple grounds of Jains and Hindus.
- var. *pubinervia* (Blume) Miquel: tree, up to 50 m tall and 1.8 m in trunk diameter; stipular scar on the petiole usually shorter, ranging from 0.3–0.7 times its length; leaf blade elliptical with cuneate to rounded base and a short, oblique acumen at apex. In the wild it occurs in evergreen primary forest on fertile soil in Peninsular Malaysia, Sumatra, Java and the Lesser Sunda Islands (Sumbawa). This variety is also easily cultivated for its valuable wood in Java.

Ecology In general *Michelia* is found scattered in primary lowland to montane rain forest, up to

2100 m altitude. *M. ×alba* is usually grown below 1000 m altitude. *M. champaca* occurs in humid tropical evergreen forest or at the edge of forest on deep fertile soils at 250–1500 m altitude, in Java mostly between 1000–1200 m. Mean maximum temperature of the hottest month ranges from 35–40°C, the mean minimum temperature of the coldest month from 3–10°C.

Propagation and planting As *M. ×alba* does not produce seed, it is propagated vegetatively, usually by marcotting. Methods for micropropagation of *M. ×alba* using tissue culture have been developed in the Philippines. *M. champaca* is easily raised from seed, which germinates in about 3 months after sowing. Stump planting has been successful in some places. Propagation by cuttings is also used, and trees coppice well. Grafting is also possible. In Nepal and India *M. champaca* is planted in the rainy season in nurseries. The fleshy aril contains a powerful germination inhibitor and has to be removed before planting. Seed can be stored for several months: for 7 months under moist conditions at 5°C; for about 4 months in a pit at about 13°C. Other reports indicate that the oil in the seed may deteriorate fairly rapidly, resulting in a rapid loss of viability (within 2 weeks). Seedlings 12–15 months old are usually converted into stumps with a diameter of at least 1.5 cm before planting in the field. In Java planting distance is 3 m × 2.5–3 m, making a cover crop or regular weeding necessary. In the lowland area around Bangkok (Thailand) plantings of *M. ×alba* and *M. champaca* are made on raised beds. Planting is carried out in March–April before the onset of the rainy season. Plant spacing is about 4 m × 6 m. After planting, daily watering or rain is required until the seedlings are well established.

In vitro production of active compounds Tissue culture of *M. ×alba* using callus obtained from petal tissue for secondary metabolite production has given promising results in the Philippines.

Husbandry Although *Michelia* is widely cultivated, little information is available on its husbandry. For flower production ample watering is needed except during the rainy season. On very dry days water may be applied twice. In the area around Bangkok farmyard manure is applied once per year and NPK fertilizer (e.g. 15-15-15) is given very frequently. The amount of fertilizer applied varies. Old trees of *M. ×alba* are replaced after 10–15 years, those of *M. champaca* after 5–6 years. However, with intensive management *M. champaca* can remain productive for 9–10 years. *M. champaca* is susceptible to fire and intolerant of air pollution when planted as a roadside tree.

Diseases and pests In India *M. champaca* is affected by the fungus *Phomopsis micheliae* causing a leaf spot disease. *Rhizoctonia solani* causes a leaf spot disease in seedlings; it can be controlled by removing affected seedlings and weeding during humid periods. *M. champaca* is sometimes attacked by caterpillars and grasshoppers but they are easily controlled. The Lepidoptera *Papilio argamemnon* (green caterpillar) and *Ploneta diducta* have been found on *M. champaca* in Indonesia. The scale insect *Icerya pulcher* attacks *M. champaca* in Peninsular Malaysia. In Thailand caterpillars and mealy bugs occasionally cause some damage to leaves and flowers.

Harvesting In Central Java flowers of *M. ×alba* are only harvested when market conditions are favourable. The flowers are picked by hand or by using a long stick with a hook at the end if the trees are tall. Picking is done once or twice per week. In Thailand harvesting is done daily when trees are in bloom. *M. ×alba* flowers are collected at 8–9 p.m. and are kept in cooled storage until the next morning; flowers of *M. champaca* are picked at 2–3 a.m. The flowers arrive in the markets in Bangkok very early in the morning.

Yield In Thailand the flower yield of *M. ×alba* is about 50 flowers per day; that of *M. champaca* about 70 flowers per day. No information is available on essential oil yield.

Handling after harvest The essential oil from *Michelia* is obtained by solvent extraction of fresh flowers. It is necessary to process flowers rapidly because only a few hours after picking they turn brown and begin to lose their fragrance, yielding an oil with a less agreeable scent. Enfleurage has also been used to collect the aroma compounds from the flowers. The essential oil from the leaves is obtained by distillation.

Genetic resources and breeding In Arunachal Pradesh (India) a germplasm bank with 33 clones and 2 seed orchards with 25 clones each of *M. champaca* have been established. No breeding programmes exist, however.

Prospects *Michelia* essential oils are characterized by their complex rich fragrance and remain sought after for the composition of high quality perfumes. Strict quality control is essential to maintain market interest.

Literature |1| Ashton, P.M.S., Gunatilleke, I.A.U.N. & Gunatilleke, C.V.S., 1995. Thinning guidelines for tree species of different successional status. Journal of Tropical Forest Science 8:

44–52. |2| Bahuguna, V.K. & Dhawan, V.K., 1990. Growth performance of Dalbergia sissoo, Eucalyptus grandis, Michelia champaca, Grevillea robusta, Bauhinia variegata and Bauhinia purpurea for planting under social forestry programmes. Indian Forester 116: 609–617. |3| Dasuki, U.A., 1998. Michelia L. In: Sosef, M.S.M., Hong, L.T. & Prawirohatmodjo, S. (Editors): Plant Resources of South-East Asia No 5(3). Timber trees: Lesser-known timbers. Backhuys Publishers, Leiden, the Netherlands. pp. 376–378. |4| Mandal, B. & Maity, C.R., 1992. Physicochemical and nutritional characteristics of Michelia champaca seed oil. Acta Alimentaria 21: 131–135. |5| Nooteboom, H.P., 1988. Magnoliaceae. Michelia. In: de Wilde, W.J.J.O. (Editor): Flora Malesiana, Series 1, Vol. 10. Kluwer Academic Publishers, Dordrecht, the Netherlands. pp. 598–605. |6| Phondi, O., 1993. Champichampa [Michelia ×alba and M. champaca]. Kasikon 66 (6): 556–558. |7| Toda, H., Yamaguchi, K. & Shibamoto, T., 1982. Isolation and identification of banana-like aroma from banana shrub (Michelia figo Spreng.). Journal of Agricultural and Food Chemistry 30: 84–88. |8| Zhu, L.F., Li, Y.H., Li, B.L., Lu, B.Y. & Xia N.H., 1993. Aromatic plants and essential constituents. Hai Feng Publishing Company, Hong Kong, China. pp. 13–17.

Undang Ahmad Dasuki & Kuswanto MS.

Ocimum gratissimum L.

Sp. pl.: 1197 (1753).
LABIATAE
2*n* = 40, (48, 64)

Synonyms *Ocimum viridiflorum* Roth (1800), *O. suave* Willd. (1809), *O. viride* Willd. (1809).

Vernacular names Shrubby basil, East Indian basil, Russian basil (En). Menthe gabonaise (Fr). Indonesia: kemangi hutan, ruku-ruku rimba (Sumatra), selaseh mekah. Malaysia: selaseh besar, ruku-ruku hitam. Cambodia: ling leak kranam. Thailand: kaphrao-chang, horapha-chang, yira. Vietnam: h[uw][ow]ng nhu tr[aws]ng, [es] l[as] l[ows]n.

Origin and geographic distribution *O. gratissimum* is found throughout the tropics and subtropics, both wild and cultivated. Its greatest variability occurs in tropical Africa (from where it possibly originates) and India. In South-East Asia it is cultivated mainly as a home garden crop, only in Vietnam is it grown on a commercial scale as well.

Uses *O. gratissimum* is grown for the essential oil in its leaves and stems. Eugenol and to a lesser extent thymol extracted from the oil are substitutes for clove oil and thyme oil. In Indonesia (Sumatra) a tea is made from the leaves, while in Thailand the leaves are applied as a flavouring. In Indonesia the eugenol-type of *O. gratissimum* is used in the ceremonial washing of corpses and is planted in graveyards. In India *O. gratissimum*, named 'ram tulsi', is widely used in religious ceremonies and rituals. The whole plant and the essential oil have many applications in traditional medicine, especially in Africa and India. Preparations from the whole plant are used as stomachic and in treating sunstroke, headache and influenza. The seeds have laxative properties and are prescribed against gonorrhoea. The essential oil is applied against fever, inflammations of the throat, ears or eyes, stomach pain, diarrhoea and skin diseases. It is being tested as an antibiotic. The essential oil is also an important insect repellent. *O. gratissimum* is also cultivated as a hedge plant.

Production and international trade As the essential oil of *O. gratissimum* is mainly a substitute for clove oil or thyme oil, it is rarely traded internationally. Its main use is in countries where import of the latter oils is difficult. Worldwide its annual production is currently estimated at 50 t, valued at US$ 0.8 million.

Properties The fresh aboveground parts of *O. gratissimum* contain 0.8–1.2% essential oil. The chemical composition of the oil is variable and at least 6 chemotypes have been reported, characterized by the main component of the essential oil: eugenol, thymol, citral, ethyl cinnamate, geraniol and linalool. An overview of the occurrence of the various types and possible implications for the taxonomy is lacking. The eugenol type is the most important economically; the thymol type was formerly important, but most thymol is now produced synthetically, while natural thymol is mostly obtained from *Thymus vulgaris* L. or *Trachyspermum ammi* (L.) Sprague ex Turrill. The other types are of little economic importance.

The eugenol-type oil is a brownish-yellow to pale yellow liquid with a powerful, warm-spicy and aromatic odour, reminiscent of clove oil, but with a sweet-woody, almost floral top note. The dry-out is more bitter than that of clove oil. Analysis of a sample of an essential oil of the eugenol type from Vietnam indicated that the main component was eugenol (71%) with small amounts of D-germacrene and (Z)-β-ocimene. In a sample from southern China the eugenol content was as much as

95%. Samples from Madagascar had eugenol contents of 40–90%, with very variable other components.

The thymol-type oil is a dark yellow to orange-yellow or brownish liquid with a medicinal-spicy, warm and somewhat herb-like odour. Its flavour is warm, slightly astringent and burning, and has a sweet medicinal aftertaste. Analysis of several samples of essential oils from *O. gratissimum* from Central and West Africa rich in thymol indicated that their main constituents were thymol, γ-terpinene, p-cymene and eugenol. The concrete obtained by solvent extraction is much richer in thymol than the distilled oil. A geraniol-rich type, found in the United States, contained mainly geraniol (84–88%) with small amounts of γ-muurolene, neral, β-caryophyllene and limonene. The citral type, reported from Iran, Pakistan and India is rich in citral (67%) and geraniol (26%). See also: Composition of essential-oil samples.

Description Aromatic, perennial herb, 1–3 m tall; stem erect, round-quadrangular, much branched, glabrous or pubescent, woody at the base, often with epidermis peeling in strips. Leaves opposite; petiole 2–4.5 cm long, slender, pubescent; blade elliptical to ovate, 1.5–16 cm × 1–8.5 cm, membranaceous, sometimes glandular punctate, base cuneate, entire, margin elsewhere coarsely crenate-serrate, apex acute, puberulent or pubescent. Inflorescence a verticillaster, arranged in a terminal, simple or branched raceme 5–30 cm long; rachis lax, softly pubescent; bracts sessile, ovate, 3–12 mm × 1–7 mm, acuminate, caducous; pedicel 1–4 mm long, spreading or ascending, slightly curved; flowers in 6–10-flowered verticillasters, small, hermaphrodite; calyx 2-lipped, 2–3 mm long, in fruit 5–6 mm, pubescent, upper lip rounded and recurved, reflexed in fruit, lower lip with 4, narrow, pointed teeth, central pair of teeth minute and much shorter than the upper lip; corolla campanulate, 3.5–5 mm long, 2-lipped, greenish-white, pubescent outside, upper lip truncate, 4-fid, lower lip longer, declinate, flat, entire; stamens 4, declinate, in 2 pairs, inserted on the corolla tube, filaments distinctly exserted, upper pair with a bearded tooth at the base; ovary superior, consisting of 2 carpels, each 2-celled, style 2-fid. Fruit consisting of 4, dry, 1-seeded nutlets enclosed in the persistent calyx (the lower lip closing the mouth of the fruiting calyx); nutlet subglobose, 1.5 mm long, rugose, brown; outer pericarp not becoming mucilaginous in water.

Ocimum gratissimum L. – 1, flowering branch; 2, part of inflorescence.

Growth and development In a growth trial in Colombia, germination of *O. gratissimum* was very poor (<10%); cuttings took 28 days to take root. Flowering started after 136 days and continued until 195 days. Seed matured after 259 days. Flowering and seed set were much poorer than in *O. basilicum* L. or *O. minimum* L. In South-East Asia flowers can be found year-round.

In northern India, oil content of young plants was low (2.3%) until the seed setting stage, then remained constant at 2.8% until the seed maturation stage.

Other botanical information *O. gratissimum* is a variable polymorphic complex species, often subdivided into subspecies, varieties and formas, mainly based on differences in chemical content, the morphology of the fruiting calyx, and on different degrees of hairiness, but the variation forms a continuum. Sometimes *O. gratissimum* (existing chromosome counts: $2n = 40, 48, 64$), *O. suave* ($2n = 32, 48, 64$) and *O. viride* ($2n = 38, 40$) (here treated as one complex species *O. gratissimum*) are considered as three different species. Although more research is needed it seems certain that those three taxa are closely related and have 10 homologous chromosomes in common. Crosses between *O. gratissimum* and *O. viride* resulted in partially fertile F_1 hybrids. Variability is greatest in Africa and India. In Java, 2 chemotypes exist, the eugenol and the thymol type, respectively described as *O. gratissimum* L. forma *caryophyllatum* Backer and forma *graveolens* Backer. Forma *caryophyllatum* is characterized by: leaves clove-scented when bruised, upper side short-haired, lower side densely gland-dotted, bracts 4–6 mm long, much longer than wide, lower lip of corolla not flushed with violet; and forma *graveolens* by: leaves strongly odoriferous but not clove-scented when bruised, upper surface covered with minute hairs, bracts 2–4 mm long, about as long as wide, lower lip of corolla flushed violet inside.

Most *Ocimum* species contain essential oil but are primarily used as vegetable (e.g. hoary basil, *O. americanum* L.), as spice (e.g. sweet basil, *O. basilicum* L.), or as vegetable and medicine (e.g. sacred or holy basil, *O. tenuiflorum* L.).

Ecology In its native area *O. gratissimum* occurs from sea-level up to 1500 m altitude in coastal scrub, along lake shores, in savanna vegetation, in submontane forest, and disturbed land. In South-East Asia it is not frequently found in open locations like roadsides and clearings, but more often cultivated as a hedge plant, up to about 300 m altitude.

Agronomy *O. gratissimum* is propagated by seed or cuttings. The time for transplanting seedlings into the field in the delta of the Hong River in northern Vietnam is February–March, in southern Vietnam from May–August. Plants are spaced at about 40 cm × 50 cm. The optimum harvesting time for distillation of the essential oil is when 3 branches per plant or 75% of the branches are flowering. In northern Vietnam 2–3 cuts can be obtained in an average year, 4–5 cuts per year in the south. In Vietnam, *O. gratissimum* remains productive for 5–10 years.

Yield In India, yields of 70–75 t/ha green herbage of *O. gratissimum* producing 400 l essential oil in 2 years have been obtained experimentally. In Thailand harvesting every 10–12 days resulted in an annual green herbage yield of only 13 t/ha and an oil yield of nearly 200 l.

Handling after harvest After harvesting the aboveground parts of *O. gratissimum* the plants are left to wilt in the shade for a few days and are then steam-distilled to extract the essential oil.

Genetic resources and breeding Germplasm collections of *Ocimum* L., including *O. gratissimum* are being maintained at the National Biological Institute, Bogor (Indonesia) and at the North Central Regional Plant Introduction Station, Ames, Iowa (United States). Hardly any breeding work has been done.

Prospects The essential oil obtained from *O. gratissimum* may serve as a substitute for oils of higher quality and value. It is therefore unlikely that its importance will increase.

Literature |1| Charles, D.J. & Simon, J.E., 1992. A new geraniol chemotype of Ocimum gratissimum L. Journal of Essential Oil Research 4: 231–234. |2| De Medici, D., Pieretti, S., Salvatore, G., Nicoletti, M. & Rasoanaivo, P., 1992. Chemical analysis of essential oils of Malagasy medicinal plants by gas chromatography and NMR spectroscopy. Flavour and Fragrance Journal 7: 275–281. |3| Dung, N.X., Leclercq, P.A., Moi, L.D. & Thai, N.T.P., 1987. About the chemical composition of the essential oil from Ocimum of Vietnam, and dynamical accumulation of essential oil in Ocimum basilicum L. var. basilicum. Proceedings of the NCSR of Vietnam. Vol. 1(2). pp. 27–34. |4| Guenther, E., 1952. The essential oils. Vol. 3. D. Van Nostrand, New York, United States. pp. 424–428. |5| Khosla, M.K., 1989. Chromosome meiotic behaviour and ploidy nature in genus Ocimum (Lamiaceae), 'Sanctum group'. Cytologia 54: 223–229. |6| Khosla, M.K., 1995. Study of inter-relationship, phylogeny and evolutionary tendencies in genus Ocimum. Indian Journal of Genetics 55: 71–83. |7| Ntezurubanza, L., Scheffer, J.J.C. & Baerheim Svendsen, A., 1987. Composition of the essential oil of Ocimum gratissimum grown in Rwanda. Planta Medica 53: 421–423. |8| Paton, A., 1992. A synopsis of Ocimum L. (Labiatae) in Africa. Kew Bulletin 47: 403–435. |9| Podimuang, V., 1980. Kaprao oils. Witthayasat Maha Witthayalai Khon Kaen [Journal of Science and Arts of the Khon Kaen University] 8: 42–49. |10| Zhu, L.-F, Li, Y.-H., Li, B.-L, Lu, B.-Y., Xue, N.H. & Zhang, W.-L., 1993. Aromatic plants and essential constituents. Hai Feng Publishing Company, Hong Kong, China. p. 99 & Suppl. 1, p. 62.

Diah Sulistiarini

Pelargonium L'Hérit. cv. group Rosat

Aiton, Hortus Kew. 2: 417 (1789); cv. group name is proposed here.

GERANIACEAE

$2n = 77$ (heptaploid)

Synonyms *Pelargonium graveolens* auct., *P. roseum* auct., *P. ×asperum* Ehrh. ex Willd. (1800).

Vernacular names Rose-scented pelargonium, Bourbon geranium (En). Pelargonium rosat (Fr). Indonesia: daun ambré. Philippines: malvarosa. Vietnam: chi phong l[uwx].

Origin and geographic distribution *Pelargonium* comprises about 260 species, most originating from coastal South Africa from Namaqualand to Port Elizabeth. Many *Pelargonium* species are so easy to grow and have become so popular as garden plants that they are now cultivated worldwide.

Nearly all cultivars of *Pelargonium* grown for their rose-scented essential oil, called geranium oil, arose in Europe from crossings between introductions from South Africa and are of hybrid origin. Commercial cultivation began in the early 19th Century in Grasse, France. Grasse remained the main centre of production until the Second World War. As a result of a change in the economic climate, cultivation there is now limited to a few fields yielding top-quality oil. The production of *Pelargonium* cv. group Rosat became important in Algeria, Morocco and Réunion, using plants from Grasse, but after increasing steadily for some time, production declined. The most important producers of geranium oil are currently China, Egypt, Morocco and Réunion, but extensive industries of local importance exist in India and the Crimea Peninsula, the Caucasus and Tajikistan.

In East Africa independent introductions of *Pelargonium* from South Africa (or possibly via India) led to the development of the 'Mawah oil' industry in the early 20th Century. The industry all but ceased during the Second World War. After the war a new industry was built up using plant material from Réunion. The odour of the oil produced was intermediate between the original Mawah oil and Réunion geranium oil. Production of this oil virtually stopped after independence.

In South-East Asia *Pelargonium* is only grown as an ornamental.

Uses *Pelargonium* cv. group Rosat is grown for the essential oil obtained from the leaves. The rose-scented oil is one of the most widely used fragrance materials and an essential component of most rose-scented perfumes and soaps. Extracts of the leaves of *Pelargonium* cv. group Rosat (reported but probably misidentified as *P. graveolens*) have anti-feedant properties against slugs. In India, the essential oil has shown nematicidal activity against *Meloidogyne incognita*. In Singapore, Malay women sometimes hide a fragrant *Pelargonium* leaf in their hair.

Production and international trade The main producer of geranium oil in the past was Réunion and its oil still sets the standard against which oils from other origins are valued. China is now the main producer. Other major producers are Egypt, Morocco, Réunion, India and the former Soviet Union. Annual world production is about 300 t, while demand is estimated at 500 t. The main importers are the United States, Europe and Japan. The production from India and the former Soviet Union is used entirely locally. Growing of *Pelargonium* cv. group Rosat by smallholders is very common. It is often intercropped, e.g. in fruit orchards or with pulses. Investments for mechanization and distillation become profitable for plantations of 200–300 ha.

Properties Geranium oil freshly steam distilled from the herbage of *Pelargonium* cv. group Rosat is a pale green, mobile liquid with an unpleasant top note partly due to the presence of dimethylsulphide. This note disappears on proper aeration or ageing of the oil. When the oil ages, the green colour fades, the oil becomes more yellow and its odour acquires a green leafy-rosy body with minty notes and a sweet-rosy herbaceous dry-out lasting about 5 days. The fragrance compounds are stable under slightly alkaline conditions, e.g. in soap. Geranium oil is only occasionally used as a flavouring material because of its bitter taste. The main chemical components of geranium oil from Réunion are: geraniol, citronellol, isomenthone, geranyl formate, citronellyl formate, linalool, guaia-6,9-diene and cis-rose-oxide. Although the proportions of the compounds may vary and oils from different origins can be distinguished by their odour, geranium oils are quite uniform in composition.

'Rhodinol ex Geranium' and 'Terpeneless Geranium oil' are selected fractions of vacuum-distilled geranium oil. In this distillation process the monoterpenes and several other low-boiling components are removed and usually also the 'tail' fractions of the distillation. The odour of terpeneless geranium oil varies according to the supplier. Rhodinol ex Geranium is a delightfully sweet, yet fresh and rosy, uniform and tenacious aroma material, used extensively in perfumery.

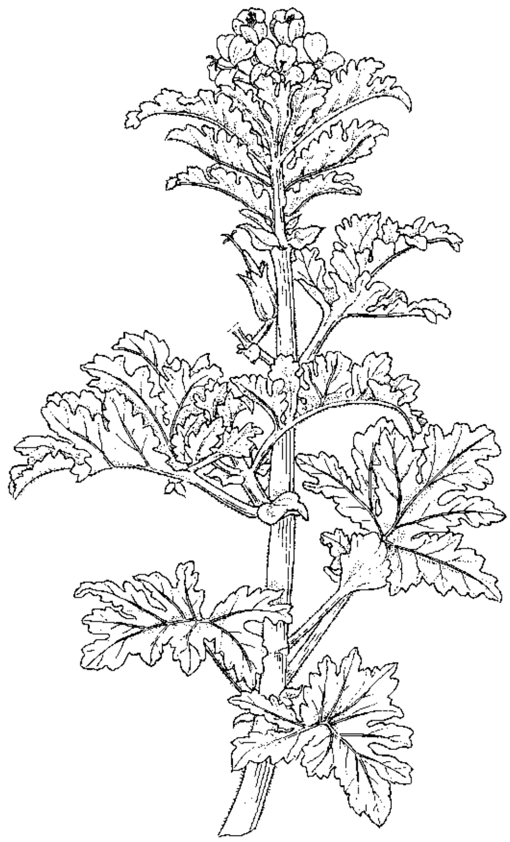
In Morocco, herbage of *Pelargonium* cv. group Rosat is often extracted with petroleum-ether to yield geranium concrete, which can be subsequently distilled to produce geranium absolute. The concrete is a dark-green or brownish-green waxy substance with an intensely earthy-herbaceous, somewhat sharp rosy odour with a note of green foliage and of great tenacity. It is used in expensive soap perfumes. The absolute is a green or dark green liquid with an intense and very powerful odour. The leafy-green top notes are quite pronounced, but the body and dry-out are characterized by rich rosy notes with a minty undertone. The odour is less sharp and more tenacious than that of the steam-distilled oil. The absolute is used in high-class rose bases that are used in a wide variety of perfumes.

Geranium oil has been approved for food use by the Food and Drug Administration (FDA) of the United States under paragraph 182.20. The oil has been 'generally recognized as safe' in the United States (GRAS No 2508) and is registered by the Council of Europe under number 324n. Geranium oil is used in food products, including alcoholic and non-alcoholic beverages. Concentrations are below 0.001% (10 ppm) in finished products. See also: Composition of essential-oil samples and the Table on standard physical properties.

Adulterations and subsitutes Geranium oil is sometimes adulterated with synthetic citronellol and geraniol.

Description More or less erect, much-branched shrub, up to 1.4 m tall and 1 m in crown diameter, strongly rose-scented, with an extensive, spreading, superficial root system seldom penetrating below 30 cm. Stem soft, grey-green, hairy, becoming darker and woody with age. Leaves opposite, soft, fragrant, hirsute with glandular and non-glandular hairs; stipules asymmetrically triangular, about 6 mm × 4 mm; petiole up to 3 cm long; blade ovate in outline, about 7 cm × 5 cm, 5–7-palmatifid to palmatisect, base cordate, margins somewhat revolute, apex obtuse. Inflorescence terminal, head-like, with 5–10 rose-violet flowers in a small compact pseudo-umbel; peduncle up to 6 cm long; flower zygomorphic, 5-merous; sepals 5, lanceolate, imbricate, unequal, connate at base, green-brown; receptacle forming a hypanthium with a nectariferous spur opening at base of the posterior sepal, lower end of spur thickened and with a nectariferous gland; petals 5, spatulate, 2 posterior larger than the 3 anterior ones; stamens 10, connate at base, staminodial, usually sterile; pistil with a 5-lobed ovary, a style and a stigma with 5 recurved, thin branches. Fruit usually never formed.

Growth and development Oil content of *Pelargonium* cv. group Rosat changes during development. In Israel, it was found to be 1.2 g per 100 g dry matter at the beginning of flowering, gradually increasing to 1.3% at full bloom and dropping to 1.2% one week later and to 0.6% at the end of blooming. At full bloom, oil content was found to be highest in the flowers (3.3%), followed by the leaves (1.8%). Stems contained only traces of oil.



Pelargonium L'Hérit. cv. group Rosat – habit of flowering branch.

Main flowering periods in Réunion are April–May and August–September.

Other botanical information Most *Pelargonium* species occur in South Africa, several are known from eastern Africa, 2 from Turkey and Iraq, several in south-eastern Australia and Tasmania, some of which may have been introduced from South Africa or developed from such introductions. Pelargoniums are commonly called geraniums in commerce and by users. It should be noted, however, that botanically the genus *Geranium* L. is different from the genus *Pelargonium* L'Hérit. *Geranium* species (about 400) have regular flowers with 10 fertile stamens and without a nectar spur; *Pelargonium* species (about 260) have irregular flowers with usually only 2–7 fertile stamens and with a nectar spur.

All *Pelargonium* species contain essential oil but none of the wild species is directly involved in commercial oil production. Three wild species are indirectly involved in the development of commercial essential-oil cultivars, mainly by hybridization and subsequent vegetative propagation:

- *P. capitatum* (L.) L'Hérit.: 2*n* = 66 (hexaploid). Synonyms: *Geranium capitatum* L., *Pelargonium drummondii* Hook.f. A decumbent, much-branched, rose-scented subshrub up to 1 m tall, with crisped, villous, 3–5-lobed or -partite leaf blades, flowers pale pink to pink-purple in a 8–20-flowered head-like pseudo-umbel and with pedicel much shorter than the hypanthium. It grows wild along most of the south coast of South Africa on sandy dunes or flats.
- *P. graveolens* L'Hérit.: 2*n* = 88 (octoploid). Synonyms: *P. asperum* Ehrh. ex Willd., *P. terebinthinaceum* (Cav.) Desf. An erect, much-branched, strongly rose-scented shrub, up to 1.3 m tall, with palmatipartite to pinnatisect leaf blades soft to the touch (villous) and with irregularly pinnatipartite to pinnatisect segments, flowers white to pinkish-purple in a 3–7-flowered pseudo-umbel, pedicel usually shorter than hypanthium. It grows wild in mountainous areas in southern Africa (known from Zimbabwe, South Africa, Mozambique).
- *P. radens* H.E. Moore: 2*n* = 88 (octoploid). Synonyms: *P. radula* (Cav.) L'Hérit., *Geranium revolutum* Jacq. An erect, much-branched, rose-scented shrub, up to 1.5 m tall, with palmatisect to pinnatisect leaf blades with narrow, pinnatisect, scabrous segments, flowers pinkish-purple in a 3-8-flowered pseudo-umbel and pedicel as long as hypanthium. It grows wild in coastal regions of the southern Cape Province of South Africa, often in mountainous, rather moist habitats.

Pelargonium cv. group Rosat are those cultivars yielding commercial rose-scented geranium oil. This group originates from the cultivars that have long been grown in Grasse (France) and which have been distributed from there to all major production areas. It is not clear, however, to what extent later independent introductions have contributed to the complex of hybrids. The typical and commercially most important cultivar in Réunion is 'Rosé', a hybrid between *P. capitatum* and *P. radens*. Other cultivars may be hybrids of other combinations of *P. capitatum*, *P. graveolens* and *P. radens*. Réunion type cultivars are typical of *Pelargonium* cv. group Rosat. Future research should more clearly demarcate the cultivar group.

Before the Réunion Rosat cultivars were proven to be hybrids of *P. capitatum* and *P. radens*, the pelargoniums grown for their essential oil were often called *P. graveolens*, *P. roseum* or *P.* ×*asperum* in the botanical literature, with scant regard for botanical accuracy. The name *P. roseum* has been applied by various authors to 3 different hybrid combinations (one of which possibly includes Rosat cultivars but is not the oldest one and should be rejected). *P.* ×*asperum* Ehrh. ex Willd. was proposed by H.E. Moore as the correct name, being a hybrid of *P. graveolens* × *P. radens* (synonyms: *Geranium radula* Roth, *Pelargonium roseum* Willd. ex Sprengel (not *P. roseum* Ehrh., nor *P. roseum* (Andrews) Aiton) and *P. rosodorum* Hoffm.). As *P. graveolens* is not involved in the origin of Rosat cultivars, *P. graveolens* and *P.* ×*asperum* are not acceptable as correct names. Moreover, a cultivar classification is more appropriate for cultivated plants; hence *Pelargonium* L'Hérit. cv. group Rosat is preferred.

'Scented-leaved pelargoniums' are a different group of cultivars grown as ornamentals. This group contains cultivars with a wide range of habits and foliage, often with numerous small flowers and characterized by their fragrance. They are scented of apple, lemon, nutmeg, peppermint or rose. 'Attar of Roses' and 'Clorinda' (rose-scented), 'Chocolate Peppermint' and 'Joy Lucille' (peppermint-scented), 'Mabel Grey' and 'Lady Mary' (lemon-scented), 'Peach Cream' (peach-scented), 'Prince of Orange' (orange-scented) and 'Viscosissimum' (balsam-scented) are some well known cultivars. Their relation to wild species with fragrant leaves should be further investigated, e.g. the relation to *P. citriodorum* auct. (citron-scented), *P. crispum* (Berg.) L'Hérit. (lemon-scented), *P. fragrans* Willd. (nutmeg-scented), *P. odoratissimum* (L.) L'Hérit. (apple-scented) and *P. tomentosum* Jacq. (peppermint-scented).

Although the essential oils extracted from *Pelargonium* are called geranium oil in commerce, only one true *Geranium* species is grown commercially for its essential oil: *Geranium macrorrhizum* L., yielding zdravetz oil. All zdravetz oil is produced in managed natural stands in Bulgaria, the former Yugoslavia and former Soviet Union.

Ecology For optimum growth *Pelargonium* cv. group Rosat requires an average annual rainfall of 1000–1500 mm. Rainfall may be evenly distributed, but a 3-month dry period improves herbage yield and oil content. Oil produced after a 3-month wet period, however, had a slightly milder note and an increased geraniol content. Heavy rainfall combined with mist or fog may lead to root and stem rot. The plants require much light; cloudy weather reduces leaf growth and oil content. An average daytime temperature of 20–25°C is optimal, but growth is acceptable from 15–30°C and absolute maximum temperatures of 42°C for several weeks are tolerated in Hyderabad, India. Growth stops at 6°C; frost and even prolonged exposure to 3°C kills the plants. In termperate areas, it is therefore grown as an annual crop. In Réunion *Pelargonium* cv. group Rosat can be grown up to 1400 m altitude, but other crops are more profitable from sea-level to 400 m altitude. In the Highlands of Kenya it is grown at 2000–2500 m altitude, in southern India at 1200–1500 m. Altitude and temperature have a pronounced influence on the character of the oil. In a trial in India herbage and oil yields at 900 m altitude were higher than at 550 m and at 2200 m. At the lower altitudes the essential oil was richer in isomenthone and citronellyl formate, at higher ones in methone, citronellol and geraniol. At the lowest altitude the content of rose oxides was significantly higher than at the other altitudes. High maximum temperatures reduce oil content, but increase the content of citronellol and citronellyl formate. In Réunion cyclones often cause havoc in *Pelargonium* fields; soils saturated by prolonged heavy rains associated with cyclones also cause extensive damage.

Pelargonium cv. group Rosat grows best on fertile, well drained, slightly sandy soils with pH 5.5–8.0. Heavy clays, alkaline and very acid soils are generally unsuitable. Waterlogging is not tolerated. Selected cultivars are tolerant of low to moderate salinity.

Propagation and planting *Pelargonium* cv. group Rosat is propagated vegetatively, mostly by stem cuttings. Micropropagation methods have given excellent results, but are more expensive. Leafy stem cuttings of 15–20 cm length with 4–6 nodes and a terminal bud are taken from healthy plants. Some 20–25 cuttings can be taken from a vigorous plant. Direct planting is common and striking rates are high when planted in moist soil, but nursery planting is also used. Before the cuttings are planted the lower leaves are removed and the base of the stem is cut at an angle and dipped in a fungicide. Cuttings should be planted immediately after preparation. To plant 1 ha 30 000–50 000 cuttings are needed. Equipment for mechanized planting is available, but manual planting is common. Prior to planting careful soil cultivation and removal of weeds and crop residues are essential, as *Pelargonium* cv. group Rosat is very susceptible to root infections and because weeds are difficult to remove from an established crop.

Husbandry Regular weeding of *Pelargonium* cv. group Rosat is needed until the crop is established. Cultivation should be careful and shallow to avoid damage to the root system. Herbicides have been used successfully and should be applied as directed sprays with drift shields. For small farmers, who do most weeding manually, spot spraying against persistent weeds is recommended.

Nutrient uptake is high, but amounts reported very greatly. In Réunion a crop of 7 t/ha fresh herbage removes an estimated 100 kg N, 14 kg P, 134 kg K, 179 kg Ca, 15 kg Mg and 10 kg S; in India the estimated amount of nutrients removed by a similar crop was 110 kg N, 25 kg P, 40 kg K, 45 kg Ca and 30 kg Mg. Fertilizers have little effect on the oil content of the foliage. Where irrigation facilities are available for other crops in a rotation, supplemental irrigation is recommended during dry periods and to promote regrowth after harvesting. The economic life of a well-managed plantation can be 10 years. It should not be less than 5–7 years as the cost of establishment is high. After this period rotation with other crops is recommended.

Diseases and pests In *Pelargonium* cv. group Rosat diseases generally cause more damage than pests. The most damaging are leaf diseases such as anthracnose (caused by *Glomerella*, *Gloeosporium* and *Colletotrichum* spp.), leaf spot (caused by *Alternaria*, *Cercospora*, *Fusarium* spp.), and rust (caused by *Puccinia pelargonii-zonalis*). *Pelargonium vitifolium* (L.) L'Hérit. has good resistance to anthracnose and has been used in breeding programmes in Réunion. Root and stem rots may cause severe damage in newly planted fields, but can be controlled by dipping cuttings in a fungicide solution before planting. Established plants may become infected when soil moisture is high or during periods of high air humidity. Frequently recorded causal agents are: *Xanthomonas pelargonii* causing black rot, *Pythium* spp. causing root rot and *Sclerotinia* spp. causing stem or root decay. Spraying a fungicide along the plant row after harvesting can often contain an outbreak. Resistance to some diseases has been found in Indian selections and in ornamental cultivars. Several pathogenic viruses have been isolated from *Pelargonium*, thus only virus-free cuttings should be used for propagation. Nematodes have been recorded, but seem to cause only limited damage, possibly because geranium oil has nematicidal properties. *Pelargonium* plants grown for essential oil are much less affected by insects than ornamental cultivars. A large number of insects including aphids, caterpillars, myrids, scale insects and whiteflies have been recorded, but rarely justify spraying with insecticides, especially as the residues of many insecticides adversely affect the quality of the oil.

Harvesting Under favourable conditions the first harvest of *Pelargonium* cv. group Rosat can be taken when the crop is 6–8 months old. Cutting too early may kill plants or retard regrowth. Subsequently, harvesting is done 2–3 times per year. To obtain maximum oil yield the crop should be sampled regularly to determine its oil content, but cutting time is normally related to plant height and flowering. Cutting is done manually or mechanically, normally at 12–20 cm above the ground. Field trials should establish the optimum cutting height, as nearly all oil is contained in the top 15 cm of a plant. Harvesting is best done during slightly overcast, but dry weather. Heavy rain or several misty days can reduce oil content to half; cutting should then be suspended until oil content has recovered. Cut branches should be loaded directly into a cart. Any contamination with soil, especially if rich in Fe or Al, can affect oil quality.

Yield Annual herbage yields of *Pelargonium* cv. group Rosat in Réunion are 15–30 t/ha, the average being 18 t/ha yielding 5–20 kg oil. In India yields average 6–10 t/ha and may reach 20 t/ha.

Handling after harvest Wilting of the herbage of *Pelargonium* cv. group Rosat before distillation may increase still efficiency, but should be carefully managed to avoid contamination with soil and loss of oil due to intense insolation. Geranium oil is obtained by water or steam distillation, the distillation method having little influence on oil quality. In Réunion the oil is produced by peasants operating small simple stills. The desired quality of the oil is maintained by traders mixing numerous small lots of oil. Modern steam-distillation equipment is loaded directly or after chopping the herbage. The load should not be too densely packed as this will channel the steam and cause local overheating. Since significant quantities of aroma compounds remain in the distillation water, cohobation is used. Up to 25% of the oil yield may be obtained from solvent extraction of the distillation water. This 'secondary oil' has a higher free alcohol content, but contains less ester. Water remaining in direct-fired water stills contains a different oil. This oil should be discarded as it contains undesirable compounds, probably as a result of overheating. Crude oil should be dried, filtered and stored in opaque containers, preferably at a temperature below 10°C. At higher temperatures the ester content decreases and the content of acids increases.

Solvent extraction of herbage yields a concrete that for most purposes should be distilled with alcohol to remove wax.

Genetic resources Germplasm collections of *Pelargonium* cv. group Rosat have been established at the Horticultural Research Station, Kodaikanal, India and at the Indian Institute of Horticultural Research, Bangalore, India. Morphological and yield (herbage and oil) studies have been made to identify promising strains.

Breeding Breeding work in *Pelargonium* cv. group Rosat is hampered by male sterility in most cultivars. Most breeding work has therefore relied on selection of superior plants. Cultivars with a high yield potential and high oil content have been selected in India e.g. PG-7, PG-20, Alg-4n. Tolerance of heavy rainfall conditions and associated tip rot has also been found. Cultivars with high geraniol content and a moderate resistance to wilt have been identified in Egypt. In India a mutant characterized by fertile stamens and gigas traits has been found in a cultivar originally from Réunion. Hybrids between this mutant and a seed-setting cultivar (Alg-4n) form the basis of a breeding programme.

Prospects Because of the strong demand for geranium oil, *Pelargonium* cv. group Rosat will remain an important crop. Its adaptability to tropical conditions, and the relative uniformity of geranium oil from different origins seems to justify testing this crop in South-East Asia.

Literature |**1**| Angadi, S.P. & Vasantha Kumar, T., 1995. Geranium. In: Chadha, K.L. & Rajendra Gupta (Editors): Advances in Horticulture, Vol. 11, Medicinal and aromatic plants. Malhotra, New Delhi, India. pp. 668–687. |**2**| Demarne, F. & van der Walt, J.J.A., 1989. Origin of the rose-scented pelargonium cultivar grown on Réunion Island. South African Journal of Botany 55: 184–191. |**3**| Demarne, F.-E., Viljoen, A.M. & van der Walt, J.J.A., 1993. A study of the variation in the essential oil and morphology of Pelargonium capitatum (L.) L'Hérit. (Geraniaceae). Part 1. The composition of the oil. Journal of Essential Oil Research 5: 493–499. |**4**| Huxley, A., Griffiths, M. & Levy, M. (Editors), 1992. Pelargonium. The new Royal Horticultural Society dictionary of gardening. Vol. 3. McMillan, London, United Kingdom. pp. 498–504. |5| Lawrence, B.M., 1992. Progress in essential oils. Perfumer and Flavorist 17(2): 46–49; 17(6): 59–60. |6| Prakasa Rao, E.V.S., Ganesha Rao, R.S. & Ramesh, S., 1995. Seasonal variation in oil content and its composition in two chemotypes of scented geranium (Pelargonium sp.). Journal of Essential Oil Research 7: 159–163. |7| van der Walt, J.J.A., 1985. A taxonomic revision of the type section of Pelargonium L'Hérit. (Geraniaceae). Bothalia 15: 345–385. |8| van der Walt, J.J.A. & Vorster, P.J., 1977–1988. Pelargoniums of South Africa. Vol. 1. Purnell, Cape Town, South Africa. 84 pp.; Vol. 2. Juta, Kenwijn, South Africa. 176 pp.; Vol. 3. National Botanic Gardens, Kirstenbosch, South Africa. 187 pp. |9| Webb, W.J., 1984. The Pelargonium family: the species of Pelargonium, Monsonia and Sarcocaulon. Croom Helm, London, United Kingdom. 104 pp. |10| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 24–58.

Undang Ahmad Dasuki

Pimenta racemosa (Miller) J.W. Moore

Bernice P. Bishop Mus. Bull. 102: 33 (1933).
MYRTACEAE
$2n = 22$

Synonyms *Caryophyllus racemosus* Miller (1768), *Myrtus acris* Swartz (1788), *Pimenta acris* (Swartz) Kostel. (1835).

Vernacular names Bay rum tree, West Indian bay tree, bay-berry (En). Bois d'Inde (Fr).

Origin and geographic distribution *P. racemosa* occurs naturally in northern South America and throughout the Caribbean. It is cultivated in the Caribbean, south-eastern United States, Cameroon and India. Bay rum was probably first produced in the Virgin Islands. The main producers of bay leaf oil from *P. racemosa* are the Caribbean islands Dominica and Puerto Rico. *P. racemosa* has been grown experimentally in Bogor (Indonesia) and in Singapore, but did not perform well.

Uses Traditionally, the leaves of *P. racemosa* are distilled with rum to produce bay rum, which has soothing and antiseptic properties and was formerly a very popular toilet water and hair tonic. It is reported that bay rum is occasionally drunk in Trinidad. On water or steam distillation the leaves yield bay leaf oil (sometimes called myrcia oil). The oil is used in perfumery, mainly in cosmetic products, such as hair lotions, after-shaves and other toiletries for men.

Bay leaf oil is often converted into terpeneless bay leaf oil by removal of the monoterpene hydrocarbons. Bay rum is now prepared by mixing this oil with rum. Terpeneless bay leaf oil blends excellently with many aroma materials and is used in many perfumes and perfume bases. Although the components of this oil are readily available from other sources, there is no really suitable substitute for it. The oil is used on a limited scale for flavouring foods, chiefly sauces. The dried green berries have a spicy flavour with hints of cinnamon, clove and nutmeg and are used as a spice.

The hard and heavy, fine-grained wood is used in carpentry, for making walking sticks, and for posts. It splits easily and is excellent fuel.

Bay rum tree has many uses in traditional medicine, mostly based on the antibiotic properties of the phenols in the oil. A tea from the leaves is drunk as a stimulant and against colds and fever.

Production and international trade Major producers of bay leaf oil are Dominica and Puerto Rico, but no statistics are available on production and trade. In New York bay rum fetches a wholesale price of US$ 35/kg (1998).

Properties The leaves of Puerto Rican bay rum trees contain 1–3.5% essential oil, the highest content occurring in regions of lower rainfall (1100 mm annually), the lowest in more humid areas (2200 mm annually); in individual trees it may reach 5%. Bay leaf oil is distilled from *P. racemosa* var. *racemosa* and is a yellowish to dark brown liquid. Its odour is fresh-spicy, somewhat medicinal, but it has a lasting, sweet-balsamic undertone. To some people the sensory properties of the oil can be quite offensive, sickly sweet and nauseating; others perceive it as quite fresh and pleasant. Its flavour is warm, almost pungent, spicy and somewhat bitter. The chemical composition of bay leaf oil is variable. The main chemical components are eugenol and myrcene, while chavicol and methyl eugenol occur in variable amounts. In the production of terpeneless bay leaf oil, the terpenes (mostly the monoterpenes with a low boiling point) are removed by vacuum distillation. Myrcene is the most important compound removed. Oxygenated compounds with a low boiling point such as citral and 1,8-cineole may be removed by careless distillation. Terpeneless bay leaf oil is a pale straw-coloured to brownish-orange liquid with an intensely sweet, deep and mellow spicy-balsamic odour and lemon-like top note that is less pronounced than in the 'crude' oil. It is easily dissolved in diluted alcohol, which is an advantage as it is often used in preparation with a low alcohol content, such as hair lotions. An absolute can be prepared by extracting the 'crude' oil with alcohol. The absolute contains neither monoterpene nor sesquiterpene hydrocarbons.

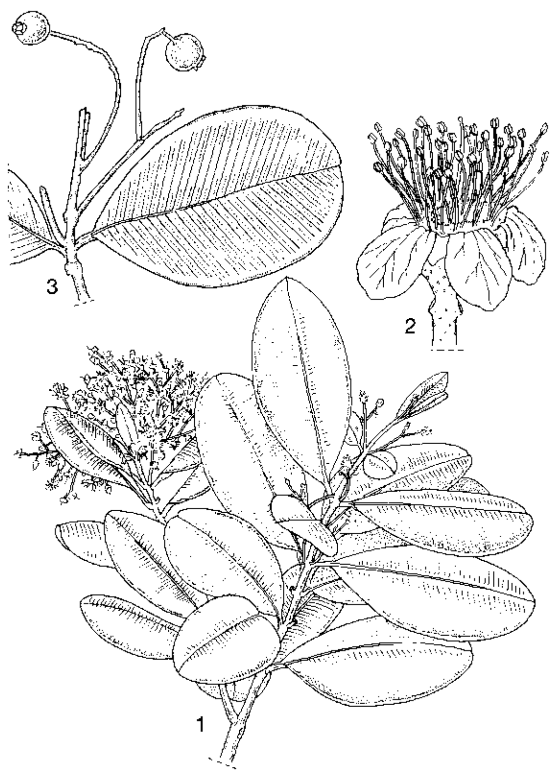
Bay rum used in hair dressings and aftershaves may cause irritation of the skin. Contact dermatitis caused by the components eugenol and phellandrene has been reported.

Bay oil is approved for food use by the Food and Drug Administration of the United States and is 'generally recognized as safe' (GRAS).

The botanical classification in varieties does not match well with the variation in the chemical composition of different samples of *P. racemosa*. Two different oils distilled from var. *racemosa* have been reported: a 'lemon' type and an 'anise' type. Both types are reported from the Caribbean island Guadeloupe and may have been introduced into Java in the 1880s. The 'lemon' type is rich in citral (geranial and neral); the 'anise' type contains mainly methyl eugenol and estragol (methyl chavicol). Samples of var. *hispaniolensis* were characterized by thymol and γ-terpinene, 1,8-cineole and methyl eugenol, 1,8-cineole and methyl chavicol or 1,8-cineole and terpinen-4-ol, while samples from var. *ozua* were high in 1,8-cineole and α-terpineol. The essential oil from var. *grisea* was characterized by trans-methyl isoeugenol, methyl eugenol or geraniol. Var. *grisea* is so common and has such a negative effect on the quality of the oil that it is called 'false bay rum tree'. See also: Composition of essential-oil samples and the Table on standard physical properties.

The heartwood is very hard, heavy (specific gravity 0.9), strong and durable. It is resistant to attack by dry-wood termites.

Description Erect, evergreen tree, up to 15(–25) m tall; trunk up to 20 cm in diameter, often slightly ridged and grooved; bark smooth, grey to light brown, peeling off in thin strips; inner bark pinkish; crown dense, columnar, dark green; young branchlets flattened, 4-angled. Leaves opposite, simple, entire, highly aromatic; petiole 3–12 mm long, green with reddish tinge; blade elliptical to obovate or elliptical-oblong, 4–18 cm × 3–8 cm, base attenuate, obtuse or rounded, margins often recurved, apex rounded, emarginate, stiff, leathery, with very numerous, minute glandular dots, shining dark green above, paler beneath, midrib sunken, lateral veins prominent on both surfaces. Inflorescence a terminal or subterminal corymbiform panicle, 3–12 cm long; flowers 10 mm or more in diameter, white; hypanthium obconical, about 1.5 mm long, subglabrous, sepals 5, up to 1.5 mm long, wider than long, spreading; petals 5, 3–4 mm long, spreading; stamens numerous, 4–5 mm long, white; pistil with 2-celled ovary, slender style 4–5 mm long. Fruit a fleshy, subglobose to ellipsoid berry, 8–12 mm long, red-brown to black, with 1–3 seeds and sepals persistent at apex. Seed 4–7 mm long, brown.



Pimenta racemosa (Miller) J.W. Moore – 1, flowering branch; 2, flower; 3, fruiting branch.

Growth and development Although *P. racemosa* is evergreen, individual trees shed their leaves every 2–3 years. Flowering in the Caribbean is mainly from April–August, fruiting from August–October. Fruits are eaten by birds, which are the main dispersal agents for the seed. The life of plantations is indeterminate, as trees regenerate from stumps, but the effect of regular harvesting on the life expectancy is not known. Individual trees of 50 years old are known.

Other botanical information Several varieties are recognized in *P. racemosa*: var. *racemosa*, the most common and widespread variety, probably native to the Lesser Antilles, Puerto Rico and Cuba; var. *hispaniolensis* (Urban) Landrum and var. *ozua* (Urban & Ekman) Landrum are endemics to north-central Hispaniola; var. *grisea* (Kiaerskov) Fosb., a common forest tree below 800 m altitude in Hispaniola, Puerto Rico and Tortola with dense, fine, grey to white hairs on the underside of leaves, young twigs, flower stems and fruits; var. *terebinthina* (Burret) Landrum, endemic to the Dominican Republic. Within var. *racemosa* several chemotypes have been described which are morphologically similar, but are distinguished by their smell, reminiscent of either clove, lemon or anise.

Other *Pimenta* species also yield essential oils, of which the most important one is pimento or allspice (*P. dioica* (L.) Merrill). Its fruits are mainly used as a spice, but also yield an essential oil named pimento berry oil, whereas its leaves yield pimento leaf oil. Both oils are used industrially as substitutes for allspice. Eugenol is their main component.

Confusion is possible with the word 'bay'. Bay leaf oil refers to oil obtained from the leaves of *P. racemosa*. Bay leaf, however, is also a common name for the leaf spice *Laurus nobilis* L. (*Lauraceae*) from the Mediterranean which is also called sweet bay, laurel or bay laurel and from which an essential oil can be produced. Oil obtained from the Californian bay or California olive originates from *Umbellularia californica* (Hook. & Arn.) Nutt. (*Lauraceae*).

Ecology *P. racemosa* prefers an annual rainfall of 2500 mm evenly distributed over the year with few months with less than 200 mm rainfall, but natural stands occur in areas with only 750 mm annual rainfall. Although trees grow well with 1250–1500 mm annual rainfall, regrowth following pruning is too slow for commercial plantations to be profitable. It grows best at temperatures of 15–35°C; temperatures below 15°C having a more adverse effect on growth than temperatures higher than 35°C. Frost is not tolerated. Trees are found up to 750 m altitude. Clear sunny weather promotes leaf growth and reduces the incidence of leaf diseases. Leaf-oil content is often highest during periods of warm, dry weather. Growth is best on deep fertile loamy soils with a slightly acid to neutral pH, but most plantations are on marginal soils on slopes, better soils being allocated to food crops.

Propagation and planting Propagation of *P. racemosa* is mostly by seed. Seedlings may be collected from natural stands or are grown in nurseries. In the Caribbean mature fruits are usually collected in August–October. When collecting seed or seedlings from the wild care should be taken to avoid those of var. *grisea*. Seed is removed from the fruit, washed and planted within 2 days. Germination generally takes 2–6 weeks. Seedlings are ready for transplanting to the field in 18–24 months. Before planting the stem is topped to 15 cm and the taproot is pruned to 7 cm to encourage lateral rooting. Some fertilizer may be applied at planting. An application of 250 g of a 10-10-10 compound NPK fertilizer mixed with surrounding topsoil and compost and applied in the plant hole is recommended. After planting, protection from direct sunlight until the seedling is well established is beneficial. Vegetative propagation is rarely practised, but budding which is applied successfully to *P. dioica* is probably suitable for *P. racemosa* as well. Spacing is determined mainly by topography; on flat land 2–5 m × 5–10 m is common.

Husbandry Topped seedlings of bay rum tree often produce several main shoots. Two main shoots are sometimes retained, since experience has shown that foliage yield is higher than from single-stemmed trees. After 2–3 years trees are topped at 3–5 m and are maintained at that height. *P. racemosa* coppices well and misshapen or diseased trees can be cut back to ground level, allowing a new shoot to grow from the stump. Weed control is generally limited to slashing grass and other vegetation between the trees. Care should be taken to remove spontaneous seedlings of *P. racemosa* that do not yield commercially acceptable bay leaf oil. Fertilizer is rarely applied after planting, although large amounts of nutrients are removed with the leaves. Spent leaves and ash from the distilleries are often returned to the field.

Diseases and pests The most serious disease of *P. racemosa* is a leaf rust caused by *Puccinia psidii*, which covers young leaves, shoots and inflorescences with a bright yellow mass of spores. Severe infection results in defoliation and successive attacks severely weaken trees and may kill young ones. The disease is most common in areas where fog or heavy dew occurs frequently. A dieback or canker, known in the Caribbean as fireblight, caused by *Ceratocystis fimbriata* affects older trees. The disease is widespread, but outbreaks can be very local.

Leaf-eating caterpillars are the most damaging pests. Bag-worms (*Oeceticus abboti*) and related species are often recorded. Whiteflies, thrips and weevils also cause some damage. Black ants cause damage by transferring scale insects between trees and by making harvesting unpleasant.

Harvesting Well managed groves of bay rum tree are harvested once a year or 3 times in 4 years. The harvesting interval depends more on the age of the leaves than on the rate of regrowth. Leaves are shed after 2–3 years, so a harvesting interval longer than 2 years may result in reduced yields. Harvesting can be done year-round. Where there is a dry period, harvesting during this period is preferred. It is not clear whether the higher yield during this period is due to a higher leaf oil content or to a higher proportion of mature leaves. Where labour costs are low, small twigs and leaves are plucked from the trees, packed in bags and taken to the distillery. Alternatively, branches are cut and taken to the distillery where leaves are removed. Per day a person can harvest about 300 kg leaves.

Yield Leaf yield of bay rum tree in established groves may vary between 8–35 t/ha (oil content 1–3.5%) due to differences in location and management.

Handling after harvest Harvested leaves of bay rum tree are processed immediately or stored for up to a week. Storage under suitable, well aerated conditions does not lead to loss of oil. Leaves are finely chopped before distillation. Water, water and steam and steam distillation are used. Cohobation is common in direct-fired stills. Salted fresh water or a 1:3 mixture of seawater and fresh water is used to increase steam temperature, resulting in a higher oil yield and a higher content of phenols. Distillation takes about 9 hours for water or water and steam distillation and 4–6 hours for high-pressure steam distillation. On distillation 2 fractions are obtained, a first fraction lighter than water and a second one that is heavier. Both fractions are separated from the distillation water and subsequently combined to obtain the complete oil.

Genetic resources and breeding No germplasm collections of *P. racemosa* are known to be maintained. Since there is ample leaf supply from natural stands and cultivated trees to satisfy current oil demand, hardly any selection of high-yielding trees has been undertaken.

Prospects Bay leaf oil is a minor essential oil and its production is well established in the Caribbean. Production in South-East Asia is only worthwhile if *P. racemosa* performs well and if production costs can be maintained at a substantially lower level than elsewhere in the world.

Literature |1| Abaul, J., Bourgeois, P. & Bessiere, J.M., 1995. Chemical composition of the essential oils of chemotypes of Pimenta racemosa var. racemosa (P. Miller) J.W. Moore (Bois d'Inde) of Guadeloupe (F.W.I.). Flavour and Fragrance Journal 10: 319–321. |2| Fournet, J., 1978. Flore illustrée des phanérogames de Guadeloupe et de Martinique [Illustrated flora of the phanerogams of Guadeloupe and Martinique]. Institut National de la Recherche Agronomique, Paris, France. p. 901. |3| Landrum, L.R., 1986. Campomanesia, Pimenta, Blepharocalyx, Legrandia, Acca, Myrrhinium, and Luma (Myrtaceae). Flora Neotropica: Monograph 45. New York Botanical Garden, New York, United States. 178 pp. |4| Lawrence, B.M., 1977. Chemical evaluation of various bay oils. Proceedings of the 7th International Conference on Essential Oils, Kyoto, Japan. pp. 172–179. |5| Little, L.E. & Wadsworth, F.H., 1964. Common trees of Puerto Rico and the Virgin Islands. Agriculture Handbook No 249. United States Department of Agriculture, Washington, D.C., United States. pp. 414–415. |6| Tucker, A.O., Maciarello, M.J., Adams, R.P., Landrum, L.R. & Zanoni, T.A., 1991. Volatile leaf oils of Caribbean Myrtaceae. 1. Three varieties of Pimenta racemosa (Miller) J. Moore of the Dominican Republic and commercial bay oil. Journal of Essential Oil Research 3: 323–329. |7| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 323–330.

Trimurti Hesti Wardini

Pogostemon Desf.

Mém. Mus. Hist. nat. Paris 2: 154 (1815).

LABIATAE

$x = 16$; *P. cablin*: $2n = 32, 34, 64$; *P. heyneanus*: $2n = 32, 64$.

Major species and synonyms

- *Pogostemon cablin* (Blanco) Benth., in: A. DC., Prodr. 12: 156 (1848), synonyms: *Pogostemon patchouly* Pellet. (1845), *P. comosus* Miquel (1859), *P. javanicus* Backer ex Adelb. (1954).
- *Pogostemon heyneanus* Benth., in: Wallich, Pl. asiat. rar. 1: 31 (1830), synonyms: *Origanum indicum* Roth (1821), *Pogostemon patchouli* sensu Hook.f. (1885), non Pellet. (1845).

Vernacular names

- *P. cablin*: Patchouli (En). Patchouli (Fr). Indonesia: nilam wangi (general), nilam (Aceh), singalon (Batak). Malaysia: dhalum wangi, tilam wangi. Philippines: kabling (Tagalog), katluen (Bisaya), kadlum (Bikol, Bisaya, Sulu). Thailand: phimsen (Bangkok). Vietnam: ho[aws]c h[uw][ow]ng.

- *P. heyneanus*: Indian patchouli, Java patchouli (En). Indonesia: dilem (Sumatra), dilem kembang (Javanese), dhilep (Madurese). Malaysia: boon khalif, nilam bukit, pakochilam. Philippines: kadlum (Bisayas), lagumtum, malbaka (Subanun).

Origin and geographic distribution *Pogostemon* comprises about 80 species occurring throughout South and South-East Asia up to China and Japan, with 1 species extending into Australia. The origin of *P. cablin* is uncertain, the border region between South-East Asia and China has been suggested as its origin, and the Philippines as a secondary centre of diversity. It is widely distributed in South and South-East Asia and has been introduced all over the tropics and subtropics. Cultivation of *P. cablin* for its essential oil probably started in Penang (Malaysia) in the 19th Century using plants from the Philippines. From there it was taken to Java in 1895 and to Sumatra in 1910. By 1920 production was well established in Aceh (northern Sumatra). It is mainly cultivated for the production of essential oil in Sumatra (Indonesia), southern China and Brazil and to a lesser extent in India, the Seychelles, Madagascar, and Taiwan. *P. heyneanus* is widespread in South and South-East Asia, from southern India and Sri Lanka to Indonesia and the Philippines, but it is probably not native to Malesia. It is cultivated for its fragrant leaves in South and South-East Asia and also outside this region (e.g. in the Seychelles).

Uses *Pogostemon* has a long history of use in southern Asia and the Far East as incense, body and garment perfume and as a repellent of insects and leeches. In China, where it was probably grown 2000 years ago, ink was also perfumed with it. Traditionally, the dried leaves of several *Pogostemon* species are placed between stored clothing to repel insects and to impart a pleasant smell. Through the import of Indian shawls and clothing the fragrance became well known in Europe, but not until 1844 did the first dried leaves arrive in London. Cloth producers in France were then quick to copy the practice.

Patchouli oil steam distilled from *P. cablin* leaves is almost universally used as a fixing agent in perfumery, blending beautifully with an exceptionally wide range of fragrance and body-care materials. It is mostly used in very small dosages, but in Oriental-type perfumes it is often a fundamental note. Its odour has a masking effect when used in depilatory creams. Combined with other flavour materials, it is an important ingredient in Oriental-type after-dinner candies, appreciated for their masking effect on alcoholic, onion and garlic odours. Recently, patchouli oil has become one of the additives to cigarettes and tobacco as one of the components added to compensate the loss of taste due to a reduced tar content. In Goa the inflorescence of *P. cablin* is sold to dress the hair of women.

P. heyneanus is widely cultivated for its fragrant leaves, but mostly on a minor scale. An essential oil distilled from the leaves in Java is much inferior to patchouli oil and its production has been abandoned. Small quantities are occasionally produced in India for local use or as an adulterant for patchouli oil. In Java crushed leaves of *P. heyneanus* were formerly used to wash clothes.

Pogostemon species have many uses in traditional medicine. In Chinese medicine a decoction of the leaves is used with other drugs to treat nausea, vomiting, diarrhoea, colds and headache. In the Philippines an infusion of the leaves is taken to allay painful menstruation. In Japan and Malaysia patchouli oil is erroneously considered an antidote to snakebite. In Thailand a preparation of equal parts of *P. cablin* leaves, guava and orange peel is recommended against diarrhoea. In aromatherapy it is used as a relaxant. Leaves are added to bath water to alleviate rheumatism. *P. heyneanus* is used as a carminative and diuretic.

Production and international trade World production of patchouli oil has grown steadily and had reached about 1000 t/year in 1995. Over 80% of the annual world production comes from Sumatra, where *P. cablin* is cultivated on over 18 000 ha. Between 1985–1995 Indonesia exported 350–850 t annually. China produces about 60 t/year and Brazil, Malaysia and the Seychelles produce smaller quantities. In 1995, the United States alone imported about 500 t with a value of US$ 20 million. The price of patchouli oil in Indonesia is about US$ 50 per kg (1998).

Properties Indonesian-distilled patchouli oil is a dark orange or brownish, viscous liquid with a tenacious, extremely rich, sweet-herbaceous, aromatic-spicy and especially earthy, woody-balsamic odour. Good quality patchouli oil has an ethereal-floral, wine-like sweet top note, that is, however, often absent in freshly distilled, otherwise good oils. Sweet notes, present in all stages of evaporation, are very persistent and remain perceptible on a perfumer's blotting paper for months. Their intensity is so great that high concentrations are nauseating to many people. The top note is sometimes reminiscent of the aroma of cade oil (from *Juniperus oxycedrus* L.) and cedarwood oil (from *Cedrus libani* A. Rich. subsp. *atlantica* (Endl.) Battand. & Trabut). This top note is useful for specific purposes, but not generally considered desirable. Occasionally the top note has distinct, but undesirable tar-like characteristics. The body notes of good quality patchouli oil should be outstandingly rich, with a delicate, root-like earthiness, without mouldy or musty notes. Because of variations in the composition of the oil, many other notes have been described, e.g. minty, swampy and barnyard-like.

Patchouli oil distilled in Europe or the United States is a pale orange or amber-coloured, viscous liquid. Its odour resembles that of Indonesian-distilled patchouli oil, but has a more pronounced fruity, wine-like top note and less pronounced woody-balsamic notes. Moreover it is generally more tenacious. The difference between the two types of oil may be caused by the dried leaves curing during transport and storage before distillation in Europe or the United States. Both patchouli oils improve on ageing, losing the sharp-green or wet-earthy and minty notes.

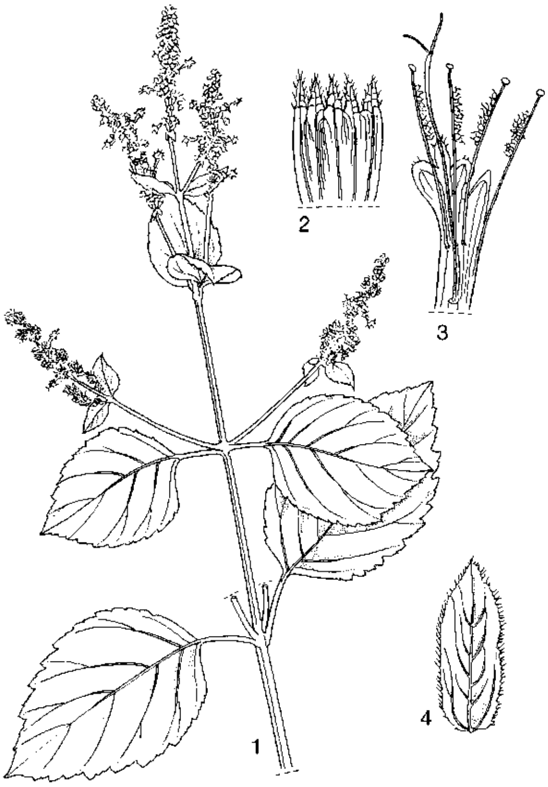
Patchouli resinoid or concrete is a benzene or petroleum-ether extract of *P. cablin* leaves. Its character is similar to that of patchouli oil distilled in Europe or America. On alcohol distillation the petroleum ether extract yields an absolute that captures the essence of the patchouli odour. The main chemical components of patchouli oil are patchouli alcohol, guaiene, patchoulene and seychellene. Other characteristic compounds are norpatchoulenol, nortetrapatchoulol, α-cedrenal and several pyridine derivatives. *P. cablin* from different origins and different cultivars may yield oils of divergent composition, e.g. a cultivar from Tsukuba (Japan) grown in the southern Philippines yielded an oil poor in guaiene and rich in longifolene (possibly a misidentification for seychellene, which is a common constituent of patchouli oil). Dhelwangine (pogostone), a minor constituent of *P. cablin*, is reported to have antibiotic activity against fungi and bacteria and is responsible for the bactericidal properties of patchouli oil. In preliminary tests in the Philippines, spraying potatoes with a low concentration of patchouli oil solution effectively inhibited sprouting for up to 4 months.

In the United States patchouli oil has been approved for food use by the Food and Drug Administration under paragraph 172.510 and has been 'generally recognized as safe' (GRAS No 2838). As a flavour ingredient, use levels of the oil are mostly less than 2 ppm. A monograph on the physiological properties has been published by the Research Institute for Fragrance Materials (RIFM). The essential oils from other *Pogostemon* species are poorly known. See also: Composition of essential-oil samples and the Table on standard physical properties.

Adulterations and substitutes Essential oils extracted from several other plants are sold as patchouli oil, e.g. Chinese patchouli (*Microtoena insuavis* (Hance) Prain ex Briquet (synonyms: *Plectranthus patchouli* C.B. Clarke ex Hook.f., *Microtoena cymosa* Prain). *P. cablin* leaves for export used to be frequently mixed with leaves of *P. heyneanus*, *Microtoena insuavis*, *Ocimum basilicum* L. or *Urena lobata* L. There are synthetic patchouli substitutes, but these are expensive and do not have the broad odour profile of the true essential oil. Sometimes, solvents that have a high boiling point, such as benzyl benzoate and propylene glycol are added as extenders to adulterate patchouli oil.

Description Usually pubescent, sometimes strongly scented, herbs or small shrubs. Leaves opposite or whorled, petiolate or sessile, often doubly crenate-serrate. Inflorescence a verticillaster, arranged in simple or branched, axillary or terminal, often densely flowered false spikes or racemes, which again are often united into a terminal panicle; bracts and bracteoles small, densely hairy, persistent; flowers small; calyx campanulate-tubular, 5-veined, ending in 5 subequal teeth; corolla tubular, shortly 2-labiate, 4-lobed, 3 lobes forming upper lip, lower lip entire; stamens 4, exserted from the corolla, often in 2 pairs, divaricating, filaments usually pilose, anthers unilocular; disk subentire; ovary deeply 4-partite, glabrous; style exserted, 2-lobed at apex. Fruit consisting of 4 smooth or granulate, glabrous nutlets, enclosed in the persistent calyx.

– *P. cablin*. Erect or ascending aromatic herb, up to 1 m tall. Stem branched, solid, angular, tomentose. Leaves decussately opposite, thin- or thick-membranaceous, with short appressed hairs; petiole 1–3(–8) cm long; blade ovate, 5–10(–14) cm × 3.5–6.5(–10) cm, base cuneate, margin simple or double crenate-serrate, apex acute, gland-dotted below. Spicate racemes 3–many, forming a terminal panicle 15–30(–40) cm long; verticillasters slightly apart below, closely approximate above, grey pubescent; bracts ovate to lanceolate, up to 9 mm × 4 mm, entire to toothed, imbricating; calyx tubular, 4–6



Pogostemon cablin (Blanco) Benth. – 1, flowering branch; 2, inner surface of dissected calyx; 3, dissected corolla with stamens; 4, inner surface of bract.

mm long, densely hairy outside, subglabrous inside, teeth about 2 mm long and ciliate; corolla 6–7 mm long, white, lavender-blue or violet; filaments inserted at about 2 mm in the tube, about 6 mm long, violet, soft-haired but glabrous towards the base; style 6 mm long, lobes 1.5–2 mm long. Nutlets ellipsoidal, 0.6–1 mm × 0.5–0.6 mm, reticulate-punctate, black.

– *P. heyneanus*. Erect or ascending, aromatic subshrub, up to 1.5 m tall. Stem branched, slender, solid, obtusely 4-angular, subglabrous and rooting at the base, short-haired in upper part. Leaves decussately opposite, thin-membranaceous, subglabrous to rather densely soft-haired; petiole 1–6 cm long; blade ovate, 1–14 cm × 1–8 cm, base cuneate, margin simple or double crenate-serrate, apex acuminate, gland-dotted below. Inflorescence paniculate, terminal, 6–18 cm long; verticillasters globular, 0.5–1.5 cm apart at the base, more approximate upwards; bracts ovate to lanceolate, 3–5 mm long; calyx tubular, 3–5 mm long, tomentose outside, subglabrous at base inside, teeth triangular, 1–1.5 mm long, ciliate; corolla 4–5 mm long, white or with pale violet upper lip, glabrous; filaments inserted at about 1.7 mm in the tube, straight, about 4 mm long, bearded around the middle but glabrous towards the base; style 5–6 mm long, lobes 0.6–0.7 mm long. Nutlets orbicular, 0.5–0.6 mm long, reticulate-punctate, shiny black.

Growth and development In cultivation *P. cablin* rarely flowers; only in the Philippines and in China, where it occurs wild, does it flower freely. In the Philippines flowering is between May to February, in southern China in April. *P. heyneanus* flowers year round.

Other botanical information The taxonomy of especially the cultivated *Pogostemon* species such as *P. benghalensis* (Burm.f.) Kuntze (northern India to China), *P. cablin*, *P. heyneanus*, and *P. plectranthoides* Desf. (Indian subcontinent) is not well investigated. These species are often propagated vegetatively and several cultivars seldom or never flower. It is possible that most cultivars belong to one botanical species.

Besides these 4 species which all produce a kind of patchouli oil, several other ones are also known to produce essential oils which are, however, mainly used medicinally. These include *P. auricularius* (L.) Hassk. (India, China, throughout South-East Asia), *P. glaber* Benth. (from India and Nepal to China and Thailand), *P. menthoides* Blume (from India to Indonesia), *P. purpurascens* Dalzell (India) and *P. verticillatus* (Roxb.) Bhatti & Ingr. (aquatic plant, from India and China throughout South-East Asia to Australia).

In Java, a cultivated *Pogostemon* occurs which is named 'dilem Java', and which also has never been found in flower. It has tentatively been named *Pogostemon hortensis* Backer ex Adelb., but it is most probably a cultivar of *P. cablin* with a more vigorous growth. It yields an essential oil inferior to patchouli oil.

Although *Pogostemon* plants are traded commercially, named cultivars are rarely used. In India 5 introduced cultivars of *P. cablin* have been named after their origin: 'Indonesian', 'Java', 'Johore', 'Malaysian' and 'Singapore'. 'Java' and 'Singapore' have a high yield potential but produce oils of inferior quality; the oil from 'Indonesian', 'Johore' and 'Malaysian' produce oils matching the quality of fine internationally traded oils.

Two types of oil glands occur in the leaves of *P. cablin*: glandular trichomes on the epidermis and mesophyll glands. The glandular trichomes consist of a large (16 μm × 27 μm) secretory head, a stalk of several cells and a basal cell embedded in the epidermis, but different from the normal epidermis cells. This type of secretory trichome is common in *Labiatae*. The mesophyll glands are complex structures located in the palisade tissue or occasionally in the spongy parenchym. They consist of a large (30 μm × 38 μm) secretory cell located near a small vascular bundle. The secretory cell has very dense cytoplasm and a large nucleus and is surrounded by a cuticula. The essential oil produced is contained in the space between the cell wall and the cuticula. The vascular bundles associated with the secretory cells consist of xylem and phloem elements, idioblasts and bundle sheath cells. In in vitro cultures of *P. cablin* tissues or cells, which do not contain mesophyll glands, no cyclic sesquiterpenes, which are characteristic of patchouli oil, are produced.

Ecology *P. cablin* can adapt to a wide range of climate and soil conditions. For optimal growth it requires a damp and per-humid climate with an evenly distributed annual rainfall of 2000–3000 mm, a drier season of not more than 12–14 weeks, and average temperature of 22–28°C. For commercial production an annual rainfall of 1750–2000 mm is suitable, but below 1500 mm supplemental irrigation is required. *P. cablin* is probably not tolerant of frost, but can be grown in the tropics up to 2000 m altitude. Relative humidity should be high; a minimum monthly average of 75% is considered essential for sustained growth in Indonesia. Continuous bright sunshine can damage young plants, resulting in dwarfing and yellowish leaves. Although *P. cablin* tolerates intermittent shade, intercropping in established rubber or coconut plantations leads to poor vigour and regrowth and to reduced leaf-oil content. The risk of damage by nematodes is also high when planted as an intercrop. Intercropping in newly established rubber or coconut plantations, however, has been recommended in Indonesia, Malaysia and India. *P. cablin* can grow on a wide range of soils, but very fertile soil is required for commercial production. Where possible it is planted on newly cleared forest land. Tolerance of waterlogging is poor, 3–4 days of standing water may kill young plants.

P. heyneanus occurs in thickets, old clearings, coconut plantations and stream banks, from sea-level up to 1800 m altitude.

Propagation and planting *P. cablin* is propagated vegetatively by cuttings. In Indonesia cuttings 5–10 cm long are taken from the central part of semi-mature stems. Cuttings from 9-month-old plants give the highest success rate. Alternatively, 10–12 cm long cuttings with 3 or 4 nodes and a terminal bud are used. Cuttings are planted in nursery beds and transplanted into polybags after 3–5 weeks. Rooted cuttings are planted out in the field at a spacing of about 60 cm × 60 cm. Cuttings are sometimes planted directly into the field using cuttings 15–20 cm long and planting them at an angle of 60° to the soil surface at a rate of 2–3 per hill. Adequate moisture and shade are essential during the early stages. When propagation material is scarce or when selected plants are multiplied, 2.5–5 cm long, single-node cuttings can be used, provided the nodes are buried in the rooting medium. In vitro multiplication using stem meristems has been successful in India and the Philippines. In this procedure plantlets are formed directly from meristem tissue and not from callus, which reduces the risk of mutations. The procedure involves hormone treatments to induce stem formation and shoot growth; to promote root growth, the plantlets are transferred to hormone-free medium. Plants developed from these plantlets grow well and yield an essential oil of normal composition.

P. heyneanus can easily be propagated by seed and by cuttings.

Husbandry During the 2–3 months immediately after planting of *Pogostemon* until the canopy closes and weeds are suppressed, 2–3 weedings are required. Weeding is also necessary in the first month after harvesting.

As large amounts of plant nutrients are removed with the harvested leaves and as *P. cablin* is very sensitive to nematode infestation, it is mostly grown on virgin forest land or as the first crop after fallow. Dwarfing and yellowing of the leaves caused by continuous bright sunshine can be mitigated by the application of N fertilizer. The highest yields are obtained under 25–50% shade in combination with N fertilizer. In India, application of 40 kg N, 15 kg P and 15 kg K per ha at planting time gave the best economic results. Topdressing with 25 kg N after about 8 weeks and twice after each harvest is recommended.

Diseases and pests *Pogostemon* is affected by several fungi attacking the roots and leaves. *Alternaria* and *Cercospora* spp. may cause extensive damage to the leaves. *Fomes, Pythium* and *Sclerotium* spp. may affect the root system; *Fomes* is especially serious where *P. cablin* is interplanted in rubber plantations.

Nematodes, particularly *Heterodera marioni* in

Indonesia and *Helicotylenchus dihystera* and *Meloidogyne incognita* in India cause extensive damage in *Pogostemon*. In some cases infestation is so serious that it reduces crop life and causes replanting to be unprofitable unless a long fallow or rotation period is observed. *Pogostemon* is often affected by viruses. Patchouli mottle virus (PaMoV, a potyvirus), patchouli mild mosaic virus (PaMMV, a faba-group virus) and tobacco necrosis virus (TNV) have been isolated. Virus-free plants can be produced by meristem-tip culture. Increased biomass and oil yields of virus-free plants have been reported, while the quality of the oil produced was very similar to that obtained from the original material. The rate of reinfection in the field can be high; 30% in 4 months has been observed.

Few pests cause serious damage. Crickets, grasshoppers and snails have been reported to affect *Pogostemon*, but they can be controlled easily. Leaf-rolling caterpillars are a more serious pest, as they are difficult to control.

Harvesting The first harvest of *Pogostemon* is usually taken when the plants are 6–8 months old, having attained a height of 0.5–1 m. The best quality oil is obtained from leaves harvested in the wet season. Subsequent harvests, if possible also in wet periods, are taken every 3–5 months until the crop is about 3 years old, when yield and quality of the oil decrease. Harvesting should not be done when leaves are saturated following rain or from morning dew. When harvesting during hot dry periods, cutting in the morning or evening is preferable. Plants are cut 10–20 cm above the ground. In Indonesia it used to be recommended to harvest only the top 3–5 pairs of leaves. Such selective harvesting is still possible for small farmers, as this system allows rapid regrowth and a regular supply of leaves to small local stills.

Yield In Indonesia 1 ha of *Pogostemon* yields 40–60 kg patchouli oil.

Handling after harvest Stems and leaves of *Pogostemon* are dried for 2–5 days on wooden racks, hard-packed earth or a concrete floor. The method of drying and subsequent curing strongly influence the quality of the oil. Drying in the shade with ample ventilation is preferable, but sun-drying is common. Sun-drying may cause leaves to become overdried and brittle. This results in loss of oil, while small fragments and dust from shattered leaves are difficult to handle in stills. A drying temperature over 40°C in Malaysia resulted in 80% loss of oil. After drying, leaves are stripped from the stems and packed under humid conditions in woven baskets or steel drums for curing. Skilled growers can control the curing process by smelling the leaves. Over-fermentation produces a mouldy note in the oil, under-fermentation reduces oil yield. In Malaysia leaves are not deliberately cured by the grower, but only packed in bags. Curing takes place during transport to the still and in storage. For export, leaves are dried and pressed into bales. Bales store well provided they are kept clean and dry. The long period of curing during transport and storage may explain the high quality of oil distilled in Europe or the United States.

In small-scale production, direct-fired stills are used in which leaves are placed on a perforated plate or grille above the water level. It takes 6–8 hours to distill a charge of 75–100 kg, but distillation is sometimes prolonged to up to 24 hours as the most desirable fractions are the last to distill over. Yields of essential oil are strongly influenced by the intensity of distillation. A still with an open wire grille yields significantly more oil than one with a perforated steel plate. Distillation temperature affects the yield, but not the quality of the essential oil. In Indonesia, raising steam temperature from 100°C to 200°C increased yield from 1.3% to 2.2%. After distillation patchouli oil is stored to mature. The quality of the oil improves in storage.

Genetic resources and breeding No substantial germplasm collections of *Pogostemon* are known to exist. At the Indian Institute of Horticultural Research, Bangalore a research programme is in progress aiming at high oil yields and with emphasis on the induction of mutations to increase genetic variability.

Prospects Research on disease and pest management is urgently needed to enhance the longevity of *Pogostemon* crops. Collection and thorough inventory of germplasm followed by selection programmes would also contribute to increased yields of oils of higher quality. Although it has been claimed that synthetic patchouli oils can match the odour of genuine oils, no effective substitutes for high quality perfumes have yet been developed.

Literature |1| Angadi, S.P. & Vasantha Kumar, T., 1995. In: Chadha, K.L. & Gupta, R. (Editors): Advances in Horticulture. Vol. 11. Medicinal and aromatic plants. Malhotra Publishing House, New Delhi, India. pp. 751–771. |2| Keng, H., 1978. Labiatae. Pogostemon. In: van Steenis, C.G.G.J. (Editor): Flora Malesiana. Vol. 8. Sijthoff & Noordhoff International Publishers, Alphen aan den Rijn, the Netherlands. pp. 351–356. |3| Lawrence, B.M., 1995. Progress in essential oils. Perfumer and Flavorist 20: 67–73. |4| Maeda, E. & Miyake, H., 1997. Leaf anatomy of patchouli (Pogostemon patchouli) with reference to the disposition of mesophyll glands. Japanese Journal of Crop Science 66: 307–317. |5| Raza Bhatti, G. & Ingrouille, M., 1997. Systematics of Pogostemon (Labiatae). Bulletin of the Natural History Museum (London), Botany Series 27: 77–147. |6| Reglos, R.A. & de Guzman, C.C., 1991. Morpho-physiological modifications in patchouli, Pogostemon cablin (Blanco) Benth., under varying shade and nitrogen levels. The Philippine Agriculturist 74: 429–435. |7| Soepadyo, R. & Tan, H.T., 1968. Patchouli, a profitable catch crop. World Crops 3: 48–54. |8| Sugimura, Y., Ichikawa, Y., Otsuji, K., Fujita, M., Toi, N., Kamata, N., del Rosario, R.M., Luingas, G.R. & Taga-an, G.L., 1990. Cultivarietal comparison of patchouli plants in relation to essential oil production and quality. Flavour and Fragrance Journal 5: 109–114. |9| Sugimura, Y., Padayhag, B.F., Ceniza, M.S., Kamata, N., Eguchi, S., Natsuaki, T. & Okuda, S., 1995. Essential oil production increased by using virus-free patchouli plants derived from meristem-tip culture. Plant Physiology: 44: 510–515. |10| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 138–154.

L.P.A. Oyen

Rosa L. cv. group Damascena

Sp. pl.: 491 (1753), Gen. pl. ed. 5: 217 (1754); cv. group name proposed here.

ROSACEAE

$2n = 28$ (tetraploid)

Synonyms *Rosa damascena* Miller (1768), *R. gallica* L. var. *damascena* Voss (1894), *R. damascena* Miller var. *trigintipetala* (Dieck) Koehne (1893).

Vernacular names Damask rose, pink damask rose (En). Rose de damas, rose de tous les mois, rose de puteaux (Fr). Indonesia: kembang eros, bunga ros. Malaysia: bunga ayer mawar, ros, gul. Cambodia: kolaab. Laos: kuhlaab. Thailand: kulaap-on (northern), kulaap mon (central), yee sun (Bangkok). Vietnam: huong.

Origin and geographic distribution The damask rose is only known from cultivation and its exact origin is not known. It probably originated as a hybrid in the Anatolian region in Turkey, but semi-wild plants (escapes from cultivation) are also found in the Caucasus, Syria and Morocco. The damask rose is known from ancient times and was introduced early from Turkey into Europe and the Middle East, where Iran has been a centre of rose cultivation and rose oil production for centuries. In the Balkans and the Mediterranean it is cultivated as a source of rose oil. The most important growing areas are in Bulgaria, Turkey, southern Russia and Morocco. Elsewhere it is mainly grown as an ornamental. In South-East Asia damask rose is only occasionally cultivated as an ornamental.

Uses Damask rose is the most important rose grown for its essential oil. On water distillation it yields rose oil and rose water (mostly from the flowers, rarely from the leaves); on solvent extraction it yields rose concrete and rose absolute. Rose oil is commercially the most important product (for cv. group Damascena it is also called rose otto or rose attar) and it is one of the oldest and most valuable perfumer's materials. Because differences in odour exist between rose oils from different origins, in commerce the oil is usually also named by the country of origin, e.g. rose oil Bulgaria. Rose oil is virtually indispensable in perfumery and cosmetics, either as a primary scent or as a modifier. In flavourings it is often used to modify a primary taste and has many applications in sweets, confectionery and tobacco products. The fruit can be processed to make jam or syrup with high vitamin C content. Rose petals can be crystallized with sugar to make a sweetmeat; dried, they are added to drinks as a flavouring, while after extraction with boiling water the residue is used to flavour confectionery and foods, especially in the Middle East and India. Petals are macerated in sesame oil to make a hair-oil in India and Malaysia. Damask rose is an officinal in medicine and is used as a fungicide and insecticide. Preparations of flowers, fruits and roots are said to be astringent. A tonic made by steeping fruit in boiling water for 5 minutes is drunk hot to alleviate the effects of a cold.

Production and international trade World production of rose oil and rose concrete was estimated at 15–20 t in 1986 with Turkey, Bulgaria, Russia, Morocco, France and Italy as the largest producers. For the damask rose alone, oil production in Bulgaria in 1994–1995 was estimated at 750–1000 kg (down from 3 t in 1984 before the start of the economic reforms). Oil produced in Russia is mainly traded and consumed locally. The bulk of all export is to France, the United States, Switzerland and the United Kingdom. In

1991 the United States imported 4.5 t rose oil with a total value of 6 million US$.

Properties Analysis has revealed more than 300 constituents in rose oil, most in very small proportions, but many of them important for the depth of the oil's fragrance. The major constituents are citronellol and stearoptene (non-volatile). The ratio of the three main terpene alcohols, citronellol to geraniol and nerol (the C:G+N ratio), is of major importance in determining the quality of rose oil. The major constituents (more than 1%) of damask rose oil are: citronellol, geraniol, nerol, linalool and phenylethyl alcohol. Bulgarian rose oil is pale yellow to yellow-green; fresh oil is often greener because of the presence of azulenes which gradually decompose over time; when cooled below 20°C white or colourless crystals of stearoptene precipitate out; the remaining liquid is known as elaeoptene. Stearoptene is odourless and constitutes 15–25% of the oil; on cooling below 16°C the oil solidifies into a translucent mass with surface crystals. The oil has an intense warm, deep floral, waxy odour, slightly spicy, very rich with traces of honey and a rosy-aldehydic dry-out lasting about 5 days. Rose oil does not reflect the true scent of rose flowers, since certain aroma components, particularly phenylethyl alcohol, are partially lost during distillation. Rose oil is slightly soluble in water, very slightly soluble in alcohol, but soluble in fatty oil and chloroform. Rose concrete is a waxy solid, dark yellow to brown-orange, with a melting point of 45–55°C, used in similar products as the essential oil, but is mainly extracted to produce rose absolute. Rose absolute is an orange-yellow to orange-brown viscous liquid, usually with a richer odour than rose concrete. The main uses are the same as for rose oil and concrete, but because of its strong concentration it is normally used very diluted in the end-products. Rose concrete and absolute, like rose oil, are marketed under the rose name and country of origin. In the United States, rose oil Bulgaria has been 'generally recognized as safe' (GRAS No 2988). See also: Composition of essential-oil samples and the Table on standard physical properties.

Adulterations and substitutes Because rose oil is expensive, commercial lots are frequently extended with a wide range of natural compounds of different origin or with synthetics, but most alter the oil's natural odour or persistence perceptibly. Several formulations to compound synthetic rose fragrances have been published and even modifications to match the odour of rose oil of different origins. Oil from various *Rosa* species is marketed as otto or attar of roses: *R. centifolia* L. in Morocco and France, *R. gallica* L. in Russia and Egypt, *R. rugosa* Thunb. ex Murray and other *Rosa* species in China, but experienced perfumers can readily identify these.

Description Robust, erect, multi-stemmed and branched shrub, 1–2 m tall, with well-developed, extensive root system. Prickles usually many, unequal, straight to slightly curved, reddish-brown when young, grey when old. Leaves alternate, compound, with 5–7 leaflets, waxy; stipules almost entire, elongated; petiole with red-brown hairs; leaflet elliptical, 2–7 cm × 1.5–5 cm, margin serrate, usually hairy below, not glandular. Inflorescence a terminal raceme or thyrsus, bearing 3–10 flowers, rarely more; flowers up to 8 cm in diameter, often double, very fragrant, usually pinkish; pedicel up to 7 cm long, with many glandular bristles; hypanthium glandular-bristly outside, hairy inside; sepals triangular, broadly cuspidate, reflexed during anthesis, caducous afterwards, glandular; petals red to white, preferably rosy-pink to rosy-red, usually 20–30 normal and 5–10 deformed ones; stamens 100–120; pistils many,

Rosa L. cv. group Damascena – habit of flowering branch.

styles free, hairy. Fruit an ovoid hip, up to 2.5 cm long, fleshy, bristly, light to dark red, 1–3-seeded. Seed rounded triangular, 3–5 mm long, brownish.

Growth and development A period of winter dormancy is essential for damask rose to induce bud development. In Europe, adventitious buds for flowering shoots form in the crown of annual branches in spring. Bud formation is best with night/day temperatures of 3–4°C/15–16°C. In the inflorescence the flowers bloom consecutively; main flowering period in Europe is June–July, in India March–April and September–October. Flowering period is directly influenced by climatic conditions, but is normally completed in 20–25 days. It can be affected by growth regulators like ethephon. The optimum temperature range is 15–20°C and optimum relative humidity 60%. All flower parts contain essential oil which generally reaches its maximum when the petals become cup-shaped and the stamens bright yellow; the petals contain most oil. Whole flowers are picked for rose oil; young buds are selected for highest yield of concrete. Most of the fruits are shed before ripening. The economic life of a plantation is 10–12 years, flower yield normally increases during the first 5–7 years and then declines gradually until the plantation becomes unprofitable. Individual plants can live for up to 50 years.

Other botanical information 'What's in a name? that which we call a rose, by any other name would smell as sweet...' This horrifying – for taxonomists – statement of Shakespeare in 'Romeo and Juliet' was unintentionally also visionary, because the correct scientific name for the damask rose has always been disputed. *R. damascena* Miller is most often used in the literature, but *R. ×damascena* Miller is also used, to express its hybrid origin. Unfortunately, the name *R. damascena* was already used by Herrmann in 1762 for a different taxon (included in *R. centifolia* L.), thus invalidating Miller's name. Instead of looking for the correct botanical binomial it seems better to classify the damask roses as what they really are: a group of cultivars grown especially for their scent or essential oil. It is undisputed that damask roses have a hybrid origin but the parentage is not absolutely clear. The influences of the wild roses *R. centifolia* L., *R. gallica* L. and *R. phoenicea* Boiss. seem most certain, but *R. alba* L., *R. canina* L. and *R. moschata* J. Herrm. have also been mentioned.

Several subgroups can be distinguished within the cv. group Damascena:

- cv. subgroup Autumn Damask (other names: four seasons or monthly rose, *R. damascena* Miller var. *semperflorens* (Loisel) Rowley, *R. bifera* Poiret, *R. calendarum* Borkh.). When pruned appropriately, this group of cultivars is able to produce flowers in 2 or 3 flushes during the growing season and could even be forced to flower in the winter months. Their supposed parentage is *R. gallica* L. × *R. moschata* J. Herrmann.
- cv. subgroup Versicolor (other names: York or Lancaster rose, *R. damascena* Miller f. *versicolor* West.). This group is summer-flowering and has variegated flowers.
- cv. subgroup Trigintipetala (other names: Kazanlik rose, pink damask rose, *R. gallica* L. var. *damascena* f. *trigintipetala* Dieck). Summer-flowering roses but without variegated flowers. To this group belongs the most important rose cultivar for essential oil production in the world, 'Trigintipetala' (30 petals), mainly grown in the Kazanlik area of Bulgaria, and in Turkey. Other well known cultivars are 'Kazanlik' and 'Iskra'.
- cv. subgroup Portlandica (other names: portland rose, scarlet four seasons, *R. portlandica* West.). A group of low-growing roses with bright red, semi-double flowers in clusters of 3–4, flowering from midsummer into autumn. The Damask perpetuals or portland roses have been derived from this group.

Most other roses cultivated commercially for their essential oil are cultivars of *R. alba* L. (the 'white cottage rose' is hardier and more resistant to unfavorable climatic factors and is grown around fields of damask cultivars in Bulgaria), *R. centifolia* L. (the 'light pink cabbage rose' is grown mainly in France, Morocco ('rose de mai') and Spain), *R. gallica* L. (particularly in Russia and Egypt) and *R. rugosa* Thunb. ex Murray (especially in China).

Ecology Cv. group Damascena is adaptable to a wide range of environmental conditions. In general a mild climate is preferred with no extremes of temperature and long periods of warm, sunny weather and an evenly distributed rainfall. In Kazanlik (Bulgaria), the major cultivation area, an average spring temperature of 5–15°C is considered as optimum. Low night temperatures of 10–12°C during flowering inhibit oil synthesis, but night temperatures up to 20°C increases it. Regular rainfall is important, especially in spring and early summer, and a daily relative humidity in May–June of 70% is considered optimum. Waterlogging should be avoided, but damask roses can withstand waterlogging to a considerable extent. Hot dry periods during flowering rapidly reduce oil yield by evaporation. Shade is inimical to flowering in Bulgaria, but in India, where temperatures in the sun are higher, shade is essential. Frost during early vegetative growth or bud formation causes extensive damage. Mature plants are frost resistant but pruned ones require protection in areas with severe winter frosts. A deep, fertile loam (pH 6–7.5) is most suitable for commercial rose growing but climate is more important than soil type. In India, alkaline saline soils of pH 8–9 are well suited for damask rose growing.

Propagation and planting Propagation is by cuttings or division (splits) of mature damask rose plants, but grafting or budding on rootstock of other rose species (e.g. *R. multiflora* Thunb. ex Murray) is also common. Micropropagation is a possibility but is not yet commercially practised. Cuttings are preferably 20–30 cm long, 2-noded, taken from shoots which begin to lignify. The lower leaves are removed, the end treated with a rooting compound and the cutting is then inserted into the ground for up to half its length, in a nursery. After 1 year the rooted cuttings can be transplanted to the field. In India a bed of 20 m × 5 m accommodates 10 000 cuttings, sufficient for planting 1 ha. Splits are obtained by dividing mature plants so that each split has a section of root attached. In Bulgaria 1 ha produces sufficient splits to plant 2 ha and the splits are often planted directly in the field. Before establishing a plantation it is advisable to apply manure and plough in (e.g. 50 t/ha). Deep ploughing is necessary to facilitate root development. Hedge planting is most popular, with rows 2–2.5 m and plants 1–1.5 m apart. Roses are seldom underplanted or intercropped.

Husbandry Weed control is essential in damask rose; it is done manually or shallowly mechanically, or even by mulching with black plastic or applying herbicides. Irrigation is necessary when rainfall is insufficient. Soil moisture should be maintained at 85% capacity. Young bushes are pruned annually in early summer to promote uniform branching, and all flower buds are removed in the first and sometimes also the 2nd year. Seasonal pruning is done to remove dead or diseased shoots. In the 3rd year flowering is allowed and harvesting may start. Older plants may be cut back severely (e.g. to 15 cm) to promote new and vigorous growth. This is usually done at least once in a plantation's life, but a less severe pruning every 3 years is usually adequate. Harvested roses in Bulgaria extract yearly per ha 64 kg N, 8.7 kg P and 36 kg K. In India, up to 10 t/ha manure is applied annually and in Egypt whatever is available. Once growth has started N is normally supplied as a top dressing in one or more applications. In Bulgaria 300 kg/ha ammonium nitrate is applied yearly, in India 200 kg/ha calcium ammonium nitrate is preferred. Phosphate is usually applied as triple-superphosphate. K applications depend on soil type; sulphate of potash is preferred. Mg is often deficient and should be applied when lacking.

Diseases and pests Damask roses suffer much from many diseases and pests and control measurements are absolutely necessary to limit losses. Large differences in the prevalence of pathogens exist between regions and cultivars. Important diseases include: rose rust (*Phragmidium* spp.), which attacks all aboveground parts, forming orange-coloured pustules; black spot (*Marssonina rosae*), which mainly affects leaves and young shoots, forming circular black spots; powdery mildew (*Sphaerotheca* spp., *Uncinuma* spp.), which mainly damages leaves and young shoots, covering them with a white powder; damping off (*Pythium* spp.) and root rot (*Phytophthora* spp.), which mainly occur in rooted cuttings and splits. Major rose pests that damage the roots include: root mealy bugs (*Rhizococcus* spp.), root aphids (*Maculolachnus* spp.), rootworms (*Paria* spp.) and nematodes (*Pratylenchus* spp.). Stems and branches are attacked by stem borers and girdlers (*Agrilus* spp., *Oberea* spp.), scale insects (*Aulacaspis* spp.) and stem sawflies (*Syrista* spp.). Leaves are liable to damage by caperpillars (*Argyrotaenia* spp., *Sibine* spp., *Parasa* spp., *Archips* spp.), beetle larvae (*Macrodactylus* spp.), rose slugs (*Endelomyia* spp.) and whiteflies (*Bulgarialeurodes* spp., *Trialeurodes* spp.). Flowers are attacked by cerculios (*Rhynchites* spp.), chafer beetles (*Macrodactylus* spp. and *Cetonia* spp.), rose beetles (*Nodonota* spp.), midges (*Dasineura* spp.) and thrips (*Thrips* spp.).

Harvesting Flowers of damask rose are usually picked manually (nipped off just below the calyx) which is very labour intensive and limits expansion of rose cultivation. Simple hand-held mechanical pickers are coming in use. Picking should be done between 5 and 10 a.m. when the flowers open and oil content is highest. Whole, fully open flowers should be selected because they have the highest oil content, not buds or previous day flowers. An experienced worker can pick 3–6 kg per hour.

Yield Annual damask rose flower yield averages 1–3.5 t/ha and 2–4 t are required to produce 1 kg oil. Average annual flower yield per ha is 2–3 t in

Bulgaria, 2–2.5 t in Turkey, 1.5–2 t in Russia, 1–1.5 t in India. In Morocco, flower yield of *R. centifolia* averages 2.5 t/ha; in Egypt, flower yield of *R. gallica* is 2.5–4 t/ha. In Egypt *R. gallica* yields 2.2 kg concrete or 1 kg absolute from 1000 kg flowers; in Morocco 1.8 kg concrete or 0.9 kg absolute is obtained from 1000 kg *R. centifolia* flowers.

Handling after harvest Damask rose flowers should be transported to the distillery without delay, but storing bagged flowers in clean, cold (4–10°C) water maintains oil content and quality for up to 3 days. Spreading flowers for short periods (not more than 24 hours) in layers in a cool shady place retains most of the oil. Rose oil is produced by a 2-stage distillation process because many of the aroma compounds of roses are water-soluble. In the initial stage whole flowers are water distilled and the distillate is separated into 'decant' or 'first oil' and the remaining liquid. The latter is redistilled to produce 'second oil' and 'rose water'. The 'decant' and 'second oil' are combined to make 'rose oil'. After distillation the oil should be stored in full, airtight, opaque containers and kept cool. Oil exposed to air and light quickly deteriorates. In India rose water is more important than rose oil and the first distillate is not returned to the still but sold directly as rose water, e.g. as 'rose water 20/40', i.e. 20 l of distillate from 40 kg flowers. Solvent extraction of rose flowers is now frequently used. Rose concrete is obtained by extraction of rose flowers, often with hexane; rose absolute by extraction of the concrete with alcohol. Water distillation yields 0.01–0.04% of essential oil. Solvent extraction typically yields about 10 times the amount obtained by distillation, or 0.1–0.2% concrete. Concrete, in turn, yields about 50% absolute.

Genetic resources Extensive living rose collections, including damask roses, exist at e.g. Gardens of the Rose, St Albans, Hertfordshire (United Kingdom); Das Rosarium, Sangerhausen (Germany); Botanical Gardens, Wageningen Agricultural University (the Netherlands), and the Botanic Garden of Gap-Charance (France).

Breeding Although most damask cultivars are tetraploids, diploid, triploid and pentaploid cultivars are known. The genetic background of most damask rose cultivars is obscure and most probably there is ample scope for improvement of many characteristics (e.g. oil content, disease resistance, flowering time, drought resistance, cold requirement for flowering) to create cultivars most suited to local circumstances. Because of easy vegetative propagation, multiplication of interesting improved selections poses no problems.

Prospects Damask rose oil production is especially interesting for those areas where labour costs are low and where enough land is available. Attractive prices for the oil are guaranteed if the quality is high. Damask rose is not suited for small-scale production, since considerable investments are required for the application of advanced distillation or extraction techniques. Potentially it could be an interesting plantation crop for higher altitude areas in South-East Asia and much could be learned from experiences in India.

Literature |**1**| Bayrak, A. & Akgül, A., 1994. Volatile oil composition of Turkish rose (Rosa damascena). Journal of Science and Food in Agriculture 64: 441–448. |**2**| Bean, W.J., 1980. Trees and shrubs hardy in the British Isles. 8th Revised edition (Clarke, D.L. & Taylor, G., editors). Vol. 4 (Ri–Z). John Murray, London, United Kingdom. pp. 35–205, particularly pp. 79–84. |**3**| Guenther, E., 1952. The essential oils. Vol. 5. Oil of rose. D. van Nostrand Company, New York, United States. pp. 3–48. |**4**| Kalkman, C., 1973. The genus Rosa in Malesia. Blumea 21: 281–291. |**5**| Krüssmann, G., 1974. Rosen, Rosen, Rosen, unser Wissen über die Rose [Roses, roses, roses, our knowledge about the rose]. Verlag Paul Parey, Berlin & Hamburg, Germany. 447 pp., particularly pp. 209–217. |**6**| Lawrence, B.M., 1993. Essential oils 1988–1991. Rose oils and extracts. Allured Publishing Corporation, Carol Stream, United States. pp. 144–165. |**7**| Touw, M., 1982. Roses in the Middle Ages. Economic Botany 36: 71–83. |**8**| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 393–416. |**9**| Widrelchner, M., 1981. History and utilization of Rosa damascena. Economic Botany 35: 42–58.

P.C.M. Jansen

Santalum album L.

Sp. pl.: 349 (1753).

SANTALACEAE

$2n = 20$, (18)

Synonyms *Sirium myrtifolium* L. (1771), *Santalum ovatum* R. Br. (1810), *Santalum myrtifolium* (L.) Roxb. (1814).

Vernacular names East Indian sandalwood, white sandalwood, yellow sandalwood (En). Bois santal (Fr). Indonesia: cendana (general), ai nitu (Sumba), hau meni (Timor). Malaysia: chendana. Burma (Myanmar): san-ta-ku. Thailand: chantana.

Origin and geographic distribution The exact origin of *S. album* is not known. It is probably native to the Outer Banda arc of islands in south-eastern Indonesia, of which Timor and Sumba are the most important ones. Its current distribution extends from Bondowoso District in East Java eastwards to Timor, Sulawesi and the Moluccas and as far as northern Australia. The earliest records of sandalwood trade from Timor date back to the 3rd Century AD. Large stands also occur in southern India. It has been suggested that *S. album* is native to southern India, but it is more often assumed that it was introduced into India about 2000 years ago. It occurs naturalized in India from Uttar Pradesh to southern Karnataka and to south-western Andhra Pradesh. Small stands are found in Rajastan, Maharashtra and Uttar Pradesh. *S. album* was introduced into several other tropical countries e.g. the Mascarene Islands, where it also naturalized, China (Guangdong), Sri Lanka and Taiwan. In south-eastern Indonesia where it once was a common forest tree, natural stands have been decimated and exploitable natural stands now remain only in Timor. In Sumba, once called Sandalwood Island, it has become rare. *S. album* is commercially cultivated in India, Indonesia, China and Australia and it has been tried in southern Africa and several Pacific islands.

Uses Since time immemorial Hindus, Bhudists, Chinese and Muslims have used sandalwood as incense for its sweet fragrance in their ceremonies. It has been suggested that the original source of the incense in India may have been *Pterocarpus santalinus* L.f. (red sandalwood), and that this was gradually replaced by *S. album* after its introduction from Indonesia. Formerly, in China the most expensive coffins were made of sandalwood, while in India it was the preferred wood for funeral pyres. Even today it is customary to add at least a single piece of sandalwood. When supplies of *S. album* became scarce, sandalwood from Australian *Santalum* species was used for such purposes. Larger pieces of heartwood are now mostly used for wood sculptures and carvings (e.g. statues, 'keris' handles). Incense is made from sandalwood sawdust mixed with gum arabic and saltpetre and often with other aroma materials and made into sticks (agarbattis or joss-sticks). Sawdust from sapwood and spent heartwood, remaining after distillation, are used for the same purpose. Fine sawdust is also put in sachets used to scent stored clothes. In Indonesia finely ground sandalwood mixed with water is rubbed on the body for its cooling effect.

Sandalwood oil, steam distilled from the heartwood of *S. album*, is an indispensable aroma material in perfumery, where its outstanding fixative properties and excellent tenacity, blending ability and highly attractive fragrance have made it a basic component of countless perfumes, cosmetics and toiletries. An essential oil is also obtained by acid hydrolysis of distilled sandalwood chips and sawdust. This oil differs in scent and appearance from true sandalwood oil.

Sandalwood oil has slight antiseptic properties but is now rarely used medicinally, except in aromatherapy. A few drops taken internally give relief in chronic bronchitis. Sapwood ground to a powder and mixed with water was taken in Indonesia against gonorrhoea. In China the oil is used to treat vomiting, stomach-ache and gonorrhoea. A compound extracted from the bark exhibits hormone activity in insects, disrupting their development. It also has a chemosterilant effect, but is not used commercially.

S. album is sometimes grown as an ornamental and as a low-branching wind-break. In India it is considered as a practical agroforestry species. The leaves provide green manure. The fruits are edible. The seeds yield a red drying oil mainly used as lamp oil, while fresh leaves yield a pale yellow wax.

Production and international trade No reliable production figures are available for sandalwood, as much of the trade remains unrecorded. About 30% of the world production of sandalwood and sandalwood oil is exported from the ports of Kupang and Dili in Timor, whereas most of the remainder comes from southern India. Towards the end of the 1960s about 30 t of sandalwood oil (then worth US$ 3.5 million) plus an equivalent amount of sandalwood were exported annually from Timor. Smaller amounts were sold as incense sticks, carvings and spent wood. The total value of the exports of sandalwood and its products from Indonesia was about US$ 9.5 million annually. Because of overexploitation, exports of sandalwood oil and heartwood gradually declined between 1989 and 1994 to a yearly average of 12 t oil (only 7 t in 1994) and 680 t heartwood. Domestic consumption in India exceeds its exports, but is poorly documented. In the early 1990s India exported about 48 t sandalwood oil annually. In 1986, total world production of sandalwood oil stood at about 200 t.

Properties The heartwood of the trunk, main branches and roots of *S. album* contain an essential oil. The essential oil concentration is highest in the roots and may reach 10%, followed by the trunk (4–8%) and branches (2–4%). The volatile oil is a moderately viscous, pale yellow to yellow liquid with an extremely soft, sweet-woody and almost animal-balsamic odour. It has little or no particular top note, while its very tenacious fragrance remains constant for many days. The oil blends so well and with so many fragrance materials that it has become a common blender-fixative used in countless perfumes from oriental-floral to aldehydic and from woody-floral to fougères. The oil is also used as a base for co-distillation of the most delicate flowers, e.g. *Rosa* spp., *Mimusops elengi* L., *Anthocephalus chinensis* (Lamk) A. Rich. ex Walp. and *Pandanus odoratissimus* L.f. Sandalwood oil is commonly used in the production of attars in India. It is of little importance as a flavour material as it has a bitter, resinous taste. The oil contains 90% or more sesquiterpene alcohols, of which the characteristic components are santalols, including (Z)-α-santalol (45–47%) and (Z)-β-santalol (20–30%). The oil also contains the related sesquiterpene alcohols epi-β-santalol, (E)-β-santalol and spiro-santalol. Other components of sandalwood include several cis-nuciferols and cis-lanceol. The foreruns of distillation contain degradation products of the sesquiterpene compounds representing the spicy, smoky by-notes of sandalwood oil, and N-furfuryl pyrrole with its powerful, peculiar odour. Sandalwood oil has been approved for food use by the Food and Drug Administration (FDA) of the United States under paragraph 172.510 and has been 'generally recognised as safe' (GRAS No 3005). The oil is registered by the Council of Europe under No 420n. A monograph on the physiological properties has been published by the Research Institute for Fragrance Materials (RIFM). The oil is used as a flavour component in major food products, including alcoholic and non-alcoholic beverages. Average maximum food levels in food products and drinks is generally below 0.001%. Sandalwood oil has a sedative effect on inhalation in mice. See also: Composition of essential-oil samples and the Table on standard physical properties.

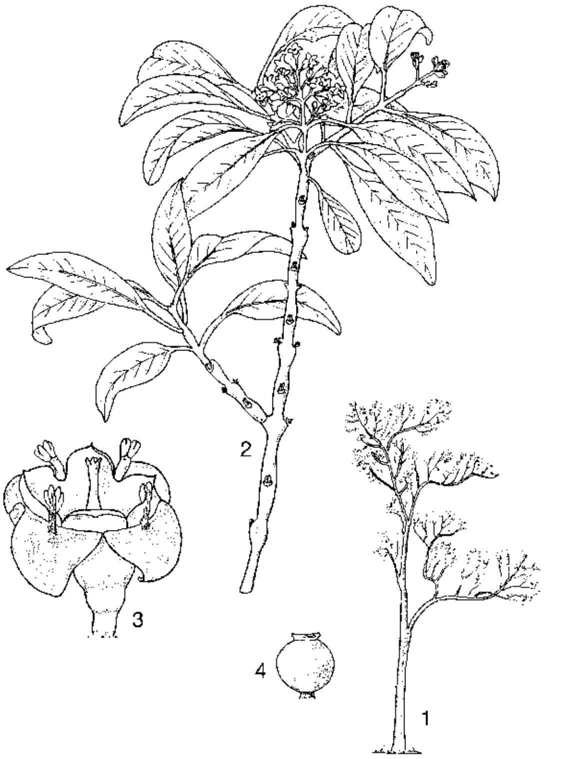
Sapwood and heartwood of *S. album* are sharply demarcated. Sapwood is white to whitish-yellow and unscented, heartwood is scented, light yellowish-brown when freshly cut, turning dark brown on exposure and ageing to dark reddish-brown. It is dull to somewhat lustrous, with an oily feel, moderately hard to hard, heavy (specific gravity 0.90–1.14), mostly straight and extremely close grained (occasionally slightly wavy grains in radial plane) and very fine and even textured. Growth rings, when present, are clearly visible under low magnifications, delimited by a band of darker, denser fibrous tissues towards the outer margin; individual rings frequently fluctuate in diameter at different points of the circumference. Vessels are small to extremely small and rays are not visible to the naked eye. The heartwood is resistant to termites.

The seed contains up to 60% of a dark red, viscous, drying oil. The oil thickens when exposed to sunlight or when heated. The pale yellow wax obtained from the leaves has a melting point of 30°C and contains 75% unsaponifiable compounds, mainly n-octacosanol, n-tricontanol, palmitone and 10-hydroxy-palmitone. There are 5000–8000 seeds per kg.

Adulterations and substitutes Most *Santalum* species yield fragrant wood, and some species in the Pacific, e.g. *S. yasi* Seem. may match the quality of *S. album*. Sandalwood oil is sometimes adulterated e.g. with oils from Australian *Santalum* spp. (which lowers the laevorotation), with araucaria oil (*Neocallitropsis pancheri* (Carr.) Laub.), Atlas cedarwood oil (*Cedrus libani* A. Rich. subsp. *atlantica* (Endl.) Battand. & Trabut), amyris oil (*Amyris balsamifera* L.), Indian bastard sandal oil (*Erythroxylum monogynum* Roxb.), various East African wood oils (e.g. *Brachylaena huillensis* O. Hoffm.) and with bleached copaiba balsam (*Copaifera* spp.). It is also occasionally mixed with various odourless solvents such as benzyl benzoate or dialkyl phtalates.

The main components of sandalwood oil can be synthesized and several synthetic substitutes have been developed, such as sandela, santalidol and several camphanyl cyclohexanols and trimethylcyclopentenyl alkanols.

Description Small, evergreen, semi-parasitic, spineless, glabrous tree up to 20 m tall and with a girth of over 1.5 m, occasionally shrubby and sometimes scandent, up to 4 m tall; trunk terete, bark coarse, greyish-brown to reddish-brown; lower branches sometimes drooping; branchlets slightly angular-striate. Leaves opposite or decussate; petiole thin, 2-ribbed, 5–15 mm long, yellowish; blade ovate, lanceolate-elliptical or oblong, 2.5–8 cm × 1.5–4 cm, base obtuse, cuneate or acute, margins undulate, flat or slightly recurved, apex acuminate, slightly discolorous, pale green above, glaucous beneath, with 6–10 pairs of secondary veins, reticulate venation evident. Inflorescence a terminal or axillary panicle or raceme,



Santalum album L. – *1, habit; 2, flowering branch; 3, flower; 4, fruit.*

2–5 cm long; peduncle 4–20 mm long; bracts caducous; pedicel usually very short but up to 3 mm long; flowers bisexual, 4(–5)-merous, perianth-tube campanulate, about 2 mm long, 4-lobed, lobes triangular-ovate, initially yellowish, turning brownish-red, with a hair tuft behind the stamens; nectaries 4, on the middle of the perianth tube, alternating with the disk lobes; stamens 4, as long as hair tufts; disk prominently 4-lobed, lobes erect-recurved, fleshy, 1.2–1.5 mm long, alternating with stamens, orange-brown at first, turning blackish-red; pistil with superior to half-inferior ovary, short style and small, slightly 3-lobed stigma. Fruit an ellipsoidal, 1-seeded drupe, about 1 cm long, with small apical collar; exocarp blue to blackish-red, mesocarp succulent or firm, endocarp smooth. Seed without testa. Seedling with epigeal germination.

Growth and development *S. album* is a semi-parasite, depending on a host for inorganic nutrients and water, but capable of photosynthesis and autotrophic for assimilates. Soon after germination, often within 3 months when nutrient reserves in the seed become depleted, the roots attach themselves to those of nearby grasses, herbs, shrubs or trees by means of haustoria. In the haustorium an intrusive wedge of cells is formed which invades the root core of the host, forming a link between the xylem systems. Over 300 species have been recorded as hosts. Suitable host plants include *Casuarina equisetifolia* L., *Senna siamea* (Lamk) Irwin & Barneby, *Acacia* spp., *Breynia cernua* (Poiret) Muell. Arg. and *Imperata cylindrica* (L.) Raeuschel. In Timor, *Calotropis gigantea* (L.) Dryander is often grown as the primary host followed by *Acacia glauca* (L.) Moench and *Senna siamea*. Although sandalwood is the main beneficiary of the link, some transfer may occur in the opposite direction. Bitter compounds found in the leaves of *Strychnos nux-vomica* L. have been detected in the leaves of adjacent sandalwood trees, while the characteristic taste of sandalwood has been noted in *Eugenia* spp. growing nearby.

Although *S. album* is evergreen, in Indonesia individual trees shed their leaves twice per year, at the beginning of the rainy season and in the dry season. Leaf-fall of individual trees is not simultaneous and bare trees and trees in full leaf can be seen next to each other.

Under normal conditions young trees grow slowly, only gradually developing a core of heartwood. In India, trees growing under favourable conditions start to make heartwood when about 10 years old and 7.5 cm in diameter, but there is considerable individual variation. Stem diameter increases at a rate of 0.5–1 cm per year, depending on the environment. Heartwood formation accelerates when trees are about 20 years old and is at its maximum in trees of 30–60 years old and 40–75 cm diameter at breast height. The proportion of heartwood to sapwood plus bark is 0.65–0.85 in healthy trees; in trees affected by spike disease it may be only 25%. The environment and resulting growth rate have a substantial effect on the quality of heartwood and oil. Trees on mountainous, rocky, and dry soils develop the hardest wood and the highest content of oil. The darker the wood, the higher is the oil content. The highly prized dark marks called birds' eyes which have a very high oil content are the result of damage to the wood.

S. album coppices well when young; damaged roots produce large numbers of root suckers. Flowering starts when trees are 3–4 years old, but seed is mostly collected from 20-year-old trees. In Indonesia *S. album* flowers year-round with a peak from December to January, and a peak in fruit maturation from March to June. It produces large amounts of seed and abundant numbers of seedlings are often found on disturbed locations near old trees. Seed viability is affected by maturity. Physiologically mature seed from red fruits gives about 80% germination. When fruits turn black the seed becomes dormant and germination becomes very uneven. Germination is promoted by light.

Other botanical information *Santalum* L. comprises 16–25 species occurring mainly in Australia and the Pacific. *S. album* is the only species occurring naturally in Asia, *S. macgregorii* F. Muell. and *S. papuanum* Summerh. are found in New Guinea. *S. spicatum* (R. Br.) A. DC. (synonym *Eucarya spicata* (R. Br.) Sprague & Summerh.), yielding West Australian sandalwood oil, occurs widely in western and southern Australia. It is the most important source of Australian sandalwood and was once extensively cut and exported, but at present only small quantities are harvested (see also the chapter on minor essential-oil plants). Small-leaved and large-leaved forms are occasionally distinguished in *S. album*, but such forms belong to the normal natural variation and do not merit formal classification.

Ecology *S. album* is found in regions with an annual rainfall of 600–2000 mm. However, 850–1350 mm is considered optimal and 2500 mm is only tolerated on freely draining locations. Its natural habitat has a pronounced dry season and a short rainy season of 2–3 months. Trees are intolerant of waterlogging, especially when young, but are less affected when mature. Permanently wet sites are unsuitable. During periods of drought, considerable amounts of water are extracted from the host plants and wilting symptoms often show first on the latter. *S. album* grows naturally up to 1500 m altitude, with the best quality heartwood being produced at 600–900 m. It requires a sunny climate and is most common in open forest and at the edges of deciduous forest. Long periods of excessive heat or intense sunshine, however, severely reduce growth and are often fatal to seedlings, whereas in older trees bark may split and form deep cracks. Under extreme conditions the bark may peel off, exposing the wood. Most soils on Timor and Sumba are heavy clays derived from marine deposits, but *S. album* now occurs mostly on shallow stony soils. The best wood is from trees growing in open forest on rather poor and stony soils. It also grows well on laterite. On fertile loamy soils growth is fast and trees become large, but the oil content of the heartwood is low and the quality of the oil poor. *S. album* is intolerant of saline and highly calcareous soils but tolerates sodic soils.

Propagation and planting Propagation of *S. album* is usually by seed. The blue to purple-black ripe fruit is juicy and sweet and much liked by birds, which eat the outer fleshy part and drop the hard seed. In plantations, *S. album* is often sown directly in the field, because seedlings must parasitize a host when still very young. Sowing is done after the first showers of the monsoon rains. As only 30–40% of the seeds germinate in the field, about five seeds are planted per hole near a number of primary host plants. Secondary host plants should be well established on the site before sowing or planting. In the field, seed is spaced at about 2.5 m × 4 m. Shading seedlings to protect them from sun, extreme temperatures and wind is beneficial. About 50% shade is usually optimal. Growing seedlings in a nursery and transplanting is possible, provided seed is sown together with seed of a primary host plant. Seedlings are transplanted when about 1 year old and 25–30 cm tall. They may grow to 60–70 cm in the second year. Natural regeneration often occurs by root suckers, which are also suitable for vegetative propagation. Methods using hypocotyl segments, shoot and leaf cuttings have also been developed.

Husbandry Young plantations of *S. album* must be protected from rodents and grazing animals. Fire is also a major cause of mortality in young plantations. Where *S. album* is a major forest tree, seedlings are ring-weeded until well established. Host plants overtopping seedlings should be pruned or lopped.

Diseases and pests The gravest peril to *S. album* in India is spike disease, resembling witches' broom disease and caused by a mycoplasma-like organism (MLO). It is transmitted by insects. Trees of all ages are susceptible and once infected, they often succumb within 3 years. The MLO spreads through the phloem, thereby blocking the vessels. The first symptoms are shortening of internodes, severe narrowing of leaves and reduction in leaf size, leaves turning yellow and red before falling and death of root tips and haustoria. When symptoms develop, infection is usually severe and advanced, as symptoms may be masked for some time. Several insects have been implicated in the transfer of spike disease, e.g. *Coelidia indica*, *Moonia albimaculata*, *Cocostirphus tuberculatus*, *Nezara viridula* and most recently *Redarator bimaculatus*, but none of these reports has been confirmed. A high density of vectors is required to infect sandalwood trees. Such density is only sustained where additional suitable host plants are available. Clearing rank vegetation around sandalwood reduces the incidence of spike disease and is recommended in India. No chemical control methods giving permanent recovery have yet been developed. Injection of benomyl and tetracycline has given temporary recovery for about 6 months. When spike disease is found in a plantation it is important not only to control vectors, but also to completely uproot and remove affected trees, as several other species may develop witches' broom type symptoms when grown near diseased sandalwood trees. *Lantana camara* L. as host for *S. album* seems to increase the risk of contracting spike disease. Natural stands of *S. album* are generally free from fungal diseases. In Indonesia, konmeo disease, a leaf-gall disease of unknown origin, occasionally provokes some damage. In India mottled sponge rot caused by *Ganoderma applanata*, spongy or butt rot by *Ganoderma lucidum*, sooty mould by *Asterina congesta* and leaf curl by Santalum virus 2 result in some damage. Nursery diseases and pests include pathogenic fungi (*Fusarium* spp., *Phytophthora* spp.) and nematodes. Sandalwood trees may be damaged by insects, e.g. the red coffee borer *Zeuzera coffeae*, *Chionapsis* sp. and *Valanga*, but none is a widespread, serious pest.

Harvesting The cutting of sandalwood is strictly regulated. In Indonesia sapwood should be at least 2.5 cm thick and heartwood should have a diameter at breast height of at least 12 cm. Trees are preferably cut during the dry season when they do not have a new flush of leaves. The number of trees cut and the weight of sandalwood delivered at the government depot have to be registered. Trees are sometimes dug out around the base and winched down, to collect as much of the roots as possible. After felling the sapwood is removed leaving a 2–3 cm thick covering of sapwood to protect the heartwood during transport and against loss of oil in storage. Before transport to the collection point the trunk and main branches are cut into billets for ease of transportation. Sawdust is carefully collected and used.

Yield The yield of sandalwood oil varies; it is highest in the roots and lowest in chips of a mixture of heartwood and sapwood. Average yield of oil from good billets and roots is 4.5–6.25%. Trees yield 75–150 kg heartwood.

Handling after harvest For sandalwood oil extraction, billets are first reduced to chips and then milled to powder. In small traditional stills the wood used to be soaked in water for 2 days before being water distilled for a long time. In modern steam stills, charges of 750–1000 kg are distilled for 48–72 hours at a steam pressure of 1.4–2.8 kg/cm^2. In general, higher pressures increase oil yield, but above 3 kg/cm^2 the oil may acquire an undesirable harsh note. After distillation the oil is separated from the distillation water and purified by steam distillation followed by vacuum distillation to remove all traces of water. Solvent extraction of sandalwood yields sandalwood concrete but the process is not economic.

Genetic resources No substantial germplasm collections of *S. album* are known of.

Breeding Little breeding work has been done, apart from the identification of superior seed trees of *S. album* in India and Indonesia.

Prospects Although synthetic substitutes are available, few even approach the fragrance and tenacity of sandalwood oil, so the demand for the natural oil for high quality perfumery is expected to remain very strong. To protect dwindling natural stands and maintain production, expansion of plantations of *S. album* must be a first priority. Botanical and agronomic research to back up its cultivation is urgently needed.

Literature |1| Backer, C.A. & Bakhuizen van den Brink Jr., R.C., 1965. Flora of Java. Vol. 2. Noordhoff, Groningen, the Netherlands. p. 78. |2| Barrett, D.R. & Fox, J.E.D., 1994. Early growth of Santalum album in relation to shade. Australian Journal of Botany 42: 83–93. |3| Barrett, D.R. & Fox, J.E.D., 1994. Santalum album: kernel composition, morphological and nutrient characteristics of pre-parasitic seedlings under various nutrient regimes. Annals of Botany 79: 59–66. |4| Harisetijono & Suriamihardja, S., 1993. Sandalwood in Nusa Tenggara Timur. Australian Centre of International Agricultural Research. ACIAR Proceedings 49: 39–43. |5| Kharisma & Suriamihardja, S., 1991. Pengaruh lama naungan terhadap pertumbuhan bibit cendana (Santalum album L.) [Influence of the duration of shade on the growth of sandalwood seedlings]. Santalum; Buletin Penelitian dan Pengembangan Kehutanan Nusatenggara dan Maluku Tenggara 6: 23–27. |6| Perry, L.M. & Metzger, J., 1980. Medicinal plants of East and Southeast Asia. Attributed properties and uses. MIT Press, Cambridge, Massachusetts, United States. p. 372. |7| Rao, P.S. & Bapat, V.A., 1995. Somatic embryogenesis in sandalwood (Santalum album L.) In: Jain, S., Gupta, P. & Newton, R. (Editors): Somatic embryogenesis in woody plants. Vol. 2. Kluwer Academic Publishers, Dordrecht, the Netherlands. pp. 153–170. |8| Raychaudhuri, S.P., 1996. Sandal spike: retrospect and prospect. In: Raychaudhuri, S.P. & Maramorosch, K. (Editors): Forest trees and palms: diseases and control. Science Publishers, Lebanon, New Hampshire, United States. pp. 199–216. |9| Risseeuw, P., 1950. Sandelhout [sandalwood]. In: van Hall, C.J.J. & van de Koppel, C. (Editors): De landbouw in de Indische archipel [Agriculture in the Indonesian Archipelago]. Vol. 3. van Hoeve, the Hague, the Netherlands. pp. 686–705. |10| Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 516–538.

Razali Yusuf

Vetiveria zizanioides (L.) Nash

in: Small, Fl. south-eastern U.S.: 67 (1903).

GRAMINEAE

$2n = 20$ (diploid); 40 (tetraploid)

Synonyms *Phalaris zizanioides* L. (1771), *Andropogon muricatus* Retzius (1783), *A. zizanioides* (L.) Urban (1903).

Vernacular names Vetiver (grass), khus, khus-khus (En). Vétyver, chiendent odorant (Fr). Indonesia: akar wangi (general), larasetu (Javanese), usar (Sundanese). Malaysia: nara wastu, akar wangi, kusu-kusu. Philippines: moras (Tagalog), amora (Cebu), anis de moro (Ilokano). Thailand: faek, ya-faekhom, ya-faeklum. Vietnam: c[of] h[uw][ow]ng b[af]i, h[uw][ow]ng b[af]i.

Origin and geographic distribution *V. zizanioides* grows naturally in swamp areas of northern India, Bangladesh, Burma (Myanmar) and occurs probably naturalized in many parts of South-East Asia. It has been in cultivation in India for centuries and is now found throughout the tropics and in many subtropical areas. It is grown for its oil mainly in Haiti, West Java, India, Réunion, China and Brazil. To a very limited extent it is grown commercially as far north as Texas. The use of vetiver in erosion control spread first from India to the Caribbean and Fiji and later to many tropical areas, including all countries of South-East Asia.

Uses From the rhizome and roots of vetiver an essential oil, vetiver oil, is steam-distilled, which is used in perfumes, deodorants, soaps and other toilet articles. Its scent is heavy and woody. In perfumery, the essential oil and vetiveryl acetate, synthesized by acetylation of vetiver oil, are important fixatives for more volatile fragrance materials. The chemical stability of vetiver oil under alkaline conditions makes it a suitable scent compound for soaps. In certain canned foods e.g. asparagus and peas, fractions of vetiver oil are used to reinforce the natural odour and taste. The roots are used for making mats, fans or 'pamaypay' in the Philippines and cooling screens named 'tatties' in India. These give a pleasant smell to a room, especially when dampened. Dried roots or sachets of powdered roots are stored between clothes to give them a pleasant smell and to repel insects. Vetiver oil and roots have insecticidal and insect-repellant properties about which little is known. The oil is used medicinally as a carminative, diaphoretic, diuretic, emmenagogue, refrigerant, stomachic, tonic, antispasmodic and sudorific. A stimulant drink is made from fresh rhizomes in India. The plants are used as an anthelmintic in Madya Pradesh (India).

Young leaves of *V. zizanioides* are eaten by cattle and goats, though older clumps are left alone when other fodder is available. Stems and old leaves are an excellent, long lasting thatch and can be processed into a coarse paper-pulp.

Traditionally, *V. zizanioides* is planted in southern India in strips as permanent field boundaries and occasionally in contour strips to control erosion, while in Java it is planted to protect sloping drains. Its use as an erosion-control plant spread throughout the tropics, but for a long time remained restricted to small areas. Recent interest started in Fiji, where it was grown in contour strips in sugar-cane plantations on steep slopes. Since the late 1980s, its planting for erosion control has been promoted strongly, not only around fields, but also to protect terraces and road shoulders. Strips of densely packed, stiff and tough grass stems break the speed of run-off water and divide it evenly, reducing the risk of formation of run-off streams and gully erosion. The very dense root system has a strong tendency to grow downwards and effectively anchors strips of plants and soil behind it.

Production and international trade Indonesia and Haiti export the largest quantities of vetiver oil, about 50–100 t/year each, while China exports about 20 t/year. The largest area of production in Indonesia is in Garut Regency in West Java where it is grown on about 20 000 ha. The best quality, called Bourbon oil, comes from Réunion. Production in Réunion declined from 50 t in 1960 to only 6 t in 1989. World production is estimated at about 250 t of oil per year. The main importing countries are the United States and western Europe (each with 100 t/year), and Japan (10 t/year). No statistics are available for India, which produces and uses considerable quantities.

The price of vetiver oil varies between years and sources. In the 1990s, Bourbon oil was valued at about US$ 135–155/kg, oil from Haiti at US$ 90–100/kg and oil from Indonesia at US$ 54–62/kg; vetiveryl acetate at US$ 160/kg.

Properties Roots of *V. zizanioides* contain 1–3% vetiver oil, a light to reddish brown, sometimes greenish, viscous liquid. Its aroma has a sweet earthy woody top note; a heavy earthy woody body; and a similar dry-out lasting for several days. The oil is a mixture of over 300 components, mainly bi-cyclic and tri-cyclic sesquiterpene alcohols (about 50%) and ketones. The sesquiterpenes α-vetivone, β-vetivone and khusimol are the main constituents of the oil. They are considered fingerprints of the oil, although they do not possess the typical odour characteristics. The odour of vetiver oil is chiefly due to internal sesquiterpene ethers, such as epoxyeremophiladiene and epoxyspirovetivadiene. Several derivatives of khusimol are also important: zizanal and epi-zizanal and methyl esters. Other characteristic components of vetiver oil are vetivenic acid and vetivenyl vetivenate. In industry, the alcohols are often transformed to acetates, named vetiveryl acetate, which has a less intense, lighter, more floral scent than vetiver oil and is widely used as a fixative. The foreruns of vacuum distillation containing the more volatile components of the oil have an aroma strikingly reminiscent of asparagus.

Vetiver oil from northern India differs markedly from the oil from southern India and other production countries. The oil, called khus-khus, contains a large amount of khushilal, a C_{14}-terpenoid, and has laevo-rotatory light-breaking characteristics, while oil from all other sources is dextro-rotatory. In India this oil fetches a higher price as its odour is preferred.

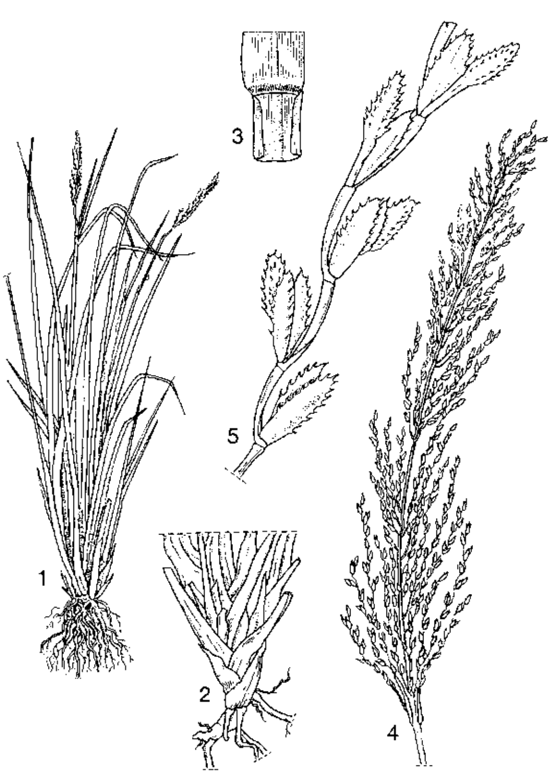
Vetiver resinoid is occasionally prepared by extracting the comminuted roots with benzene. In composition it is similar to vetiver oil but contains fewer components with a low boiling point and more truly represents the fragrance of the roots. The resinoid is a dark brown or dark amber semi-solid with a faint but extremely persistent odour reminiscent of the best vetiver oil: sweet woody, root-like, with a very rich, almost balsamic undertone. It is used in several perfumes and is unsurpassed as a fragrant fixative. Vetiver absolute has been prepared experimentally from the resinoid by alcohol extraction, but this product is not regularly available.

Vetiver oil is approved by the Food and Drug Administration of the United States under No 172.510 for use in alcoholic beverages only. The Research Institute for Fragrance Materials (RIFM) has published a monograph on the physiological properties of vetiver oil. See also: Composition of essential-oil samples and the Table on standard physical properties.

The nutritive value of the leaves varies with age and origin. Per 100 g dry material they contain: crude protein 5.5–6.7 g, ether extract 1.1–2.1 g, crude fibre 34.0–42.2 g, N-free extract 45-47 g, total ash 5–9 g, Ca 0.3 g, P 0.05–0.6 g. In vitro digestibility is 60%.

Adulterations and substitutes Vetiver oil has been adulterated by adding cheap sesquiterpenes, such as caryophyllene and its derivatives (epoxide and acetate). A more sophisticated adulteration is carried out by the addition of nagarmotha oil from *Cyperus* spp.

Description Coarse, perennial grass forming large, dense clumps with a stout, compact, aromatic, branched, spongy rhizome and fibrous root system up to a depth of 4 m. Culm erect, 1–1.5(–3) m tall, 2–8 mm in diameter, terete, solid,



Vetiveria zizanioides (L.) Nash – 1, habit of flowering plant; 2, base of leafy culm; 3, ligule; 4, inflorescence; 5, part of inflorescence branch.

glabrous. Leaf sheaths laterally compressed, 10–20 cm long, keeled; ligule a very shallow fimbriate rim, 0.3–1.7 mm long; blade linear, flat or folded, stiff, 30–75(–90) cm × 4–10(–15) mm, glabrous below, puberulent in lower upper side, scabrous along the edges and back of the midrib. Inflorescence a well-exserted, terminal panicle, 15–40 cm long, with 6–10 whorls of up to 20 slender, articulating racemes up to 10 cm long; internodes of the racemes and pedicels filiform, slightly thickened apically; internode of spikelet bearing rachis slender, 5–6 mm long, glabrous or with short scattered hairs; spikelets in pairs, 1 sessile and 1 pedicelled, 2-flowered, the pair falling as a unit; sessile spikelet 3.5–5.5 mm long, with well developed pointed, glabrous or pubescent callus, barren lower floret and perfect upper floret; glumes chartaceous, bearing papillose-based spicules or stiff hairs; lower glume lanceolate, folded about the mid-vein, as long as the spikelet, 7-veined; upper glume equal to or slightly shorter than lower glume, 3-veined; lower floret with hyaline, ciliate lemma and without palea; upper floret with lanceolate lemma, 3–4 mm long, 1–3-veined, with a short scabrid awn and palea oblong, 1.5–2.5 mm long, delicately hyaline, 1-veined, spinulose-hairy at the tip; stamens 3 with orange anthers about 2 mm long; pistil with glabrous ovary and 2 plumose, purple stigmas; lodicules 2, free, fleshy; caryopsis rarely formed, oblongoid to fusiform, apex slightly oblique; pedicelled spikelet more slender, 2.5–4.5 mm long; lower glume 3–7-veined, upper glume 3-veined; both florets staminate or with rudimentary stamens, anthers up to 2.5 mm long.

Growth and development Under favourable field conditions vetiver clump cuttings (splits) start sprouting a week after transplanting, but growth is generally slow during the first 3 months. In one year the root system becomes well developed. Some roots may reach a depth of up to 4 m and about 90% of the roots are found within a radius of 20 cm from the plant. Mycorrhizal associations are formed with several fungi. *V. zizanioides* is not an aggressive colonizer, as it forms clumps and does not spread beyond the clumps via stolons or rhizomes. When soil builds up behind a plant, its crown rises and stays at the soil surface. Clumps that grow out intertwine with neighbouring plants, forming a dense sod. The centre of the clump rarely becomes empty with age.

Other botanical information Two forms of *V. zizanioides* are sometimes recognized. One occurs in northern India, is smaller in size and has a different quality oil. It is rarely cultivated and mostly collected from wild stands. Under suitable, marshy conditions, it flowers regularly and sets fertile seed. The other form is widely cultivated and is probably a domesticated selection from southern India. Its plants are larger, rooting deeper, and yielding more oil. It very rarely flowers and produces virtually no viable seed and has to be propagated vegetatively. Neither form has been formally named and described, most probably because they are not distinguishable in herbarium material. The origin of *V. zizanioides* in Haiti is not fully understood: it spread naturally through the island and its oil differs somewhat from Javanese and South Indian oil, but is also dextro-rotatory.

'Monto', a sterile cultivar, has been released in Queensland (Australia). A few cultivars have been released in India: 'Hybrid-8' and the artificial tetraploid 'Sugandha' were developed from northern Indian plants, 'Sunshine' and 'Nilambore' are popular southern Indian cultivars.

The name *Vetiveria zizanioides* is sometimes erroneously attributed to Stapf and is often misspelled *V. zizanoides*. The taxonomy of the genus *Vetiveria* Bory is not yet well established. Although up to 10 species have been distinguished, it might appear that only one complex species exists in South-East Asia, *V. zizanioides*, with several varieties and cultivar groups. Most, if not all, so-called *Vetiveria* species are in fact *Chrysopogon* species, e.g. *Chrysopogon (Vetiveria) nemoralis* (Balansa) Holttum.

Ecology *V. zizanioides* is a hydrophyte, often dominant in fresh-water swamps, floodplains and on stream banks. It can only survive and spread naturally in swampy areas. It also exhibits, however, xerophytic properties and grows remarkably well under alternating very wet and very dry conditions with annual rainfall ranging from (300–)1000–2000(–3000) mm. Frost is not generally tolerated, but a few selections survive frequent frosts, with extremes as low as –9°C. The average maximum temperature required for good growth is 25°–35°C; absolute maxima may be about 45°C. It should not be shaded permanently, although healthy hedges of vetiver can be maintained in sugar-cane plantations, as the plants recover quickly after the harvest of the cane. *V. zizanioides* is tolerant of very poor and adverse soil conditions. It is grown on heavy clays and on leached, poor sands. Soil reaction may range from very acid (pH 4.0) to very alkaline (pH 9.6). Mature plants are tolerant of saline soil; yield reductions of 50%

(comparable to those of cotton and barley) have been found where salinity in the top 50 cm of the soil was 15–24 mS/cm. It can survive fire, rough trampling and grazing. For the production of vetiver oil, light sandy soils are required to facilitate harvesting of the smaller roots, which contain most oil.

Propagation and planting *V. zizanioides* is propagated vegetatively by dividing clumps into splits consisting of one or a few shoots of 15–20 cm long with a portion of the roots. When large numbers of plants are needed, mother plants are heavily fertilized to promote tillering. Although it is cheaper to plant splits directly in the field, the use of splits allowed to regenerate roots in mist frames or raised in containers ensures maximum survival and fast establishment. When no containers are used, nurseries should be in light soil so that plants can be pulled up easily. Culms can also be used to produce large numbers of new shoots for propagation. They are cut, placed in a nursery on damp sand and lightly covered, keeping them under mist. Slitting the leaf sheath improves the success rate. After 2 months most nodes have produced roots and start forming leaves. Plant regeneration through somatic embryogenesis of callus in vitro is possible and plantlets from a tissue-cultured clone from Mauritius are available commercially. For oil production, splits are planted in well prepared soil, in rows spaced 50–60 cm apart and at 20–30 cm between plants. They are sometimes planted on ridges or on 2-row beds. Planting is done at the onset of the rainy season. To make contour hedges, a spacing of 20 cm between plants is used.

Husbandry Two months after field planting of vetiver, the soil is earthed-up into ridges 30 cm wide and 20 cm high. To establish vetiver, early weeding is important. Weeding is done 3–4 times in the first year and a few times in the second. The final weeding is done just before harvesting to avoid roots of weeds in the harvested vetiver roots. *V. zizanioides* is tolerant of many herbicides, except those based on glyphosate. For good growth the use of manure or chemical fertilizer at a rate of 80 kg N and 30 kg each of P_2O_5 and K_2O is recommended. The N fertilizer should be applied in 3 equal doses, at planting, ridging and at about 8 months after planting. Intercropping with short-duration pulses can be done during the early stages of growth. Intercropping in coconut and areca palm plantations having a relatively open canopy is sometimes practised. Irrigation is sometimes economic. For erosion-control hedges it is essential to fill gaps between plants. When required, plants can be removed simply by cutting them off below the rhizome with a shovel, hoe or plough.

Diseases and pests *V. zizanioides* has few disease and pest problems. *Curvularia trifolii* leaf blight may cause damage during the rainy season; it causes the leaves to turn pale-yellow and to eventually dry out. *Fusarium* spp. are also reported to cause damage. A number of parasitic fungi have been identified in Malaysia, which grow on vetiver without causing much damage. They may, however, become troublesome when susceptible crops are grown with vetiver. These fungi include *Curvularia lunata* and *C. maculans*, causing leaf spot in oil palm, and a number of *Helminthosporium* spp. causing leaf spot or blight in oil palm, coconut palm, maize and sugar cane. Larvae of *Chilo* moths are the most serious pest of vetiver and crops grown in association with it. The larvae feed on the fibrovascular bundles, resulting in wilting of the affected stems and leaves. They can possibly be controlled by burning. Other reported pests are white grubs (*Eupladia* spp.) and rats. Under dry conditions, termites attack dead leaf and stem material, causing the centre of clumps to die. In extreme cases, plants are even killed. Resistance to some root-knot nematodes is effective. In trials in Brazil, vetiver was not affected by *Meloidogyne incognita* race 1 and *Meloidogyne javanica*.

Harvesting Roots and rhizomes of vetiver are harvested 15–18 months after planting when their essential oil content is highest. In Java harvesting is sometimes done already after 12 months, elsewhere it is sometimes postponed until after 24 months, which results in lower yields, but higher quality oil, being heavier and darker coloured. A light irrigation is sometimes given prior to harvesting, to make it easier to digg up the roots manually. The use of a single-disk plough digging to 40 cm depth has been time efficient and effective in trials. On sloping land, harvesting can cause serious erosion.

Yield The average yield of air-dried roots of vetiver varies from 1–2.4 t/ha, commonly yielding 12–17 kg oil. An excellent crop of vetiver in southern India and Réunion may yield 4 t/ha of roots, yielding over 40 kg vetiver oil.

Handling after harvest The harvested roots of vetiver are cleaned of adhering earth by washing in running water and drying in the field for a few days; they are then separated and allowed to dry in the shade to 10–15% moisture content. Vetiver oil is obtained by steam distillation of fresh or stored roots; storing the roots for about 6 months has been reported to improve oil quality. Chopped roots are soaked in water for 10–20 hours to render them soft before being put into stills. The duration of distillation varies from place to place, depending on the provenance and age of the roots, and the quantity loaded. In southern India, a load of 125 kg is distilled for 72–96 hours. In Java, the process normally takes 12–36 hours, in Réunion 36–48 hours. The first fraction of the oil distilled over is lighter than water, the later fraction heavier. The fractions are collected in separating tanks, eventually combined and filtered warm in steam-jacketed filters or centrifuged to free the oil from water. A small amount of salt may be added to the roots to increase the recovery of the oil fraction heavier than water. A portion of the oil is water-soluble. To recover this fraction, distillation water is collected from the separators and re-used in the distillation still. The quality of the oil improves with storage, because it converts the harsh 'green' earthy note of freshly distilled oil to a fuller, heavier and sweeter odour.

Genetic resources Several collections of vetiver germplasm are being maintained. In India, the National Bureau of Plant Genetic Resources maintains an extensive collection of both wild and cultivated material. The Essential Oils Research and Development Program of the Philippines has initiated collection of vetiver from different regions of the country, with the objective of identifying accessions which will produce a high yield and quality of essential oil. In Indonesia, about 150 accessions are being maintained by the Research Institute for Spice and Medicinal Crops with a similar objective. In Thailand, the Department of Land Development has embarked on germplasm collection of vetiver as part of an erosion control programme. Accessions have been obtained locally or introduced from India, Indonesia and Sri Lanka.

Breeding Most breeding work on vetiver is done in India by the Central Institute of Medicinal and Aromatic Plants in Lucknow, which has released several cultivars. Heritability estimates were found to be high for oil content and oil yield, but low for root yield. Genetic improvement has been tried through colchicine-induced polyploidy. Tetraploids yielding about 60% more than their parents and 40% more than the best available diploid were selected. The programme resulted in the release of the tetraploid cultivar 'Sugandha'.

Prospects The reputation of vetiver oil in the world market declined in the 1990s due to market distortions brought about by the highly regulated Haitian production and export system, the decline in production of Bourbon oil and the variability in the quality of Indonesian oil. These have prompted perfumers to look for other oils with a woody character. Consequently, world consumption has remained static. Since existing producers are more than capable of supplying any likely increase in demand in the future, prospects for new producers are not bright unless they can reliably produce a high quality oil.
Interest in *Vetiveria* spp. as erosion-control plants received a boost when the World Bank changed emphasis from bulldozer-built erosion control bunds to vetiver hedges. Experience in southern India and Fiji in large-scale commercial plantations and in subsistence farming show that vetiver can contribute to long-term erosion control, and initial experiences in South-East Asia are promising. Suggestions that vetiver can be used as an erosion-controlling crop under a wide range of conditions and with limited maintenance are exaggerated. Continuous strips without gaps can only be established where rainfall is adequate and when young plants are protected.

Literature |1| Davidse, G. 1994. Vetiveria. In: Dassanayake, M.D., Fosberg, F.R. & Clayton, W.D. (Editors): A revised handbook to the flora of Ceylon. Vol. 8. Amerind Publishing Company, New Delhi, India. pp. 448–450. |2| Gilliland, H.B., Holttum, R.E. & Bor, N.L., 1971. Grasses of Malaya. In: Burkill, H.M. (Editor): A revised flora of Malaya. Vol. 3. Government Printing Office, Singapore. pp. 232–234. |3| Grimshaw, R.G. & Helfer, L. (Editors), 1995. Vetiver grass for soil and water conservation, land rehabilitation and embankment stabilization. World Bank Technical Paper No 273. The World Bank, Washington, D.C., United States. 281 pp. |4| Grimshaw, R.G. (Editor), 1989–. Vetiver Newsletter. The Vetiver Network, Leesburg, Virginia, United States. |5| Lavania, U.C., 1991. Evaluation of an essential oil rich autotetraploid cultivar of vetiver. Journal of Essential Oil Research 3: 455–457. |6| Ohloff, G., 1994. Scent and fragrances. Springer Verlag, Berlin, Germany. pp. 172–173. |7| Rajendra Gupta, R. & Pareek, S.K., 1995. Vetiver. In: Chadha, K.L. & Rajendra Gupta, R. (Editors): Advances in Horticulture. Vol. 11. Medicinal and aromatic plants. Malhotra Publishing House, New Delhi, India. pp. 773–787. |8| Sivamohan, M.V.K., Scott, C.A. & Walter, M.F., 1993. Vetiver grass for soil and water conservation: prospects and problems. In: Pimentel, D. (Editor): World soil erosion and conservation. Cambridge University Press, Cambridge, United Kingdom. pp. 293–309. **[9]** Smadja, J., Gaydou, E.M., Lamaty, G. & Conan, J.Y., 1990. Etude de facteurs de variation de la composition de l'huile essentielle de vétyver Bourbon par analyse factorielle discriminante [Study of the factors of variation in the composition of Bourbon vetiver oil by factorial discriminant analysis]. Analusis 18: 343–351. **[10]** Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. pp. 117–137.

C.C. de Guzman & L.P.A. Oyen

3 Minor essential-oil plants

Aglaia odoratissima Blume

MELIACEAE

Synonyms *Aglaia affinis* Merrill, *A. diepenhorstii* Miquel, *A. heterophylla* Merrill.

Vernacular names Indonesia: pancal kidang (Javanese), tanglu (Lampung), pi-kopijan (Madurese). Malaysia: kasai, telur belangkas hutan, merlimau. Thailand: prayong paa (central), sangkhriat (peninsular).

Distribution Nicobar Islands, Burma (Myanmar), Thailand, Peninsular Malaysia, the Philippines, Borneo, Sumatra, Java, Sulawesi and possibly the Lesser Sunda Islands.

Uses In Java the fragrant flowers are used to flavour tea. In India, Indonesia and China an essential oil is distilled from the seed but not on a commercial scale. Several parts of the tree are used medicinally. The wood is strong and fairly durable but only available in small sizes.

Observations Dioecious tree, up to 25 m tall, trunk up to 20 cm in diameter; bark grey to red-brown, wood whitish-brown, exuding pale white latex when cut; twigs slender, often almost horizontal, with dense red-brown peltate scales and pale yellow stellate hairs. Leaves arranged spirally, imparipinnate, 10–40 cm × 5–30 cm; leaflets 1–7, elliptical, 4–24 cm × 2–8 cm, acuminate-caudate at apex. Inflorescence paniculate or racemose, male one up to 35 cm long, female one up to 12 cm long; flowers unisexual, 5-merous, small, up to 2 mm in diameter, yellow, fragrant of citronella. Fruit a 1-seeded, ellipsoid berry, 1.5–2 cm × 1–1.5 cm, yellow to orange-red, with pinkish-orange stellate scales. Seed with yellow-pink, edible, sweet-tasting aril which covers the seed completely. *A. odoratissima* is common in primary, secondary and periodically inundated swamp forest, along roadsides and on various soil types, up to 1900 m altitude.

Selected sources 1, 5, 7, 15, 42, 44.

Aquilaria beccariana van Tieghem

THYMELAEACEAE

Synonyms *Aquilaria cumingiana* (Decne) Ridley var. *parviflora* Airy Shaw, *A. grandifolia* Domke, *Gyrinopsis grandifolia* Quis.

Vernacular names Indonesia: garu tanduk (Kalimantan), mengkaras putih (Sumatra). Malaysia: gaharu, gumbil, njabak.

Distribution Peninsular Malaysia, Sumatra, Borneo.

Uses Possibly a source of agar wood, as are *A. crassna* Pierre ex H. Lecomte and *A. malaccensis* Lamk.

Observations Tree, up to 20 m tall, trunk smooth, grey, up to 36 cm in diameter. Leaves alternate, subcoriaceous; petiole 5–7 mm long; blade oblong-lanceolate, 7–27 cm × 3–8.5 cm, glabrous. Inflorescence short paniculiform, axillary or extra-axillary; pedicel 3–7 mm long; flowers 7–12 mm long, yellow-green to yellow-white; floral tube cylindrical with 5, ovate, 2–3 mm long lobes and 10 oblong, about 1 mm long petaloid appendages; stamens 10, sessile; pistil with a distinct stipe. Fruit an ellipsoid or obovoid capsule, 2–3.5 cm × 2 cm, stipe up to 1.5 cm long. Seed ovoid, 10 mm × 5 mm, black with a 5 mm long tail. *A. beccariana* occurs in primary forest from sea-level up to 800 m altitude. Other possible sources for agar or eagle wood from Malesia are: *A. filaria* (Oken) Merrill (tree, up to 17 m tall, occurring in the Philippines, Moluccas and New Guinea), *A. hirta* Ridley (synonym: *A. moszkowskii* Gilg; under surface of the leaves and the fruits densely pubescent; tree, occurring in Peninsular Malaysia, Singapore and eastern Sumatra), *A. microcarpa* Baillon (tree, up to 40 m tall with small fruits 1.5 cm in diameter, in Peninsular Malaysia, Sumatra, Belitung, Bangka and Borneo) and *A. rostrata* Ridley (under surface of the leaves and the fruits sparsely pubescent; rare tree, only known from Peninsular Malaysia).

Selected sources 16, 42.

Aquilaria crassna Pierre ex H. Lecomte

THYMELAEACEAE

Synonyms *Aquilaria agallocha* auct., non Roxb. (1832).

Vernacular names Agar wood, eagle wood, aloes wood (En). Bois d'aigle, bois d'aloès (Fr). Cambodia: crassna, chan krassna, klampeok. Thailand: kritsanaa (eastern). Vietnam: c[aa]y gi[os] b[aaf]u (for the plant), tr[aaf]m h[uw]-[ow]ng, ky nam (for the agar wood).

Distribution Cambodia, Thailand and Vietnam.

Uses In wood 15–20 years old or older there are sometimes deposits of dark brown, aromatic resin in the vascular tissue. Wood patterned with this resin (e.g. like the feathers of an eagle) constitutes the valuable agar wood. This wood has a pungent odour, sour, sweet and bitter. It burns with a blue flame and its smoke spreads a penetrating, long-persisting fragrance. Since antiquity, the wood has been burned in religious ceremonies and as incense sticks in rooms, to release this fragrance. On water distillation the wood produces an essential oil which is used in the perfume industry. In traditional medicine this wood is considered to be stomachic and tranquillizing and is prescribed in gastralgia, nausea, vomiting and against anxiety (3–4 g per day in powder or tincture). It is also used against malaria and cholera. The fresh non-resinous wood has a characteristic strong odour and is used for wood carving. The bark is used to make paper and cordage.

Observations Tree, 15–30 m tall, with a straight, grey trunk up to 1 m in diameter. Leaves alternate; petiole 4–5 mm long; blade elliptical-lanceolate, 8–12.5 cm × 3.5–5.5 cm, with swollen marginal vein. Inflorescence an axillary umbel; flowers yellow, fine-haired; pedicel up to 1 cm long; floral tube campanulate, about 4 mm long; calyx lobes 5, ovate, accrescent, 12–15 mm × 11–12 mm, with 10 small petaloid appendages; stamens 10 in two whorls; pistil with 1 mm long style and blackish, globose stigma. Fruit a flattened, suborbicular capsule, 3–4 cm × 3 cm, yellow-haired, opening with 2 valves. Seeds 1–2, glossy black. *A. crassna* occurs scattered in closed forest on rocky soil at 300–900 m altitude. It flowers in February and fruits in May. Because agar wood is extremely expensive *A. crassna* is overexploited in the natural forests and endangered by extinction. It is not known what causes the resin deposits; they only occur in injured trees. Fungal or bacterial activity have been suggested as causal agents (see *A. malaccensis* Lamk). In Cambodia 2 principal qualities of agar wood are distinguished: the best quality is 'khlem', the second one 'tok'. It is not known whether two other *Aquilaria* species from Indo-China can also produce agar wood (*A. baillonii* Pierre ex Lamk, tree up to 10 m tall or shrub 3–4 m tall, leaves 13–17 cm long, occurring in Cambodia and Vietnam; *A. banaensis* Pham Hoang Hô, shrub of 2–3 m tall, leaves 5–10 cm long, only occurring in Vietnam). *A. subintegra* Ding Hou (a shrub from Thailand with characteristic, connate, ring-shaped petaloid appendages) might also produce agar wood. It is worthwhile to include those species in *Aquilaria* research in Malesia.

Selected sources 1, 10, 16, 26, 27.

Backhousia citriodora F. v. Mueller

MYRTACEAE

Vernacular names Australian lemon myrtle, citron myrtle (En).

Distribution Australia (Queensland).

Uses The leaves contain an essential oil with high citral content, which is used in perfumes and soaps and as a flavouring. The oil resembles lemongrass oil, but is said to be of a better quality (e.g. lacking grassy-fatty or harsh notes) and of higher yield. Fresh and dried leaves are used as a flavouring herb in food. The essential oil possesses anti-microbial activity.

Observations Tall shrub or small tree, up to 8 m tall. Leaves opposite, coriaceous; petiole up to 1.5 cm long; blade ovate-lanceolate, 7.5–12.5 cm long. Inflorescence an axillary, umbel-like cyme with a cluster of numerous small flowers at the end of a branch; peduncle 2.5–3 cm long, pedicel longer than 1 cm; calyx tubular, broadly campanulate, 4-lobed; petals 4, shorter than the calyx lobes; pistil with a 2-loculed ovary, each locule with 6–8 pendulous ovules, style filiform, stigma small. Fruit an indehiscent capsule, surrounded by the persistent calyx. *B. citriodora* occurs in coastal notophyll vine forest. More than 90% of the essential oil from the leaves is citral. The high prices of fresh leaves (US$ 10–15/kg) and the oil (AUS$ 1000/kg) stimulated the start of cultivation of lemon myrtle with commercial potential for flavouring and oil production in Australia. Propagation is possible by cuttings. Commercial cultivation is similar to tea cultivation (yield of fresh leaves about 8 t/ha). The essential oil is extracted from the leaves by steam distillation (oil yield up to 3.8%, citral up to 97.7%). It seems worthwhile to investigate the prospects for Australian lemon myrtle cultivation in South-East Asia, in areas with a climate comparable to Queensland.

Selected sources 1, 3, 11, 12, 32.

Cananga latifolia (Hook.f. & Thomson) Finet & Gagnepain

ANNONACEAE

Synonyms *Canangium latifolium* (Hook.f. & Thomson) Ridley, *Unona brandisana* Pierre, *U. latifolia* Hook.f. & Thomson.

Vernacular names Cananga (En, Fr). Peninsular Malaysia: kenanga, tho shui tree. Thailand: nao (northern), khae saeng (eastern), raap (peninsular). Vietnam: c[aa]y tai nghe, th[oo]m shui, s[uw] t[aa]y.

Distribution Burma (Myanmar), Thailand, Indo-China and northern Peninsular Malaysia.

Uses The fragrant flowers can be used like those of ylang-ylang (*Cananga odorata* (Lamk) Hook.f. & Thomson), but the oil is of no commercial importance. The wood is considered to act as febrifuge.

Observations Deciduous tree, 10–20 m tall. Leaves alternate; petiole 1–1.5 cm long; blade ovate-oblong, 9–15 cm × 8.5–12 cm, finely, silvery, woolly-haired especially below. Inflorescence a raceme with 1–3 fragrant flowers, opposite the leaves of young branches; sepals 3, petals 6, lanceolate, greenish; stamens numerous; carpels many, hairy, with 4-locular ovary, a short fine style and a thick stigma. Fruit consisting of many separate carpels; monocarp ovoid, 1.4 cm long, torulose, containing 2–4 seeds. Flowering is from May to July.

Selected sources 8, 11, 18, 34, 44.

Chloranthus spicatus (Thunb.) Makino

CHLORANTHACEAE

Synonyms *Chloranthus inconspicuus* Swartz, *C. indicus* Wight, *C. obtusifolius* Miquel.

Vernacular names Chulan, charan (En). Indonesia: barlen (Sundanese). Thailand: niam om (northern), foi faa (Bangkok), raam (Pattani). Vietnam: c[aa]y hoa s[os]i.

Distribution Wild in China, but widely cultivated in eastern Asia, e.g. in southern China, Vietnam, Japan, in Malesia in Java and Sumatra.

Uses An absolute can be produced from a concrete of the flowers extracted by benzene or petroleum ether. The absolute is a yellow to dark amber coloured viscous liquid with a delightfully soft, woody-floral odour, which is valuable for the perfume industry. The fragrant flowers and leaves, both rich in essential oil, were used to flavour tea and were often mixed with tea leaves before drying, to impart their scent. After drying, they were removed. In China *C. spicatus* is also used medicinally.

Observations Small, ascending to spreading, glabrous shrub, up to 1.5 m tall. Leaves opposite, fragrant; petiole 0.4–1.2 cm long; stipules linear, 2–3 mm long; blade ovate to elliptical, 4–13.5 cm × 2–8.5 cm, base cuneate, margin coarsely crenate-serrate, apex rather obtuse. Inflorescence a terminal panicle, with 10–20 ascending spiciform branches 2–5 cm long; peduncle 3–8 cm long; bracts and bracteoles 1–1.5 mm long; flowers bisexual, naked; stamens 3, connate into a 3-lobed fleshy body enveloping the ovary. Fruit a fleshy drupe, 4 mm × 2 mm, narrowed at base, greenish-yellowish. Seed 1, subglobose. *C. spicatus* is found in Malesia at 700–900 m altitude and flowering is year-round. The essential oil blends well with many other oils and is commercially promising.

Selected sources 1, 2, 5, 15, 42.

Cyathocalyx ridleyi (King) J. Sinclair

ANNONACEAE

Synonyms *Xylopia ridleyi* King.

Vernacular names Malaysia: antoi.

Distribution Peninsular Malaysia, Singapore and Borneo.

Uses The flowers smell like *Cananga* flowers and could be similarly used.

Observations Tree, up to 7 m tall with tomentose branches. Leaves alternate, thinly coriaceous, softly tomentose beneath; petiole up to 2.5 cm long; blade obovate-elliptical, 15–25 cm × 7.5–9.5 cm, beneath with prominent veins. Flowers extra-axillary on stout branches, 2–5 together, fragrant, green; pedicel 6–8 mm long; sepals 3, ovate, 8 mm long; petals 6, filiform, up to 10 cm long, greenish-yellow; stamens numerous; ovary ovoid, 4–6-ovuled, silky. Fruit apocarpous, monocarps ellipsoid, 2–3 cm long. Seed with ruminate endosperm. *C. ridleyi* occurs mainly in dense moist forest at low altitudes and is rather rare.

Selected sources 5, 33, 34, 44.

Dalbergia parviflora Roxb.

LEGUMINOSAE

Synonyms *Dalbergia cumingiana* Benth., *D. zollingeriana* Miquel.

Vernacular names Akar laka (En). Indonesia: kayu laka (Indonesian), bulangan (Palembang), takanas bini (Dayak). Malaysia: kayu laka, akar berangan. Philippines: tahid-labuyo (Tagalog), karbilan (Bikol), balauini (Ibanag). Thailand: khree, saree (peninsular).

Distribution From Burma (Myanmar) and Thailand through Peninsular Malaysia and Sumatra to the Moluccas and possibly the Philippines.

Uses The pulverized heartwood is used as a component of incense or joss sticks, especially in China, India and Malaysia. It has no odour until burnt, when it produces a pleasant smell. Only small amounts are used for joss sticks, because its strong odour easily dominates other components. A red, sticky oil which is applied to ulcerated wounds can be distilled from the wood, and a decoction of the wood in water is used as a tonic. Grated wood is rubbed on the skin to invigorate the body.

Observations Thorny liana, up to 30 m long, with a rough, peeling bark, bright to dark red heartwood and whitish sapwood. Leaves alternate, 15–20 cm long, compound; leaflets 5–9, alternate, ovate-lanceolate, 5–9 cm × 2–4 cm, glabrous. Inflorescence an axillary panicle, 7.5–10 cm long, with numerous white flowers, calyx campanulate with 5 teeth, stamens 10. Fruit a flattened-obovoid pod, 2–5 cm × 1.5 cm, indehiscent. Seeds 1–2, reniform. *D. parviflora* occurs in secondary forest on river banks, along the seashore, in freshwater swamp forest and in *Dipterocarpus* forest, mostly on fertile alluvial soils up to 150 m altitude. Only the oldest parts of mature stems are collected from the wild; the sapwood is removed, the heartwood is cut into billets which are traded. The main components of the heartwood essential oil are nerolidol, farnesol, furfurol, arylbenzofurans and neoflavonoids. It is doubtful whether *D. parviflora* is the true or the only source of 'kayu laka'; its natural scarcity is difficult to reconcile with the large amounts of incense used. It is recommended to clarify all the sources of 'kayu laka' and to investigate the prospects of cultivating it to prevent the species being eradicated from the wild.

Selected sources 11, 23, 24, 33, 37, 39, 45.

Dendrobium salaccense (Blume) Lindley

ORCHIDACEAE

Synonyms *Grastidium salaccense* Blume, *Dendrobium intermedium* Teijsm. & Binnend., *D. gemellum* Ridley.

Vernacular names Indonesia: sakat harum (Sumatra), kapias (Batak Kara), lanali (Minangkabau).

Distribution Indonesia (Java, Sumatra), Singapore and Peninsular Malaysia.

Uses The leaves have a strong liquorice-like odour, especially during drying or steaming. In Sumatra they are packed in banana leaves and steamed together with rice, to make the rice more fragrant. Women also wear the leaves in their hair.

Observations Epiphytic herb, about 70 cm tall, with thin stem (about 3 mm in diameter). Leaves linear, 12 cm × 1 cm, obtuse, thin. Inflorescence a very short 2-flowered raceme; flowers whitish, about 13 mm wide, sepals 6 mm long, petals oblong, labellum oblong, slightly constricted halfway up, with a longitudinal rib on inner side. *D. salaccense* grows in mixed and teak forest, up to 1800 m, but usually below 1200 m altitude. A much larger form has been named var. *major* J.J. Smith (stem 1–3 m long, 6.5 mm in diameter; leaves 2.7 cm wide, flowers 18 mm wide, yellowish).

Selected sources 2, 15, 35.

Enkleia malaccensis Griffith

THYMELAEACEAE

Synonyms *Enkleia coriacea* Hallier f., *E. malayana* Griffith, *Linostoma scandens* (Endl.) Kurz.

Vernacular names Indonesia: tementak akar (Bangka), terap akar (Sumatra), aka dian (Kalimantan). Malaysia: kapang akar, akar puchong kapur, akar kareh hitam.

Distribution Peninsular Malaysia, Singapore, Sumatra and Borneo.

Uses The wood is aromatic, but considered inferior to agar wood. The bast fibres can be used for tying.

Observations Woody climber, up to 30 m long and 30 cm in diameter; branches red-brown, young ones ferrugineous pubescent and sometimes transformed into hook-like organs. Leaves subopposite, coriaceous, golden-brown velutinous; petiole 6–12 mm long; blade ovate to elliptical, 3.5–15 cm × 2–10 cm. Inflorescence paniculately branched, terminal, 15–30 cm long, each branch with 4–14 flowers arranged like an umbel; calyx tubular, 5–6 mm long, 5-lobed, yellow-green, golden-brown velutinous, persistent in fruit; corolla reduced to 10 petaloid appendages of 1 mm length inside the calyx tube; stamens 10, in 2 whorls, subsessile; pistil with unilocular ovary, filiform style up to 1 mm long and clavate stigma. Fruit an ovoid drupe, 10–15 mm × 6–8 mm, prominently ribbed. *E. malaccensis* occurs in primary forest below 50 m altitude. Flowering and fruiting occur between April and October; usually only one fruit develops per inflorescence branch. *E. malaccensis* is closely related to *E. siamensis* (Kurz) Nevling, occurring in Burma (Myanmar), Thailand and Indo-China and is included in *E. malaccensis* by some authors. *E. siamensis* yields a bast fibre used for tying, a decoction of its leaves is used to cure eye diseases and the fruits are used as a purgative.

Selected sources 5, 10, 15, 25, 42.

Exocarpos latifolius R. Brown

SANTALACEAE

Synonyms *Exocarpos luzonensis* (Presl) A. DC., *E. ovatus* Blume, *Xylophyllos latifolius* (R. Brown) O. Kuntze.

Vernacular names Mistletoe tree, broad leaved cherry tree (En). Indonesia: cendana semut (Javanese), kamoneng alas (Kangean), blaping (Timor). Philippines: agsum (Tagbanua), kamiing (Pangasinan), uksur (Iloko).

Distribution From the Philippines and Indonesia to New Guinea and Australia.

Uses The wood is considered an inferior substitute for sandalwood, losing its fragrance rapidly. It is not suited for timber because it is only available in small crooked dimensions, but it is used to make small utensils and handles. The receptacle, fruit and seed are said to be edible (sometimes chewed with betel leaves because of the red colour) but aboriginals in Australia consider all parts toxic. In Australia an infusion of the bark and the seeds is used as a contraceptive.

Observations Semi-parasitic shrub or small tree, up to 10(–20) m tall, stem up to 0.5 m in diameter. Leaves alternate; petiole 2–14 mm long; blade broadly ovate, elliptical or obovate, up to 14 cm × 8.5 cm, obtuse. Inflorescence a green spike, up to 5 cm long, often clustered or branched; tepals 5, up to 1 mm long, green, persistent. Fruit an ellipsoid drupe, 6–9 mm × 6–9 mm, scurfy, yellowish to reddish, on an obovoid, bright red fruiting receptacle 4–8 mm × 10 mm. Seed globose, 5–8 mm in diameter. The wood is whitish to pale reddish-brown, heavy, hard, strong and durable. *E. latifolia* is very variable and occurs in many habitats, in shrubland, woodland and forest, especially on coastal dunes, river banks and sandstone gullies at low altitudes. The reported hosts are *Petalostigma* spp., *Canthium* spp., *Terminalia* sp., *Callitris* sp. and the species itself.

Selected sources 2, 5, 9, 15, 21, 38.

Fokienia hodginsii (Dunn) A. Henry & H. Thomas

CUPRESSACEAE

Synonyms *Cupressus hodginsii* Dunn, *Fokienia kawai* Hayata, *F. maclurei* Merrill.

Vernacular names Laos: lang len, leng le:. Vietnam: p[ow] mu, dinh h[uw][ow]ng.

Distribution South-eastern China, northern Laos and northern Vietnam.

Uses The valuable essential fokienia oil, which is used in perfumery, is distilled from old wood. In China, the dark brown, resinous, fine-grained, durable and easy to work wood is prized for making coffins.

Observations Monoecious tree, usually 15–20 m tall but sometimes reaching 35 m height. Leaves scale-like, imbricate, inserted on the twigs in groups of 4, each group consisting of 2 different, opposite pairs of scales; scales on juvenile twigs rather different from the ones on mature twigs and ending in a spiny point. Inflorescence a cone; male cone terminal, cylindrical, 2–4 mm long, consisting of 14–16 peltate, stamen bearing cone scales, each scale with 3–4 pollen sacs; female cone subglobose, 15–22 mm in diameter, consisting of 12–16 decussate-opposite, woody, peltate scales, each fertile one bearing 2 basal ovules. Seeds 2 per fertile scale, ovoid, 3–4-ridged, bearing 2 very unequal lateral wings. *F. hodginsii* occurs in ever-wet, often peaty mountain forest, in China up to 700 m, in Laos and Vietnam between 1000–2000 m altitude. Flowering is in October, fruiting in May–July but maturing takes about 2 years. It is endangered by extinction and merits protection. Research to investigate prospects for commercial cultivation in Malesia is strongly recommended.

Selected sources 10, 18.

Lepiniopsis ternatensis Valeton

APOCYNACEAE

Synonyms *Lepiniopsis philippinensis* Elmer.

Vernacular names Indonesia: pulasari pohon, tokupoa (Moluccas). Philippines: kolinos, kuyon-kuyon, magpanias (Bisaya).

Distribution The Philippines (Cebu, Luzon, Mindanao, Mindoro, Negros, Panay, Samar, Siargao, Sibuyan), Indonesia (Moluccas, Sulawesi, Talaud Islands), New Guinea, New Britain and New Ireland.

Uses The roots are fragrant (resembling *Iris* rhizomes) and are used to perfume clothes and for skin ointment. The odour is best conserved by first soaking the roots in seawater and then drying them.

Observations Shrub or tree, 6–17 m tall, rich in white latex, with 3-whorled branches. Leaves alternate; petiole 1–3.5 cm long; blade elliptical to obovate, 9–26 cm × 3–8 cm, fleshy to coriaceous, glabrous. Inflorescence dichasial, in alternating ternate groups; calyx lobes 5; corolla salverform, 5-lobed, tube orange, lobes white. Fruit syncarpous, drupaceous, ellipsoid, 2.5–5 cm × 1.5–2 cm, red, 5-locular. Seed usually 2–3 per fruit, 2–3 cm long, bony. *L. ternatensis* occurs rare and scattered, as undergrowth in lowland rain forest, up to 900 m altitude, along rivers, on sandy beaches and other open localities.

Selected sources 15, 20, 21.

Litsea pipericarpa (Miquel) Kosterm.

LAURACEAE

Synonyms *Polyadenia pepericarpa* Miquel, *Lindera pipericarpa* (Miquel) Boerl.

Vernacular names Indonesia: kulit antarsa, kulit pulaga (Sumatra). Malaysia: medang serai.

Distribution Indonesia (Sumatra), Peninsular Malaysia.

Uses All parts contain an essential oil consisting of citral, citronellal, cineole and geraniol. The fruits resemble peppercorns and are used similarly as a flavouring. In Java, seed and bark are used to make face powder. The fruits are used medicinally like cubebs (*Piper cubeba* L.f.) as a tonic, against indigestion, as antiseptic and diuretic. The wood can be used to make small objects. The tree has been suggested for reafforestation purposes and as a shade tree in tea.

Observations Dioecious tree, up to 18 m tall with grey or green smooth bark. Leaves alternate; petiole 1–2 cm long; blade narrowly elliptical, 7–12.5 cm × 2–5 cm, pointed at base and apex, glaucous below, secondary veins in 7–11 pairs. Inflorescence a small umbel, in axillary clusters or from twigs behind leaves; flowers 1–6 per umbel, enclosed in 2–4 involucral bracts, yellow, fragrant; perianth lobes 6; stamens in male flower 9 or 12, in 3 or 4 rows, 3rd and 4th rows with glands; anthers 4-celled. Fruit a 1-seeded, globose berry, 0.5 cm in diameter, green but turning black at maturity, seated on small perianth cup. *L. pipericarpa* is common and often grows gregariously in forest clearings, up to 3000 m altitude. Crushed parts (especially the bark) smell strongly of citronella or eucalyptus.

Selected sources 5, 17, 44.

Magnolia kobus A. DC.

MAGNOLIACEAE

Synonyms *Magnolia thurberi* hort.

Vernacular names Kobus magnolia (En).

Distribution Japan and southern Korea. In cultivation it can be found as an ornamental all over the world.

Uses Besides its ornamental value *M. kobus* can be used to distil a volatile oil called kabushi oil from the leaves and twigs. The oil contains cineole, citral, anethol and probably methyl chavicol.

Observations Arborescent, deciduous shrub or small tree of dense twiggy growth, up to about 10 m tall. Leaves alternate; leaf buds pubescent; blade obovate, 10–18 cm × 5–11.5 cm, often puckered or rugulose. Flowers 10–12 cm in diameter, white with some pinkish flush, appearing before the leaves, with 3 small, caducous sepals and 6–9 spatulate petals; stamens numerous; pistils many, imbricated on an elongated receptacle. Fruit a follicle, aggregated into a cone like dark brown body about 10 cm long. A much larger form from northern Japan (tree up to 25 m tall with larger leaves and flowers) has been named var. *borealis* C.S. Sargent. Several cultivars and hybrids of *M. kobus* exist and all are very frost hardy. Propagation is possible by seed and by cuttings. *M. grandifolia* L., being indigenous to south-eastern United States, but cultivated worldwide, is another possible source of flower perfume.

Selected sources 1, 5, 11, 12, 40.

Mansonia gagei J.R. Drummond ex Prain

STERCULIACEAE

Vernacular names Sandalwood (En). Burma (Myanmar): kalamet. Thailand: chan chamot (south-western), chan khaao, chan hom (central).

Distribution Burma (Myanmar) (Tenasserim) and Thailand.

Uses The fragrant wood serves as a substitute for sandalwood (*Santalum album* L.) and *Cordia fragrantissima* Kurz, e.g. in the funeral pyres of Buddhists and Hindus, as a cosmetic and in other uses where fragrance is demanded. In Thailand it is alo used medicinally.

Observations Medium sized tree, trunk diameter up to 70 cm. Leaves simple, alternate, chartaceous; petiole up to 1 cm long; blade oblong-ovate to ovate-lanceolate, 8–12 cm × 3–5 cm. Inflorescence subterminal, paniculate; flowers bisexual, with spathaceous calyx, 5 petals, 10 stamens, 5 petaloid staminodia and 5 separate carpels. Fruiting carpel 3–5 cm long, usually in a pair, indehiscent, bearing a leathery wing of about 2 cm × 1 cm. Seed black. Fresh wood has a pungent and disagreeable odour; the fragrant scent develops in decaying wood in a period of up to 6 years. The wood is brown and very hard. Possibly, *M. gagei* is also of interest for the Malesian area.

Selected sources 5, 22, 29.

Melaleuca alternifolia (Maiden & Betche) Cheel

MYRTACEAE

Synonyms *Melaleuca liniariifolia* Smith var. *alternifolia* Maiden & Betche.

Vernacular names Tea tree, narrow-leaved paperbark (En).

Distribution Australia (from Darling Downs, Queensland to Hunter River, New South Wales), wild and cultivated. It is only occasionally cultivated outside this region, mainly in botanical gardens.

Uses The valuable essential oil, tea-tree oil or Australian melaleuca oil, is water- or steam-distilled from the leaves and small twigs. This oil is mainly used for medicinal and veterinary purposes as a popular antiseptic because of its ability to penetrate unbroken skin. The oil is also of interest in the perfume industry, as it blends well with other oils while contributing its own distinctive note to soaps, deodorants and colognes.

Observations Shrub, up to 7 m tall, with layered, papery bark. Leaves variously arranged, scattered to whorled often on one branchlet; petiole 1 mm long; blade linear-acute, 10–35 mm × 1 mm, 3-veined (often only mid-vein visible), puberulous, glabrescent, dotted with oil glands visible with a lens. Inflorescence a many-flowered, open to dense, upper-axillary or terminal spike; flowers solitary within each bract with tubular calyx up to 3 mm long and white corolla 2–3 mm long, stamens 30–60, white, clawed, pistil with 3–4 mm long style and capitate stigma. Fruit a many-seeded, globose, woody capsule, 2–3 mm in diameter. *M. alternifolia* occurs in the warm, wet east coast of Australia, often in swampy circumstances in dense impenetrable thickets, on a range of soils (pH 4.5–7), up to 300 m altitude. Mean summer maximum temperature is 27–31°C, mean minimum 17–19°C, mean winter maximum 18–21°C, mean minimum 6–7°C, and the species is frost sensitive. Average annual rainfall is 1000–1600 mm. Leaf oil content is highest in warmer months. For cultivation, seed is sown in nursery beds, seedlings potted when 4–6 weeks old and transplanted at a density of at least 35 000 trees/ha. Harvesting of leafy twigs starts 15–18 months after establishment and subsequently at 12–15 months intervals. Shoots are cut when less than 2 cm in diameter and at 5–10 cm above soil level. Yield is about 8–10 t/ha, oil content 1–2%. Irrigation is very important. Wild stands have been regularly harvested for 70 years; plantation life is not yet known. The steam-distilled oil is white to pale yellowish-green, with a spicy aromatic odour, combining elements of cardamom, sweet marjoram with a camphoraceous slightly bitter, warm and spicy taste. The major components are terpinen-4-ol (up to 45%), gamma-terpinene (up to 25%), 1,8-cineole (3–17%) and limonene (up to 5%) (% not necessarily from the same sample). See also: Table on standard physical properties. In 1995 Australia produced 200 t of this oil, most of which was exported. Tea tree could be of interest in Malesian areas with suitable circumstances.

Selected sources 1, 6, 11, 12, 43.

Meliosma henryi Diels

SABIACEAE

Synonyms *Meliosma affinis* Merrill, *M. buchananifolia* Merrill, *M. thorelii* Lecomte.

Vernacular names Burma (Myanmar): ye thit nee. Laos: co lêng. Vietnam: co phi[ee]n.

Distribution Southern and central China, northern India and northern Burma (Myanmar), northern Laos and northern Vietnam.

Uses In China the bark is used for incense.

Observations Evergreen tree, up to 18 m tall. Leaves alternate, simple; petiole 0.5–3 cm long; blade obovate-oblong to obovate-lanceolate, 3–25 cm × 1–9 cm, coriaceous. Inflorescence a terminal panicle 10–35 cm long; flowers numerous, bisexual, zygomorphic; sepals 4–5, petals 5, unequal; stamens 5, 2 fertile, 3 staminodial; ovary 2-locular. Fruit a globose to obovoid berry, 5–8 mm in diameter. *M. henryi* occurs in subtropical to tropical forest at moderate altitudes. Three subspecies are distinguished: subsp. *henryi* (ovary glabrous, endocarp without reticulum, leaves up to 12 cm × 3.5 cm with 5–10 pairs of veins; central and southern China, rather rare); subsp. *mannii* (Lace) Beus. (ovary glabrous, endocarp without reticulum, leaves up to 20 cm × 7.5 cm with 10–18 pairs of veins; north-eastern India, northern Burma (Myanmar) and adjacent China, rather rare); and subsp. *thorelii* (Lecomte) Beus. (ovary densely pubescent, endocarp with distinct reticulum, leaves up to 25 cm × 9 cm with 10–25 pairs of veins; southern China and Hainan, Laos, northern Vietnam, rather common, up to 1500 m altitude). It is worthwhile to investigate possibilities for this species in South-East Asia, including the Malesian region.

Selected sources 5, 41.

Microtoena insuavis (Hance) Prain ex Briq.

LABIATAE

Synonyms *Gomphostemma insuave* Hance, *Microtoena cymosa* Prain, *Plectranthus patchouli* C. B. Clarke ex Hook.f. Note: *Microtoena* is sometimes also wrongly spelled '*Microtaena*'.

Vernacular names Chinese patchouli, khasia patchouli (En). Thailand: kham pong (northern).

Distribution From India throughout continental South-East Asia to southern China, Sumatra, Java and Bali.

Uses An essential oil is distilled from the leaves. It is used like patchouli oil (see *Pogostemon* Desf.) and in China and Vietnam as a perfume to scent soaps and fabrics. Sometimes it is used to adulterate true patchouli oil.

Observations Erect, branching, perennial, densely villose herb, up to 1 m tall. Leaves opposite, chartaceous, fragrant; petiole slender, up to 7 cm long; blade ovate, up to 10 cm × 7.5 cm, base cuneate, margin crenate-serrate, apex acute. Inflorescence a paniculate thyrse, 10–35 cm long; bracts lanceolate, 2–5 mm long; calyx turbinate, 3–4 mm long, accrescent in fruit to 6–7 mm, subequally 5-toothed; corolla tubular, 2-lipped, 12–16 mm long, yellow or reddish, upper lip hooded, lower lip shallowly 3-lobed; stamens 4 in 2 pairs; style bifid with very short upper branch. Fruit composed of 4 nutlets; nutlet flattened ovoid, 1.5 mm × 1 mm, finely granular. *M. insuavis* occurs in damp forest, often along river banks, usually between 1000–1700 m altitude, sometimes lower. Flowering is May–October in Malesia, October–December in China.

Selected sources 2, 5, 11, 42.

Nigella damascena L.

RANUNCULACEAE

Synonyms *Nigella coerulea* Lamk, *N. pygmaea* Persoon.

Vernacular names Love-in-a-mist, jack-in-the-green (En). Barbiche, cheveux de vénus, nigelle de damas (Fr).

Distribution Possibly originating from Turkey or Crete, widely distributed in the Mediterranean, southern Europe and northern Africa. Cultivated worldwide, especially as ornamental.

Uses On steam distillation the seed yields about 0.4% of a deep yellow essential oil with a blue fluorescence, the odour of wild strawberries and slightly reminiscent of ambrette seed oil. The oil can be used in perfumery for fruity and floral perfumes; it blends well with numerous other oils and is comparatively powerful, having a winy or brandy-like character. The seed can also be used as a condiment, like seed of *Nigella sativa* L. The oil contains about 9% damascenine, an alkaloid causing the blue colour, with mildly narcotic properties. *N. damascena* is very popular worldwide as an ornamental.

Observations Annual herb, up to 60 cm tall, stem simple or branched. Leaves alternate, bi- to tri-pinnate, with very narrow segments. Flowers terminal, solitary, 3.5–4.5 cm in diameter, bisexual, surrounded by about 5 involucral leaves which are dissected into many linear segments; sepals 5, clawed, petaloid, blue or whitish; petals about 8, smaller than sepals, clawed, 2-lipped, lower lip bifid; stamens numerous; carpels usually 5–6, entirely united. Fruit a subglobose inflated capsule (united follicles) with hornlike, horizontally spreading, persistent styles. Seed numerous, 3-angled, transversely ribbed, black, rugose. *N. damascena* is easily raised from seed, preferably being sown directly at the required site. Many garden cultivars exist, some with double flowers. It is worthwhile to investigate prospects for this species in South-East Asia.

Selected sources 1, 2, 11, 12, 31, 46.

Osmoxylon umbelliferum (Lamk) Merrill

ARALIACEAE

Synonyms *Aralia umbellifera* Lamk.

Vernacular names Ambon sandalwood, sasooroo (En). Indonesia: sasuru, tonokuko (Ambon).

Distribution Indonesia (Moluccas: Ambon, Seram, Sula Islands).

Uses When dried, the reddish wood is very fragrant and is prized for its scent and is burnt as incense. The wood is difficult to work and releases a strong odour of camphor during planing. Fresh yellow-red resin exuding from cracks in old trees is used for perfumery.

Observations Tree with stout trunk, the branches marked with prominent leaf scars. Leaves simple, clustered at the end of branches; petiole long; blade lanceolate, 30–36 cm × 10–12 cm, margin dentate. Flowers in a large spreading umbel, the radiating branches tripartite, about 30 cm long. *O. umbelliferum* is only known from a plate and description from Rumphius and has never been recollected. It has been described as a rare tree from the mountains in Ambon.

Selected sources 11, 15, 42.

Pittosporum pentandrum (Blanco) Merrill

PITTOSPORACEAE

Synonyms *Aquilaria pentandra* Blanco, *Pittosporum brachysepalum* Turcz.

Vernacular names Philippines: mamalis (Tagalog), antoan (Bisaya), basuit (Iloko).

Distribution Taiwan, throughout the Philippines, northern Sulawesi.

Uses After steam distillation the fruits yield a pleasantly smelling oil, called mamalis oil. A decoction of the leaves is aromatic like the fruit oil and is used in baths by women after childbirth. The bark is used as a febrifuge and in large amounts as a general antidote; it is also effective in bronchitis.

Observations Tree, 3–17 m tall, 10–30 cm in trunk diameter. Leaves arranged spirally or in a pseudo-whorl; petiole up to 1.5 cm long; blade narrowly elliptical to oblanceolate, 4–12 cm × 1–3 cm. Inflorescence terminal or axillary, many-flowered, thyrsoid, about 3–4 cm in diameter with pubescent branches; flowers functionally unisexual; sepals 5, free, ovate, about 2 mm × 1 mm; petals 5, oblong-linear, up to 8 mm × 1 mm, white; stamens 5, best developed in male flowers, pistil best developed in female flowers. Fruit a compressed globose capsule, about 7 mm in diameter, slightly apiculate, 2-valved. Seeds 6–8, subreniform, about 3 mm × 2 mm. *P. pentandrum* is characteristic in secondary forest from which the valuable timber trees have been removed, but also in rain forest, up to 2300 m altitude. Propagation is easy by seed and by cuttings. In Florida its planting is discouraged as it is invasive of pine forests. *P. dallii* Cheesem., native to New Zealand, is cultivated in Europe. Its essential oil adds a special feature to the floral bouquet of a few luxury perfumes.

Selected sources 4, 5, 11, 19, 42.

Pogostemon benghalensis (Burm.f.) Kuntze

LABIATAE

Synonyms *Origanum benghalense* Burm.f., *Pogostemon parviflorus* Benth., *P. plectranthoides* auct., non Desf.

Vernacular names Thailand: niam nguang chaang (central), om (northern).

Distribution India, Sri Lanka, Nepal, Bangladesh, Burma (Myanmar), Thailand and China. It is also occasionally cultivated.

Uses The leaves are used to distil a kind of patchouli oil which has an odour reminiscent of cedar wood. The oil is used as a stimulant and styptic. Fresh leaves are used to clean wounds and promote their healing. The flowers are a well known source of pollen and nectar for bees to produce panagol honey. Commercially, *P. benghalensis* is most important in India.

Observations Herb with strong, solid, angular stem. Leaves opposite; petiole 2.5 cm long; blade ovate, 13 cm × 6 cm, base cuneate, margin double dentate, apex acuminate. Inflorescence a verticillaster, arranged in a terminal false spike, about 7 cm long, at base branched into more than 2 lateral spikes; calyx inflated, tubular, about 4 mm long, hairy outside, glabrous inside, with 5 ciliate teeth of about 1 mm length; corolla tubular, up to 8.7 mm long, 2-lipped, upper lip 3-lobed; stamens 4, inserted at different heights in the corolla tube, filaments 5–7 mm long. Fruit composed of 4 nutlets; nutlet obovoid, 1.2 mm long, finely punctate. *P. benghalensis* occurs in open riverine forest, but is also cultivated in India. Besides an essential oil it contains an astringent resin, an alkaloid, and a yellow varnish of a slightly bitter taste. It much resembles *P. plectranthoides* Desf., but its narrower corolla tube and less crowded inflorescence are distinctive. It is worthwhile to investigate cultivation prospects for South-East Asia.

Selected sources 30, 43.

Pogostemon plectranthoides Desf.

LABIATAE

Synonyms *Mentha secunda* Roxb.

Vernacular names Thekkali (En, India), rudilo (En, Nepal). Thailand: niam nguang chaang (central), om (northern).

Distribution Throughout the Indian subcontinent from Tamil Nadu to Nepal and Bangladesh, but not in Sri Lanka. Cultivated occasionally, in the Russian Federation commercially.

Uses A kind of patchouli oil is distilled from the leaves, which, especially in the Russian Federation, is used as a substitute for the true patchouli oil of *P. cablin* (Blanco) Benth. In the Indian subcontinent *P. plectranthoides* is used similarly to *P. benghalensis* (Burm.f.) Kuntze.

Observations Semi-shrub, up to 3 m tall with a solid, angular stem. Leaves opposite, tomentose; petiole up to 3 cm long; blade ovate, up to 15 cm × 7 cm, base rounded, margin double dentate, apex acute. Inflorescence a verticillaster, arranged into a terminal false spike about 6 cm long with more than 2 lateral spikes; bracts broadly ovate, about 6 mm × 3 mm; calyx inflated, tubular, about 5 mm long, hairy outside, glabrous inside, with 5 ciliate teeth about 1 mm long; corolla tubular, up to 8 mm long, purple, 2-lipped, upper lip 3-lobed; filaments 4, up to 8.5 mm long, purple, inserted at different heights in the corolla tube, lowest one at 3.5 mm height, hairy but glabrous towards the base; style 1 cm long, purple, ending in 2 lobes about 1.2 mm long. Fruit composed of 4 nutlets; nutlet obovoid, 0.6 mm × 0.5 mm, finely punctate. *P. plectranthoides* is a very common constituent of the ground flora of *Terminalia* woodland and open bush vegetation in India. In the Russian Federation it is cultivated as an annual and the crop is harvested once a year by cutting at ground level and drying. Subsequently the oil is obtained by distillation. Little information is available on the oil. Prospects for South-East Asia should be investigated.

Selected sources 30, 43.

Santalum spicatum (R. Br.) A. DC.

SANTALACEAE

Synonyms *Eucarya spicata* (R. Br.) Sprague & Summerh., *Santalum cygnorum* Miquel, *S. diversifolium* (Miquel) A. DC.

Vernacular names West Australian sandalwood (En).

Distribution Australia (south-western and southern).

Uses *S. spicatum* used to be extensively cut and exported as sandalwood (e.g. for wood carving, incense making and for the oil). At present it is only harvested in small quantities. West Australian sandalwood oil can be obtained by water or steam distillation of the wood. This is a pale yellow viscous liquid with a soft woody, somewhat balsamic sweetness; its top note is rather dry-bitter and slightly resinous; its main constituent is santalol. The oil is valuable in perfumery just like East Indian sandalwood oil. The oil is also used medicinally, particularly as a disinfectant for the urinary tract.

Observations Semi-root-parasitic shrub, up to 4 m tall with tough grey bark and stiff spreading branches. Leaves opposite; petiole 3–5 mm long; blade lanceolate to narrowly elliptical, 2–7 cm × 3–15 mm, grey-green. Inflorescence a many-flowered panicle; peduncle 3–5 mm long, pedicel 1 mm long; receptacle 1–1.5 mm long; tepals 4, triangular-ovate, 1.5–2 mm long, red-green, with small tufts of hairs at base inside, persistent in fruit; disk shortly lobed; style 0.5 mm long, stigma bilobed. Fruit a globose drupe, 1.5–2 cm in diameter, green or brown; mesocarp firm, adhering to endocarp. *S. spicatum* occurs in loamy soils and among rocks in woodland and tall shrubland. Possibly of interest for introduction in South-East Asia because of its valuable wood and essential oil. *S. acuminatum* (R. Br.) A. DC. (synonym: *Eucarya acuminata* (R. Br.) Sprague & Summerh.), occurring in southern Australia, might be of interest as well; besides sandalwood it also produces an edible fruit, the quandong. In Fiji, *Santalum yasi* Seem. used to be a valuable source of sandalwood, but few trees now remain.

Selected sources 1, 5, 9, 11, 43.

Sphaeranthus indicus L.

COMPOSITAE

Synonyms *Sphaeranthus hirtus* Willd., *S. mollis* Roxb. ex DC.

Vernacular names East Indian globe thistle (En). Indonesia: sembung, ki heuleut (Sundanese), brincil (Javanese).

Distribution Originating from India, now spread pantropically as a weed. In Indonesia not in Kalimantan, the Moluccas and Irian Jaya.

Uses An essential oil that resembles lavender oil can be distilled from the herb. The plant is used medicinally as a tonic and as a laxative. In India it is employed against skin diseases and urinary problems.

Observations Annual herb, up to 50 cm tall, very aromatic and often sticky (glandular on most parts). Stem with broad, coarsely toothed wings. Leaves alternate; blade oblong-obovate to subspatulate, 1–8 cm × 0.5–2.5 cm, base tapering, margins coarsely dentate, apex rounded and mucronate. Inflorescence a globose-ellipsoid head, 12–15 mm long, purple at anthesis; peduncle 2–4 cm long, with broad, deeply crenate wings; involucral bracts about 20, lanceolate, whitish, purple-tipped, in upper half densely hairy; marginal (ray) flowers about 10, female, with 2 mm long corolla tube 2–3-dentate at apex; central (disk) flowers usually 3(–5), bisexual, with tubular corolla 3 mm long 5-dentate at apex; anthers 5, white, enclosing the densely hairy style with 2-lobed stigma. Fruit an achene, 1 mm long, with patent erect hairs but without glands. *S. indicus* is common on desiccated rice fields and along ditches, often gregarious, especially on heavy soils, up to 1200 m altitude. In Java flowering is from May to February. It is a weed of minor agricultural importance, easily removed manually. It much resembles the also widespread *S. africanus* L., which however has entire wings on the stem and globose flower heads with about 10 involucral bracts.

Selected sources 2, 5, 11, 36.

Wikstroemia androsaemifolia Decaisne

THYMELAEACEAE

Synonyms *Wikstroemia candolleana* Meisner, *W. junghuhnii* Miquel, *W. spanoghii* Decaisne.

Vernacular names Indonesia: baku-bakuan (Madura).

Distribution Southern China, Thailand, Vietnam, Peninsular Malaysia, Borneo, Sulawesi, Java, Madura, Kangean Archipelago, Flores, Timor and Irian Jaya.

Uses The trunk contains patches of a kind of incense wood ('chandan'). The wood smells and is used like agar wood (*Aquilaria malaccensis* Lamk) to make incense sticks. On Madura a poultice of the leaves is used to cure skin wounds on buffaloes.

Observations Shrub, up to 2.5 m tall, stem diameter up to 4 cm, branches red-brown, axillary buds covered with golden-brown hairs. Leaves opposite, papery; petiole 2 mm long; blade elliptical to ovate-oblong-lanceolate, 2–8 cm × 1–4 cm with prominent veins below. Inflorescence a raceme, 4–10-flowered, usually 3 together at the top of a branchlet (1 terminal, 2 axillary); peduncle up to 3.5 cm long, pedicel 1 mm long; flowers yellow-green, 4-merous, tubular; floral tube (hypanthium) 9–12 mm long, ending in 4, fleshy, oblong lobes up to 3.5 mm long; sepaloid appendages absent; stamens 8 in 2 whorls of 4; pistil with ellipsoid ovary, obscure style 1 mm long and globose stigma. Fruit an ellipsoid, red drupe. *W. androsaemifolia* occurs in grassy fields, brushwoods and open forest, from sea-level up to 2400 m altitude and its vegetative parts are rather variable.

Selected sources 2, 5, 10, 15, 42.

Wikstroemia tenuiramis Miquel

THYMELAEACEAE

Synonyms *Wikstroemia acuminata* Merrill, *W. clementis* Merrill.

Vernacular names Brunei: injat. Indonesia: kayu lingau (Sumatra), menameng, tementak tindat (Bangka).

Distribution Sumatra, Bangka and Borneo.

Uses The wood is harder than that of agar wood (*Aquilaria malaccensis* Lamk) and scentless, but when burned it produces a fragrance similar to agar wood. The bark is used to make ropes.

Observations Shrub or small tree, up to 10 m tall, with smooth, glabrous, red-brown branches. Leaves opposite, glabrous, rather discolorous; petiole about 4 mm long; blade ovate-elliptical to lanceolate, 6–12 cm × 1.5–4.5 cm. Inflorescence a dense, 1–5-flowered, axillary raceme, often occurring in several consecutive leaf axils along the branches; peduncle up to 1.5 cm long; flowers subsessile, tubular, yellow-cream, 4-merous; flower tube (hypanthium) 10–13 mm long, ending in 4 ovate-oblong lobes 2–3 mm long; petaloid appendages absent; stamens 8, in 2 whorls of 4; pistil with an oblongoid ovary, a subsessile style and a capitate stigma. Fruit an ovoid drupe, 8 mm × 5 mm, yellow-green or orange. *W. tenuiramis* occurs in forest, swampy land and in hills, from sea-level up to 1600 m altitude.

Selected sources 5, 15, 42.

Xylopia pierrei Hance

ANNONACEAE

Vernacular names Indo-China: yen trang.

Distribution Indo-China.

Uses The seeds are very aromatic and are thought to contain an extractable essential oil. The bark is very astringent and is sometimes chewed with betel. The wood is yellowish, hard, flexible and light but only suitable for indoor construction and to make utensils. The tree has ornamental value as well.

Observations Deciduous tree, 20–30 m tall, trunk diameter 40–60 cm. Leaves alternate; petiole 2–4 mm long, canaliculate; blade elliptical, 6–10 cm × 2–3 cm, subleathery, subglabrous. Flowers solitary or up to 3 in leaf axils; pedicel 8–16 mm long; calyx tubular, 3-lobed, small; petals 6, linear; stamens many, arranged spirally, the outer ones staminodial and obtriangular, the inner ones fertile and linear; gynoecium consisting of 2–5 distinct pistils, each one with a 1-locular, hairy ovary usually containing 6 ovules, a glabrous style and a papillate stigma. Fruit (matured carpel) berry-like, woody, ovoid, torulate with straight ventral and convex dorsal side, glabrous, dehiscent, containing 1–3(–6) seeds. Seed ovoid with a yellow aril and ruminate endosperm. *X. pierrei* occurs in mountain forest; flowering is in February–March. It is closely related to *X. parviflora* A. Richard and possibly of interest also for other areas in South-East Asia.

Selected sources 5, 18, 28.

Xylopia vielana Pierre

ANNONACEAE

Vernacular names Indo-China: gien do, kray lan, krat. Vietnam: c[aa]y d[eef]n. Thailand: kluai noi, taa laeo, sa thaang (eastern).

Distribution Thailand and Indo-China.

Uses The seeds are very aromatic and its essential oil might be extractable. The wood is yellow, rather hard and very flexible but only suitable for indoor construction and to make utensils. The tree also has ornamental value.

Observations Evergreen tree, 20–25 m tall, with reddish bark. Leaves alternate, entire, simple; petiole 5–8 mm long, pubescent; blade ovate-oblong, 5–9 cm × 3–4 cm, herbaceous, pubescent. Flowers solitary or 2–3 together in leaf axils; pedicel 0.5 cm long; calyx tubular, 3-lobed, fleshy, hairy outside; petals 6, linear, 6–12 mm long, purplish, tomentose; stamens numerous, arranged spirally, the outer ones staminodial; gynoecium consisting of 8–10 separate carpels, each with a hairy, 6-ovuled ovary and a fleshy, oblong, hairy style. Fruit (matured carpel) berry-like, torulate, the ventral side straight, 2–3 cm long, purplish, pubescent. Seed ovoid, usually 3 per carpel, with a purplish aril and ruminate endosperm. *X. vielana* often occurs in small patches of forest in cultivated or cleared areas. It flowers in June–July and resembles *X. malayana* Hook.f. & Thomson which has a wider distribution in South-East Asia.

Selected sources 5, 18, 28.

Zanthoxylum ovalifolium Wight

RUTACEAE

Synonyms *Fagara ovalifolia* (Wight) Engler, *Zanthoxylum inerme* White & Francis, *Z. sepearium* Wight.

Distribution India, Pakistan, Burma (Myanmar), Andaman Islands, Java, Borneo, Lesser Sunda Islands, Papua New Guinea and Australia (Queensland).

Uses When distilled, the fruits yield an essential oil that contains myrcene and safrole and differs widely from the oil from other *Zanthoxylum* species.

Observations Erect shrub or small tree, up to 8 m tall, with unarmed branches. Leaves alternate, trifoliolate, 8–28 cm long, subleathery, with scattered pellucid dots; leaflets ovate to elliptical, 3–19 cm long, margin subentire to crenate. Inflorescence paniculate, axillary or terminal, 3–12 cm long; flowers 2–3 mm long, white, sepals and petals 4; male flower with 4 stamens; female flower 1-carpellate with excentric style and globose stigma. Fruit a subglobose follicle, 6–7 mm in diameter, single. *Z. ovalifolium* occurs in monsoon forest and thickets, up to 2000 m altitude. It is markedly different from other Malesian species and is apparently most closely related to 2 species from south-western China: *Z. dimorphophyllum* Hemsl. and *Z. robiginosum* (Reeder & Cheo) Huang.

Selected sources 5, 13, 14.

Sources of literature

1. Arctander, S., 1960. Perfume and flavor materials of natural origin. Published by the author, Elizabeth, New Jersey, United States. 736 pp.
2. Backer, C.A. & Bakhuizen van den Brink Jr, R.C., 1963–1968. Flora of Java. 3 volumes. Wolters-Noordhoff, Groningen, the Netherlands. Vol.1 (1963) 647 pp., Vol.2 (1965) 641 pp., Vol. 3 (1968) 761 pp.
3. Bentham, G., 1863–1878. Flora australiensis. 7 Volumes. Reeve, London, United Kingdom.
4. Brown, W.H., 1941–1943. Useful plants of the Philippines. 3 volumes. Department of Agriculture and Natural Resources. Technical Bulletin 10. Bureau of Printing, Manila, the Philippines. 1610 pp. (reprint, 1951– 1957).
5. Burkill, I.H., 1935. A dictionary of the economic products of the Malay Peninsula. 2 volumes. Crown Agents for the Colonies, London, United Kingdom. 2402 pp. (slightly revised reprint, 1966. 2 volumes. Ministry of Agriculture and Cooperatives, Kuala Lumpur, Malaysia. 2444 pp.).
6. Byrnes, N.B., 1986. A revision of Melaleuca L. (Myrtaceae) in northern and eastern Australia. 1–3. Austrobaileya 2: 65–76, 131–146, 254–273.
7. Corner, E.J.H., 1988. Wayside trees of Malaya. 3rd edition. 2 volumes. The Malayan Nature Society, Kuala Lumpur, Malaysia. 774 pp.
8. Crevost, C., Lemarié, C. & Pételot, A., 1917–1941. Catalogue des produits de l'Indochine [Catalogue of the products of Indo-China]. 6 Volumes. Gouvernement Général de l'Indochine, Hanoi, Vietnam.
9. Flora of Australia (various editors), 1980–. Vol. 1–. Australian Government Publishing Service, Canberra, Australia.
10. Flore du Cambodge, du Laos et du Vietnam [Flora of Cambodia, Laos and Vietnam] (various editors), 1960– . Vol. 1–28. Muséum National d'Histoire Naturelle, Laboratoire de Phanérogamie, Paris, France.
11. Groom, N., 1997. The new perfume handbook. 2nd edition. Blackie Academic & Professional, London, United Kingdom. 435 pp.
12. Guenther, 1949–1952. The essential oils. 6 Vols. D. van Nostrand Co., New York, United States.
13. Hartley, T.G., 1966. A revision of the Malesian species of Zanthoxylum (Rutaceae). Journal of the Arnold Arboretum 47: 171–221.
14. Hartley, T.G., 1970. Additional notes on the Malesian species of Zanthoxylum (Rutaceae). Journal of the Arnold Arboretum 51: 423–426.
15. Heyne, K., 1927. De nuttige planten van Nederlandsch Indië [The useful plants of the Dutch East Indies]. 2nd edition. 3 volumes. Departement van Landbouw, Nijverheid en Handel in Nederlandsch Indië. 1953 pp. (3rd edition, 1950. W. van Hoeve, 's-Gravenhage/ Bandung, the Netherlands/Indonesia. 1660 pp.).
16. Hou, D., 1964. Notes on some Asiatic species of Aquilaria (Thymelaeaceae). Blumea 12: 285–288.
17. Kostermans, A.J.G.H., 1970. Materials for a revision of Lauraceae 3. Reinwardtia 8(1): 21–196.
18. Lecomte, M.H. & Gagnepain, F. (Editors), 1907–1950. Flore générale de l'Indo-Chine [General flora of Indo-China]. 7 volumes and supplements. Muséum National d'Histoire Naturelle, Paris, France.
19. Li, Hui-Lin et al. (Editors), 1975–1979. Flora of Taiwan. 6 volumes. Epoch Publishing Company, Taipei, Taiwan. Second Edition (1993–.) edited and published by the Editorial Committee of the Flora of Taiwan, Taipei, Taiwan (editor-in-chief: Huang Tseng-Chieng).
20. Markgraf, F., 1984. Florae Malesianae praecursores 66. Apocynaceae 7. Hunteria, Lepiniopsis. Blumea 30: 169–172.
21. Merrill, E.D., 1923–1926. An enumeration of Philippine flowering plants. 4 volumes. Bureau of Printing, Manila, the Philippines. 463, 530, 628, 515 pp. respectively.
22. Metcalfe, C.R., 1933. The structure and botanical identity of some scented woods from the East. Kew Bulletin 1933: 3–15.
23. Muangnoicharoen, M. & Frahm, A.W., 1981. Arylbenzofurans from Dalbergia parviflora. Phytochemistry 20: 291–293.
24. Muangnoicharoen, M. & Frahm, A.W., 1982. Neoflavonoids of Dalbergia parviflora. Phytochemistry 21: 767–772.
25. Nevling, L.I., 1961. A revision of the Asiatic genus Enkleia (Thymelaeaceae). Journal of the Arnold Arboretum 42: 372–396.
26. Nguyen Van Duong, 1993. Medicinal plants of Vietnam, Cambodia and Laos. Mekong Printing, Hanoi, Vietnam. 528 pp.
27. Pételot, A., 1952–1954. Les plantes médicinales du Cambodge, du Laos et du Vietnam [Medicinal plants of Cambodia, Laos and Vietnam]. 4 volumes. Archives des Recherches

Agronomiques et Pastorales au Vietnam No 14, 18, 22, 23. Vietnam.
28. Pierre, J.B.L., 1880–1907. Flore forestière de la Cochinchine [Forest flora of Cochinchina]. 4 volumes in 26 parts. Octave Doin, Paris, France.
29. Prain, D., 1905. Mansonieae, a new tribe of the natural order Sterculiaceae. The Journal of the Linnean Society, Botany 37: 250–263.
30. Raza Bhatti, G. & Ingrouille, M., 1997. Systematics of Pogostemon (Labiatae). Bulletin of the Natural History Museum London (Botany) 27: 77–147.
31. Redgrove, H.S., 1933. Spices and condiments. Isaac Pitman & Sons, London, United Kingdom. 361 pp.
32. Reese, N., 1997. An overview of the Australian Backhousia citriodora industry in December 1996. Internet: Plantwest.
33. Ridley, H.N., 1922–1925. The flora of the Malay Peninsula. 5 volumes. Government of the Straits Settlements and Federated Malay States. L. Reeve & Co., London, United Kingdom.
34. Sinclair, J., 1955. A revision of the Malayan Annonaceae. The Gardens' Bulletin, Singapore 14: 149–516.
35. Smith, J.J., 1905. Die Orchideen von Java [The orchids of Java]. Flora von Buitenzorg, vol. 6. E.J. Brill, Leiden, the Netherlands. 672 pp.
36. Soerjani, M., Kostermans, A.J.G.H. & Tjitrosoepomo, G., 1987. Weeds of rice in Indonesia. Balai Pustaka, Jakarta, Indonesia. 716 pp.
37. Spoon, W., 1931. Enkele waarnemingen over het Indische reukhout 'kayu laka' [Some observations concerning the Indonesian scented wood 'kayu laka']. Berichten van de afdeeling Handelsmuseum van de Koninklijke Vereeniging Koloniaal Instituut No 60. Amsterdam, The Netherlands. 11 pp.
38. Stauffer, H.U., 1959. Revisio Anthobolearum. Santalales-Studien 4. Mitteilungen aus dem Botanischen Museum der Universität Zürich 213: 1–256.
39. Sunarno, B. & Ohashi, H., 1997. Dalbergia (Leguminosae) of Borneo. Journal of Japanese Botany 72: 198–220.
40. Treseder, N.G., 1978. Magnolias. Faber & Faber, London, United Kingdom. 243 pp.
41. van Beusekom, C.F., 1971. Revision of Meliosma (Sabiaceae), section Lorenzanea excepted, living and fossil, geography and phylogeny. Blumea 19: 355–529.
42. van Steenis, C.G.G.J. et al. (Editors), 1950– . Flora Malesiana. Series 1. Vol. 1, 4– . Kluwer Academic Publishers, Dordrecht, the Netherlands.
43. Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. 600 pp.
44. Whitmore, T.C. & Ng, F.S.P. (Editors), 1972–1989. Tree flora of Malaya. A manual for foresters. 4 Volumes. 2nd Edition. Malayan Forest Records No 26. Longman Malaysia Sendirian Berhad, Kuala Lumpur, Malaysia.
45. Zhu Liangfeng, Li Yonghua, Li Baoling, Lu Biyao & Xia Nianhe, 1993. Aromatic plants and essential constituents. Hai Feng Publishing Company, Hong Kong. p. 262.
46. Zohary, M., 1983. The genus Nigella (Ranunculaceae): a taxonomic revision. Plant Systematics and Evolution 142: 71–107.

P.C.M. Jansen

4 Essential-oil plants with other primary use

List of species in other commodity groups (parenthesis), which are used also for their essential oil. Synonyms in the indented lines.

Achillea millefolium L. (medicinal and poisonous plants)
Acorus calamus L. (medicinal and poisonous plants)
Acronychia odorata Baillon (medicinal and poisonous plants)
Acronychia pedunculata (L.) Miq. (timber trees)
    Acronychia arborea Blume
    Acronychia laurifolia Blume
    Acronychia resinosa J.R. Forster ex Crevost & Lemarié
Aegle marmelos (L.) Correa (edible fruits and nuts)
Ageratum conyzoides L. (medicinal and poisonous plants)
Aglaia odorata Loureiro (timber trees)
    Aglaia chaudocensis Pierre
    Aglaia duperreana Pierre
    Aglaia oblanceolata Craib
Aglaia perviridis Hiern (timber trees)
    Aglaia canarensis Gamble
    Aglaia kingiana Ridley
    Aglaia maiae Bourd.
Albizia odoratissima (L.f.) Benth. (auxiliary plants)
    Acacia odoratissima (L.f.) Willd.
    Mimosa odoratissima L.f.
Allium ampeloprasum L. cv. group Leek (vegetables)
    Allium ampeloprasum L. var. *porrum* (L.) J. Gay
    Allium porrum L.
Allium cepa L. (vegetables)
Allium chinense G. Don (vegetables)
    Allium bakeri Regel
Allium fistulosum L. (vegetables)
    Allium bakeri Hoop., non Regel
    Allium bouddhae O. Debeaux
Allium sativum L. (vegetables)
Allium schoenoprasum L. (vegetables)
Allium tuberosum Rottler ex Sprengel (vegetables)
    Allium odorum auct., non L.
    Allium senescens Miq.
    Allium uliginosum G. Don
Alpinia conchigera Griffith (medicinal and poisonous plants)
Alpinia galanga (L.) Willd. (spices)
    Amomum galanga (L.) Lour.
    Languas galanga (L.) Stuntz
    Languas vulgare Koenig

Maranta galanga L.
Alpinia globosa (Loureiro) Horan. (spices)
Languas globosa Loureiro
Alpinia officinarum Hance (spices)
Alyxia laurina Gaudich. (medicinal and poisonous plants)
Alyxia reinwardtii Blume (medicinal and poisonous plants)
Alyxia forbesii King & Gamble
Alyxia lucida Wallich
Alyxia pumila Hook.f.
Alyxia stellata (Forster) Roemer & Schultes (medicinal and poisonous plants)
Amomum acre Valeton (spices)
Amomum aculeatum Roxb. (medicinal and poisonous plants)
Amomum ciliatum Blume
Amomum flavum Ridley
Amomum aromaticum Roxb. (spices)
Geocallis fasciculata Horan.
Amomum blumeanum Valeton (edible fruits and nuts)
Amomum compactum Soland. ex Maton (spices)
Amomum cardamomum auct., non L.
Amomum kepulaga Sprague & Burkill
Amomum dealbatum Roxb. (edible fruits and nuts)
Amomum maximum Roxb. sensu Backer & Ochse
Amomum gracile Blume (medicinal and poisonous plants)
Amomum hochreutineri Valeton (medicinal and poisonous plants)
Amomum krervanh Pierre ex Gagnepain (medicinal and poisonous plants)
Amomum lappaceum Ridley (edible fruits and nuts)
Amomum ligulatum R.M. Smith (medicinal and poisonous plants)
Amomum longiligulare T.L. Wu (medicinal and poisonous plants)
Amomum ochreum Ridley (spices)
Amomum pseudo-foetens Valeton (edible fruits and nuts)
Amomum repens Sonn. (medicinal and poisonous plants)
Amomum squarrosum Ridley (medicinal and poisonous plants)
Amomum stenocarpum Valeton (medicinal and poisonous plants)
Amomum subulatum Roxb. (spices)
Cardamomum subulatum (Roxb.) Kuntze
Amomum testaceum Ridley (spices)
Amomum uliginosum J.G. Koenig (medicinal and poisonous plants)
Amomum villosum Lour. (medicinal and poisonous plants)
Amomum echinosphaera K. Schumann ex Gagnep.
Amomum xanthioides Wallich ex Baker (medicinal and poisonous plants)
Amomum villosum Lour. var. *xanthioides* (Wallich ex Baker) T.L. Wu & Senjen Chen
Amomum xanthophlebium Baker (spices)
Amomum stenoglossum Baker
Anaxagorea javanica Blume var. *tripetala* Corner (medicinal and poisonous plants)
Anaxagorea scortechinii King
Anethum graveolens L. (spices)
Anethum sowa Roxb. ex Fleming

Peucedanum graveolens (L.) Hiern
Peucedanum sowa (Roxb. ex Fleming) Kurz
Angiopteris evecta Hoffm. (cryptogams -- ferns)
Annona muricata L. (edible fruits and nuts)
Annona squamosa L. (edible fruits and nuts)
Anthocephalus chinensis (Lamk) A. Rich. ex Walp. (timber trees)
Anthocephalus cadamba (Roxb.) Miq.
Anthocephalus indicus A. Rich.
Neolamarckia cadamba (Roxb.) Bosser
Anthriscus cerefolium (L.) G.F. Hoffmann (spices)
Anthriscus longirostris Bertol.
Chaerefolium cerefolium (L.) Schinz & Thell.
Scandix cerefolium L.
Apium graveolens L. (vegetables)
Apium dulce Miller
Apium lusitanicum Miller
Apium rapaceum Miller
Archidendron fagifolium (Blume ex Miq.) Nielsen (spices)
Pithecellobium angulatum auct., non Benth.
Pithecellobium fagifolium Blume ex Miq.
Pithecellobium mindanaense Merrill
Archidendron jiringa (Jack) Nielsen (vegetables)
Pithecellobium jiringa (Jack) Prain
Pithecellobium lobatum Benth.
Zygia jiringa (Jack) Kosterm.
Arctium lappa L. (vegetables)
Lappa major Gaertner
Ardisia squamulosa Presl (spices)
Ardisia boissieri A. DC.
Ardisia drupacea (Blanco) Merrill
Ardisia humilis auct., non Vahl
Armoracia rusticana P.G. Gaertner, B. Meyer & J. Scherbius (spices)
Armoracia lapathifolia Gilibert
Cochlearia armoracea L.
Nasturtium armoracia (L.) Fries
Artemisia annua L. (medicinal and poisonous plants)
Artemisia apiacea Hance (medicinal and poisonous plants)
Artemisia capillaris Thunb. (medicinal and poisonous plants)
Artemisia dracunculus L. (spices)
Artemisia inodora Willd.
Artemisia redowskyi Ledeb.
Oligosporus condimentarius Cass.
Artemisia vulgaris L. (medicinal and poisonous plants)
Ayapana triplinervis (Vahl ex Blume) R. King & H. Robinson (auxiliary plants)
Eupatoria ayapana Vent. ex Millin.
Eupatorium triplinerve Vahl ex Blume
Azadirachta indica A.H.L. Juss. (auxiliary plants)
Antelaea azadirachta Adelb.
Melia azadirachta L.

Melia indica (A.H.L. Juss.) Brandis
Baeckea frutescens L. (medicinal and poisonous plants)
Barringtonia scortechinii King (spices)
Blumea arfakiana Martelli (medicinal and poisonous plants)
Blumea balfourii Hemsl.
Blumea arnakidophora Mattf. (medicinal and poisonous plants)
Blumea lanceolaria (Roxb.) Druce (medicinal and poisonous plants)
Blumea conspicua Hayata
Blumea laxiflora Elmer
Blumea myriocephala DC.
Blumea riparia (Blume) DC. (medicinal and poisonous plants)
Boesenbergia rotunda (L.) Mansfeld (spices)
Boesenbergia pandurata (Roxb.) Schlechter
Curcuma rotunda L.
Kaempferia pandurata Roxb.
Gastrochilus pandurata (Roxb.) Ridley
Bothriochloa odorata (Lisboa) Camus (medicinal and poisonous plants)
Amphilophis odorata Camus
Brassica juncea (L.) Czernjaew (vegetables)
Brassica integrifolia (West) Rupr.
Sinapis juncea L.
Sinapis timoriana DC.
Brassica nigra (L.) Koch (spices)
Brassica sinapoides Roth
Sinapis nigra L.
Sisymbrium nigrum (L.) Prantl
Bruguiera sexangula (Loureiro) Poiret (auxiliary plants)
Bruguiera eriopetala Wight & Arnott ex Arnott
Rhizophora sexangula Loureiro
Buddleja asiatica Loureiro (medicinal and poisonous plants)
Caesalpinia sappan L. (dye and tannin-producing plants)
Biancaea sappan (L.) Todaro
Calophyllum inophyllum L. (timber trees)
Camellia sinensis (L.) Kuntze (stimulants)
Thea sinensis L.
Canarium asperum Benth. (plants producing exudates)
Canarium legitimum Miq.
Canarium villosum Benth. & Hook. ex Fernandez-Villar
Canarium zollingeri Engl.
Canarium indicum L. (edible fruits and nuts)
Canarium amboinense Hochr.
Canarium commune L.
Canarium moluccanum Blume
Canarium luzonicum (Blume) A. Gray (plants producing exudates)
Pimela luzonicum Blume
Cannabis sativa L. (medicinal and poisonous plants)
Capparis spinosa L. (spices)
Capsicum annuum L. (vegetables, spices)
Capsicum frutescens L. (vegetables, spices)

Carum carvi L. (spices)
Carum velenowskyi Rohlena
Cedrela odorata L. (timber trees)
Cedrela glaziovii C. DC.
Cedrela guianensis Adr. Juss.
Cedrela mexicana M.J. Roemer
Celtis philippensis Blanco var. *wightii* (Planchon) Soepadmo (medicinal and poisonous plants)
Celtis wightii Planchon
Celtis timorensis Span. (medicinal and poisonous plants)
Celtis cinnamomea Lindley ex Planchon
Centella asiatica (L.) Urb. (medicinal and poisonous plants)
Hydrocotyle asiatica L.
Ceratonia siliqua L. (forages)
Chamaecyparis obtusa Siebold & Zuccarini (ornamental plants)
Chenopodium album L. subsp. *amaranticolor* Coste & Reyn. (cereals)
Chenopodium ambrosioides L. (medicinal and poisonous plants)
Chromolaena odorata (L.) R.M. King & H. Robinson (auxiliary plants)
Eupatorium conyzoides Vahl
Eupatorium odoratum L.
Osmia odorata (L.) Schultz-Bip.
Cinnamomum bejolghota (Buch.-Ham.) Sweet (spices)
Cinnamomum obtusifolium (Roxb.) C. Nees
Cinnamomum burmanni (C. Nees & T. Nees) C. Nees ex Blume (spices)
Cinnamomum mindanaense Elmer
Laurus burmanni C. Nees & T. Nees
Cinnamomum cassia J.S. Presl (spices)
Cinnamomum aromaticum C. Nees
Laurus cassia L.
Cinnamomum culitlawan (L.) Kosterm. (spices)
Cinnamomum culilaban (L.) J.S. Presl
Cinnamomum culilawan (Roxb.) J.S. Presl
Laurus culitlawan L.
Cinnamomum deschampsii Gamble (spices)
Cinnamomum eugenoliferum Kosterm. (timber trees)
Cinnamomum gigaphyllum Kosterm.
Cinnamomum hentyi Kosterm.
Cinnamomum grandiflorum Kosterm. (timber trees)
Cinnamomum massoia Schewe
Cinnamomum impressinervium Meissner (spices)
Cinnamomum iners Reinw. ex Blume (timber trees)
Cinnamomum eucalyptoides T. Nees
Cinnamomum nitidum Blume
Cinnamomum paraneuron Miq.
Cinnamomum javanicum Blume (timber trees)
Cinnamomum neglectum Blume
Cinnamomum sulphuratum C. Nees
Cinnamomum loureirii C. Nees (spices)
Cinnamomum obtusifolium (Roxb.) C. Nees var. *loureiri* C. Nees ex Watt

Cinnamomum mercadoi S. Vidal (timber trees)
Cinnamomum mollissimum Hook.f. (timber trees)
Cinnamomum pendulum Cammerl. (timber trees)
  Cinnamomum endlicheriaecarpum Kosterm.
Cinnamomum porrectum (Roxb.) Kosterm. (timber trees)
  Cinnamomum glanduliferum C. Nees
  Cinnamomum parthenoxylon (Jack) C. Nees
  Cinnamomum sumatranum (Miq.) Meissner
Cinnamomum puberulum Ridley (spices)
Cinnamomum rhynchophyllum Miq. (spices)
  Cinnamomum lampongum Miq.
Cinnamomum scortechinii Gamble (timber trees)
  Cinnamomum velutinum Ridley
Cinnamomum sintoc Blume (timber trees)
  Cinnamomum calophyllum Reinw. ex C. Nees
  Cinnamomum camphoratum Blume
  Cinnamomum cinereum Gamble
Cinnamomum subavenium Miq. (timber trees)
  Cinnamomum borneense Miq.
  Cinnamomum cyrtopodum Miq.
  Cinnamomum ridleyi Gamble
Cinnamomum tamala (Buch.-Ham.) T. Nees & Eberm. (spices)
Cinnamomum verum J.S. Presl (spices)
  Cinnamomum zeylanicum Blume
  Laurus cinnamomum L.
×*Citrofortunella microcarpa* (Bunge) Wijnands (edible fruits and nuts)
  Citrus microcarpa Bunge
  Citrus mitis Blanco
Citrus aurantifolia (Christm. & Panzer) Swingle (edible fruits and nuts)
  Citrus javanica Blume
  Citrus notissima Blanco
  Limonia aurantifolia Christm. & Panzer
Citrus aurantium L. (edible fruits and nuts)
Citrus hystrix DC. (edible fruits and nuts)
Citrus limon (L.) Burm.f. (edible fruits and nuts)
Citrus maxima (Burm.) Merrill (edible fruits and nuts)
  Citrus aurantium L. var. *grandis* L.
  Citrus decumana L.
  Citrus grandis (L.) Osbeck
Citrus medica L. (edible fruits and nuts)
  Citrus aurantium L. var. *medica* Wight & Arnott
  Citrus crassa Hasskarl
Citrus ×*paradisi* Macf. (edible fruits and nuts)
  Citrus decumana L. var. *racemosa* Roem.
  Citrus grandis (L.) Osbeck var. *racemosa* (Roem.) B.C. Stone
Citrus reticulata Blanco (edible fruits and nuts)
  Citrus chrysocarpa Lushington
  Citrus deliciosa Tenore
  Citrus nobilis Andrews et auct., non Loureiro

Citrus sinensis (L.) Osbeck (edible fruits and nuts)
  Citrus aurantium L. var. *sinensis* L.
Claoxylon indicum (Reinw. ex Blume) Hassk. (spices)
  Claoxylon polot Merrill
  Erytrochilus indicus Reinw. ex Blume
Cleome gynandra L. (vegetables)
  Cleome pentaphylla L.
  Gynandropsis gynandra (L.) Briq.
  Gynandropsis pentaphylla (L.) DC.
Cocos nucifera L. (vegetable oils and fats)
Colocasia gigantea (Blume ex Hassk.) J.D. Hooker (spices)
  Caladium giganteum Blume ex Hassk.
  Colocasia indica Hassk., non Kunth
  Leucocasia gigantea (Blume ex Hassk.) Schott
Cordia fragrantissima Kurz (timber trees)
Coriandrum sativum L. (spices)
  Coriandrum diversifolium Gilib.
  Coriandrum globosum Salisb.
  Coriandrum majus Gouan
  Coriandrum testiculatum Lour.
Cosmos caudatus Kunth (vegetables)
Crocus sativus L. (dye and tannin-producing plants)
Cryptocarya massoy (Oken) Kosterm. (medicinal and poisonous plants)
  Massoia aromatica Beccari
Cuminum cyminum L. (spices)
  Cuminum odorum Salisb.
  Ligusticum cuminum (L.) Crantz
Curcuma aeruginosa Roxb. (medicinal and poisonous plants)
Curcuma aromatica Salisb. (plants yielding non-seed carbohydrates)
Curcuma aurantiaca v. Zijp (medicinal and poisonous plants)
Curcuma euchroma Valeton (medicinal and poisonous plants)
Curcuma heyneana Valeton & v. Zijp (medicinal and poisonous plants)
Curcuma longa L. (spices)
  Amomum curcuma Jacq.
  Curcuma domestica Valeton
Curcuma mangga Valeton & v. Zijp (medicinal and poisonous plants)
Curcuma montana Roxb. (plants yielding non-seed carbohydrates)
Curcuma petiolata Roxb. (medicinal and poisonous plants)
Curcuma purpurascens Blume (medicinal and poisonous plants)
Curcuma soloensis Valeton (medicinal and poisonous plants)
Curcuma xanthorrhiza Roxb. (plants yielding non-seed carbohydrates)
  Curcuma zedoaria Ridley
Curcuma zedoaria (Christmann) Roscoe (plants yielding non-seed carbohydrates)
  Amomum latifolium Lamk
  Amomum zedoaria Christmann
  Curcuma zerumbet Roxb.
Cyperus brevifolius (Rottb.) Hask. (medicinal and poisonous plants)
  Kyllinga brevifolia Rottb.

Cyperus cyperoides (L.) O. Kuntze (medicinal and poisonous plants)
  Mariscus sieberianus Nees ex Clarke
Cyperus diffusus Vahl (medicinal and poisonous plants)
Cyperus halpan L. (medicinal and poisonous plants)
Cyperus iria L. (medicinal and poisonous plants)
Cyperus kyllingia Endl. (medicinal and poisonous plants)
  Kyllinga monocephala Rottb.
Cyperus malaccensis Lamk (medicinal and poisonous plants)
Cyperus pedunculatus (R. Br.) Kern (auxiliary plants)
  Mariscus pedunculatus (R. Br.) Koyama
  Remirea maritima Aublet
  Remirea pedunculata R. Br.
Cyperus rotundus L. (plants yielding non-seed carbohydrates)
Cyperus stoloniferus Retz. (medicinal and poisonous plants)
Cyrtandra pendula Blume (spices)
Dacrydium beccarii Parl. (timber trees)
Dacrydium elatum (Roxb.) Wallich ex Hook. (timber trees)
  Dacrydium beccarii Parl. var. *subelatum* Corner
  Dacrydium junghuhnii Miq.
  Dacrydium pierrii Hickel
Daucus carota L. (vegetables)
Dendrobium anosmum Lindley (ornamental plants)
  Dendrobium superbum Rchb.f.
Desmos chinensis Loureiro (medicinal and poisonous plants)
Digitaria longiflora (Retzius) Pers. (forages)
Dioscorea hispida Dennstedt (plants yielding non-seed carbohydrates)
Dipterocarpus grandiflorus (Blanco) Blanco (timber trees)
Dipterocarpus indicus Beddome (plants producing exudates)
Dipteryx odorata (Aubl.) Willd. (spices)
  Baryosma tonga Gaertner
  Coumarouna odorata Aublet
  Dipteryx tetraphylla Spruce ex Benth.
Dodonaea viscosa Jacq. (medicinal and poisonous plants)
Dryobalanops sumatrensis (J.F. Gmelin) Kosterm. (timber trees)
  Dryobalanops aromatica Gaertner f.
  Dryobalanops camphora Colebr.
Dysoxylum alliaceum (Blume) Blume (timber trees)
  Dysoxylum costulatum (Miq.) Miq.
  Dysoxylum euphlebium Merrill
  Dysoxylum thyrsoideum Hiern
Elettaria cardamomum (L.) Maton (spices)
Embelia philippinensis A. DC. (spices)
  Rhamnus lando Llanos
  Ribesoides philippense O. Kuntze
  Samara philippinensis Vidal
Eriobotrya japonica (Thunb.) Lindley (edible fruits and nuts)
Eryngium foetidum L. (spices)
  Eryngium antihystericum Rottler
Etlingera elatior (Jack) R.M. Smith (spices)

Nicolaia speciosa Horan.
Phaeomeria speciosa Koord.
Etlingera foetens (Blume) R.M. Smith (medicinal and poisonous plants)
Achasma foetens Valeton
Hornstedtia foetens K. Schumann
Etlingera gracilis (Valeton) R.M. Smith (edible fruits and nuts)
Nicolaia gracilis Valeton
Etlingera hemisphaerica (Blume) R.M. Smith (spices)
Nicolaia atropurpurea (Blume) R.M. Smith
Phaeomeria atropurpurea K. Schumann
Etlingera littoralis (Koenig) Giseke (edible fruits and nuts)
Achasma megalocheilos Griffith
Etlingera punicea (Roxb.) R.M. Smith (edible fruits and nuts)
Achasma coccineum (Blume) Valeton
Amomum coccineum (Blume) K. Schumann
Hornstedtia macrocheilus Ridley
Etlingera rosea Burtt & Smith (spices)
Amomum roseum K. Schum., non Roxb.
Donacodes roseus Teijsm. & Binnend.
Geanthus roseus Loesen., non Valeton
Etlingera solaris (Blume) R.M. Smith (spices)
Elettaria solaris Blume
Nicolaia solaris Horan.
Phaeomeria solaris K. Schumann
Etlingera walang (Blume) R.M. Smith (spices)
Achasma walang Valeton
Eucalyptus alba Reinw. ex Blume (timber trees)
Eugenia dombeyi (Sprengel) Skeels (edible fruits and nuts)
Eugenia brasiliensis Lamk, non Aublet
Myrtus dombeyi Sprengel
Eugenia uniflora L. (edible fruits and nuts)
Eugenia michelii Lamk
Euodia amboinensis Merrill (medicinal and poisonous plants)
Euodia hortensis Forster (medicinal and poisonous plants)
Eupatorium chinense L. (spices)
Buphthalmum oleraceum Lour.
Eupatorium japonicum Thunberg ex Murray
Euphorbia neriifolia L. (medicinal and poisonous plants)
Ferula assa-foetida L. (spices)
Ferula rubicaulis Boissier
Ferula pseudalliacea Rech.f.
Narthex polakii Stapf & Wettst.
Ficus virgata Reinw. ex Blume (spices)
Ficus decaisneana Miq.
Ficus philippinensis Miq.
Ficus trymatocarpa Miq. (often erroneously *trematocarpa*)
Foeniculum vulgare Miller (spices)
Anethum foeniculum L.
Gardenia jasminoides Ellis (dye and tannin-producing plants)

Gardenia augusta (L.) Merrill
Gardenia florida L.
Gardenia grandiflora Lour.
Globba marantina L. (spices)
Goniothalamus macrophyllus Hook.f. & Thomson (medicinal and poisonous plants)
Goniothalamus sumatranus Miq. (fibre plants)
Guettarda speciosa L. (timber trees)
Haematoxylum campechianum L. (dye and tannin-producing plants)
Hedychium coronarium Koenig (medicinal and poisonous plants)
Hedychium flavum Roxb.
Horsfieldia irya (Gaertner) Warb. (timber trees)
Horsfieldia acuminata Merrill
Horsfieldia congestiflora A.C. Smith
Horsfieldia lehmanniana Warb.
Horsfieldia subglobosa (Miq.) Warb.
Myristica irya Gaertner
Horsfieldia iryaghedi (Gaertner) Warb. (vegetable oils and fats)
Hydrocotyle sibthorpioides Lamk (vegetables)
Hydrocotyle benguetensis Elmer
Hydrocotyle delicata Elmer
Hydrocotyle rotundifolia DC.
Hypericum japonicum Thunb. ex Murray (medicinal and poisonous plants)
Hypericum monogynum L. (medicinal and poisonous plants)
Hypericum papuanum Ridley (medicinal and poisonous plants)
Hypericum uralum Buch.-Ham. ex D. Don (medicinal and poisonous plants)
Hyptis suaveolens (L.) Poit. (spices)
Ballota suaveolens L.
Marrubium indicum Thunb., non Burm.f.
Schaueria graveolens Hassk.
Ilex paraguayensis St. Hilaire (stimulants)
Illicium anisatum L. (medicinal and poisonous plants)
Illicium religiosum Siebold & Zuccarini
Illicium verum Hook.f. (spices)
Jasminum officinale L. (ornamental plants)
Jasminum sambac (L.) Aiton (medicinal and poisonous plants)
Juniperus chinensis L. (ornamental plants)
Juniperus communis L. (medicinal and poisonous plants)
Juniperus excelsa M. Bieb. (ornamental plants)
Kaempferia galanga L. (medicinal and poisonous plants)
Kaempferia rotunda L. (medicinal and poisonous plants)
Kleinhovia hospita L. (auxiliary plants)
Lantana camara L. (medicinal and poisonous plants)
Lantana aculeata L.
Lantana trifolia L. (medicinal and poisonous plants)
Laurus nobilis L. (spices)
Lawsonia inermis L. (dye and tannin-producing plants)
Lawsonia alba Lamk
Lawsonia spinosa L.

Leptospermum javanicum Blume (timber trees)
  Leptospermum alpestre Blume
  Leptospermum flavescens Smith var. *javanicum* (Blume) King
  Leptospermum floribundum Jungh.
Limnophila rugosa (Roth) Merrill (spices)
  Herpestis rugosa Roth
  Limnophila roxburghii auct., non G. Don
Lindera lucida (Blume) Boerl. (timber trees)
  Lindera malaccensis Hook.f.
  Lindera selangorensis Ridley
  Litsea lucida Blume
Lippia graveolens Kunth (spices)
Litsea elliptica Blume (timber trees)
  Litsea clarissae (Teschner) Kosterm.
  Litsea nigricans (Meissn.) Boerl.
  Litsea odorifera Valeton
  Litsea petiolata Hook.f.
Litsea glutinosa (Lour.) C.B. Robinson (timber trees)
  Litsea chinensis Lamk
  Litsea geminata Blume
  Litsea glabraria A.L. Juss.
  Litsea tetranthera (Willd.) Pers.
Lysimachia foenum-graecum Hance (medicinal and poisonous plants)
Magnolia candollii (Blume) H. Keng (timber trees)
  Talauma angatensis (Blanco) S. Vidal
  Talauma beccarii Ridley
  Talauma candollii Blume
  Talauma singapurensis Ridley
Magnolia candollii (Blume) H. Keng var. *candollii* (ornamental plants)
  Talauma candollii Blume
  Talauma celebica Koord.
  Talauma rumphii Blume
Magnolia macklottii (Korth.) Dandy (timber trees)
  Magnolia eaquinoctialis Dandy
  Magnolia javanica Koord. & Valeton
  Michelia beccariana Agostini
Mallotus philippensis (Lamk) Merrill (dye and tannin-producing plants)
  Croton philippense Lamk
Matricaria recutita L. (stimulants)
  Matricaria chamomilla L.
Medicago sativa L. (forages)
Melanolepis multiglandulosa (Reinw. ex Blume) H.G. Reichenbach & Zollinger (medicinal and poisonous plants)
  Mallotus moluccanus Muell. Arg.
  Melanolepis moluccana Pax & K. Hoffm.
Mentha arvensis L. (medicinal and poisonous plants)
Mentha longifolia (L.) L. (medicinal and poisonous plants)
Mentha ×*piperita* L. (medicinal and poisonous plants)
Mentha pulegium L. (medicinal and poisonous plants)

Mentha spicata L. (medicinal and poisonous plants)
  Mentha viridis (L.) L.
Mesua ferrea L. (timber trees)
Mimusops elengi L. (timber trees)
  Mimusops elengi L. var. *parvifolia* (R. Br.) H.J. Lam
  Mimusops parvifolia R. Br.
Monodora myristica (Gaertner) Dunal (spices)
  Anona myristica Gaertner
  Monodora grandiflora Bentham
  Xylopia undulata Pal. de Beauv.
Morinda citrifolia L. (dye and tannin-producing plants)
  Morinda bracteata Roxb.
  Morinda litoralis Blanco
Murraya koenigii (L.) Sprengel (timber trees)
  Bergera koenigii L.
  Chalcas koenigii (L.) Kurz
  Murraya foetidissima Teijsm. & Binnend.
Murraya paniculata (L.) Jack (timber trees)
  Chalcas paniculata L.
  Murraya odorata Blanco
  Murraya sumatrana Roxb.
Myristica argentea Warb. (spices)
  Myristica finschii Warb.
Myristica castaneifolia A. Gray (spices)
  Myristica macrantha A.C. Smith
  Myristica macrophylla A. Gray
Myristica cinnamomea King (spices)
Myristica crassa King (timber trees)
  Myristica suavis King
Myristica dactyloides Gaertner (spices)
  Myristica diospyrifolia A. DC.
  Myristica laurifolia Hook.f. & Thomson
Myristica elliptica Wallich ex Hook.f. & Thomson (timber trees)
  Myristica calocarpa Miq.
  Myristica sycocarpa Miq.
Myristica fatua Houtt. (timber trees)
  Myristica plumeriifolia Elmer
  Myristica spadicea Blume
  Myristica tomentosa Thunb.
Myristica fragrans Houtt. (spices)
  Myristica aromatica Lamk
  Myristica moschata Thunb.
  Myristica officinalis L.f.
Myristica malabarica Lamk (spices)
Myristica muelleri Warb. (spices)
Myristica succedanea Reinw. ex Blume (spices)
  Myristica radja Miq.
  Myristica schefferi Warb.
  Myristica speciosa Warb.

Myristica womersleyi J. Sinclair (spices)
Myroxylon balsamum (L.) Harms (plants producing exudates)
Nerium oleander L. (ornamental plants)
  Nerium indicum Miller
  Nerium odorum Sol.
Nigella sativa L. (spices)
Nicotiana tabacum L. (stimulants)
Nyctanthes arbor-tristis L. (dye and tannin-producing plants)
  Nyctanthes dentata Blume
Ocimum americanum L. (vegetables)
  Ocimum africanum Lour.
  Ocimum brachiatum Blume
  Ocimum canum Sims
Ocimum basilicum L. (spices)
Ocimum tenuiflorum L. (medicinal and poisonous plants)
  Ocimum sanctum L.
Oenanthe aquatica (L.) Poiret (medicinal and poisonous plants)
  Oenanthe phellandrium Lamk
Oenanthe javanica (Blume) DC. (vegetables)
  Oenanthe stolonifera DC.
  Sium javanicum Blume
Origanum dictamnus L. (spices)
Origanum majorana L. (spices)
  Majorana hortensis Moench
  Origanum dubium Boissier
  Origanum majoranoides Willd.
Origanum onites L. (spices)
Origanum syriacum L. (spices)
Origanum vulgare L. (spices)
  Origanum gracile Koch
  Origanum hirtum Link
  Origanum viride (Boissier) Halacsy
Osbornia octodonta F. v. Mueller (timber trees)
Osmanthus fragrans Loureiro (spices)
Paederia foetida L. (medicinal and poisonous plants)
Pandanus amaryllifolius Roxb. (spices)
  Pandanus latifolius Hassk.
  Pandanus odorus Ridley
Pandanus beccarii Solms (edible fruits and nuts)
Pandanus brosimos Merr. & Perry (edible fruits and nuts)
Pandanus cominsii Hemsley (edible fruits and nuts)
Pandanus conoideus Lamk (edible fruits and nuts)
  Pandanus butyrophorus Kurz
Pandanus dubius Sprengel (fibre plants)
Pandanus englerianus Martelli (edible fruits and nuts)
Pandanus fischerianus Martelli (edible fruits and nuts)
Pandanus helicopus Kurz (fibre plants)
  Pandanus johorensis Martelli
Pandanus hollrungii Warb. (edible fruits and nuts)

Pandanus houlettei Ridley (edible fruits and nuts)
Pandanus julianettii Martelli (edible fruits and nuts)
Pandanus krauelianus K. Schumann (spices)
Pandanus leram Jones ex Fontana (edible fruits and nuts)
  Pandanus fosbergii St John
  Pandanus mellori Roxb.
  Roussinia indica Gaudich.
Pandanus magnificus Martelli (edible fruits and nuts)
Pandanus odoratissimus L.f. (fibre plants)
Pandanus tectorius Parkinson (fibre plants)
  Pandanus bagea Miq.
  Pandanus robinsonii Merrill
Papaver somniferum L. (medicinal and poisonous plants)
Peltophorum pterocarpum (DC.) Backer ex Heyne (dye and tannin-producing plants)
  Peltophorum ferrugineum (Decne.) Benth.
  Peltophorum inerme (Roxb.) Naves & Villar
Perilla frutescens (L.) Britton (vegetable oils and fats)
  Prilla crispa (Thunb.) Tanaka
  Perilla nankinensis (Lour.) J. Decaisne
  Perilla ocymoides L.
Peristrophe paniculata (Forsskall) Brummitt (auxiliary plants)
  Justicia bicalyculata (Retz.) Vahl
  Peristrophe bicalyculata (Retz.) Nees
Persea americana Miller (edible fruits and nuts)
  Persea drymifolia Schlecht. & Cham.
  Persea gratissima Gaertn.f.
  Persea nubigena L.O. Williams
Persicaria hydropiper (L.) Spach. (spices)
  Polygonum flaccidum Meisner
  Polygonum gracile R. Br.
  Polygonum hydropiper L.
Persicaria pubescens (Blume) Hara (spices)
  Polygonum leptostachyum de Bruyn
  Polygonum pubescens Blume
  Polygonum roettleri Merrill, non Roth
Petroselinum crispum (Miller) A.W. Hill (spices)
  Petroselinum hortense Hoffm.
  Petroselinum sativum Hoffm.
  Petroselinum vulgare Hill
Phaleria capitata Jack (fibre plants)
  Phaleria cumingii Fernandez-Villar
Phoenix dactylifera L. (edible fruits and nuts)
Phymatodes scolopendira (Burm.) Ching (cryptogams -- ferns)
  Pleopeltis phymatodes Moore
Pimenta dioica (L.) Merrill (spices)
  Myrtus dioica L.
  Myrtus pimenta L.
  Pimenta officinalis Lindley

Pimpinella anisum L. (spices)
Anisum vulgare Gaertn.
Carum anisum (L.) Baillon
Selinum anisum (L.) E.H.L. Krause
Piper aduncum L. (spices)
Piper bantamense Blume (stimulants)
Piper attenuatum Miq.
Piper betle L. (stimulants)
Piper caninum Blume (spices)
Piper cubeba L.f. (spices)
Piper elongatum Vahl (medicinal and poisonous plants)
Piper angustifolium Ruiz & Pavon
Piper guineense Schum. & Thonn. (spices)
Piper clusii (Miq.) C. DC.
Piper lanatum Roxb. (spices)
Piper lolot C. DC. (spices)
Piper longifolium Ruiz & Pavon (spices)
Piper longum L. (spices)
Piper sarmentosum Roxb.
Piper nigrum L. (spices)
Piper retrofractum Vahl (spices)
Piper chaba Hunter
Piper saigonense C. DC. (spices)
Pistacia lentiscus L. (plants producing exudates)
Plagiostachys uviformis (L.) Loesen. (medicinal and poisonous plants)
Alpinia uviformis Horan.
Languas uviformis Burkill
Plectranthus amboinicus (Loureiro) Sprengel (medicinal and poisonous plants)
Coleus amboinicus Loureiro
Plumeria rubra L. (ornamental plants)
Plumeria acuminata Aiton
Plumeria acutifolia Poiret
Plumiera acuminata Aiton
Polianthes tuberosa L. (ornamental plants)
Polygala chinensis L. (medicinal and poisonous plants)
Polygala glomerata Loureiro
Polygala telephoides Willd.
Polygala paniculata L. (medicinal and poisonous plants)
Polyscias cumingiana (C. Presl) Fernandez-Villar (vegetables)
Nothopanax pinnatum (Lamk) Miq.
Poncirus trifoliata (L.) Raf. (ornamental plants)
Citrus trifoliata L.
Protium javanicum Burm.f. (timber trees)
Amyris protium L.
Protium zollingeri Engl.
Pterocarpus indicus Willd. (timber trees)
Pterocarpus papuanus F. v. Mueller
Pterocarpus wallichii Wight & Arn.
Pterocarpus zollingeri Miq.

Pterocarpus santalinus L.f. (timber trees)
Quararibea funebris (Llave) Vischer (spices)
    Lexarza funebris Llave
    Myrodia funebris (Llave) Bentham
Renanthera moluccanna Blume (spices)
Rhaphidophora lobbii Schott (spices)
Ricinus communis L. (vegetable oils and fats)
Rorippa nasturtium-aquaticum (L.) Hayek (vegetables)
    Nasturtium officinale R. Br.
    Rorippa officinalis (R. Br.) P. Royen
    Sisymbrium nasturtium-aquaticum L.
Rosa centifolia L. (ornamental plants)
Rosmarinus officinalis L. (spices)
Ruta graveolens L. var. *angustifolia* Hook.f. (medicinal and poisonous plants)
    Ruta angustifolia Pers.
Salvia officinalis L. (spices)
    Salvia chromatica Hoffsgg.
    Salvia papillosa Hoffsgg.
Satureja hortensis L. (spices)
Saussurea costus (Falc.) Lipsch. (medicinal and poisonous plants)
    Saussurea lappa Clarke
Schinus molle L. (medicinal and poisonous plants)
Scutellaria baicalensis Georgi (medicinal and poisonous plants)
Scutellaria barbata D. Don (medicinal and poisonous plants)
Scutellaria javanica Jungh. (medicinal and poisonous plants)
Sesamum orientale L. (vegetable oils and fats)
    Sesamum indicum L.
Shorea robusta Gaertner f. (timber trees)
Sinapis alba L. (spices)
Sindora coriacea Maingay ex Prain (timber trees)
Sphaeranthus africanus L. (medicinal and poisonous plants)
Spilanthes iabadicensis A.H. Moore (vegetables)
    Spilanthes acmella auct., non (L.) Murr.
Spilanthes paniculata (Wall. ex DC.) R.K. Jansen (vegetables)
    Acmella paniculata misapplied to (Wall. ex DC.) R.K. Jansen
    Spilanthes acmella auct.
    Spilanthes pseudoacmella auct.
Spondias acida Blume (spices)
    Poupartia dulcis Blume
Spondias malayana Kosterm. (spices)
    Poupartia pinnata Blanco
    Spondias pinnata auct., non (Koenig ex L.f.) Kurz
    Spondias wirtgenii Hassk.
Spondias novoguineensis Kosterm. (spices)
Spondias pinnata (Koenig ex L.f.) Kurz (spices)
    Mangifera pinnata Koenig ex L.f.
    Spondias amara Lamk
    Spondias mangifera Willd.
Stevia rebaudiana (Bertoni) Bertoni (spices)

Eupatorium rebaudianum Bertoni
Styrax benzoin Dryander (plants producing exudates)
Synsepalum dulcificum (Schum. & Thonner) Baillon (spices)
Bumelia dulcifica Schum. & Thonner
Pouteria dulcifica (Schum. & Thonner) Baehni
Richardella dulcifica (Schum. & Thonner) Baehni
Syzygium aromaticum (L.) Merrill & Perry (spices)
Caryophyllus aromaticus L.
Eugenia aromatica (L.) Baillon
Eugenia caryophyllus (Sprengel) Bullock & Harrison
Syzygium jambos (L.) Alston (edible fruits & nuts)
Eugenia jambos L.
Syzygium polyanthum (Wight) Walp. (spices)
Eugenia polyantha Wight
Tagetes lucida Cav. (spices)
Tagetes patula L. (ornamental plants)
Telosma cordata (Burm.f.) Merrill (ornamental plants)
Thaumatococcus daniellii (Bennet) Benth. (spices)
Donax daniellii (Bennet) Roberty
Monostiche daniellii (Bennet) Horan.
Phrynium daniellii Bennet
Themeda gigantea (Cav.) Hackel (forages)
Thymus vulgaris L. (spices)
Thymus aestivus Reuter ex Willk. & Lange
Thymus ilerdensis F. Gonzalez ex Costa
Thymus webbianus Rouy
Toddalia asiatica (L.) Lamk (spices)
Paullinia asiatica L.
Toddalia aculeata (Smith) Pers.
Trachyspermum ammi (L.) Sprague ex Turrill (medicinal and poisonous plants)
Carum copticum Benth.
Trachyspermum roxburghianum (DC.) H. Wolff (spices)
Trigonella foenum-graecum L. (spices)
Vanilla abundiflora J.J. Smith (spices)
Vanilla gardneri Rolfe (spices)
Vanilla phaeantha H.G. Reichenb. (spices)
Vanilla planifolia H.C. Andrews (spices)
Vanilla fragrans (Salisb.) Ames
Vanilla mexicana P. Miller
Vanilla viridiflora Blume
Vanilla pompona Schiede (spices)
Vanilla tahitensis J.W. Moore (spices)
Vatica venulosa Blume subsp. *venulosa* (timber trees)
Vatica bancana Scheffer
Vitex glabrata R. Br. (medicinal and poisonous plants)
Vitex helogiton K. Schumann
Vitex minahassae Koord.
Vitex pentaphylla Merrill

Vitex negundo L. (medicinal and poisonous plants)
Vitex incisa Lamk
Vitex leucoxylon Blanco
Vitex paniculata Lamk
Vitex quinata (Lour.) F.N. Williams (medicinal and poisonous plants)
Vitex celebica Koord.
Vitex heterophylla Roxb.
Vitex sumatrana Miq.
Vitex trifolia L. (medicinal and poisonous plants)
Vitex lagundi Ridley
Vitex repens Blanco
Vitex rotundifolia L.f.
Weinmannia fraxinea Smith ex D. Don (spices)
Pterophylla fraxinea D. Don
Weinmannia sundana Heyne
Zanthoxylum armatum DC. (spices)
Zanthoxylum alatum Roxb.
Zanthoxylum planispinum Sieb. & Zucc.
Zanthoxylum avicennae (Lamk) DC. (spices)
Fagara avicennae Lamk
Zanthoxylum diversifolium Warburg
Zanthoxylum tidorense Miq.
Zanthoxylum myriacanthum Wallich ex Hooker f. (medicinal and poisonous plants)
Fagara myriacantha (Wallich ex Hooker f.) Engler
Zanthoxylum diabolicum Elmer
Zanthoxylum rhetsoides Drake
Zanthoxylum nitidum (Roxb.) DC. (medicinal and poisonous plants)
Fagara nitida Roxb.
Fagara torva (F. v. Mueller) Engler
Zanthoxylum hirtellum Ridley
Zanthoxylum rhetsa (Roxb.) DC. (timber trees)
Fagara rhetsa Roxb.
Zanthoxylum budrunga (Roxb.) DC.
Zanthoxylum limonella (Dennst.) Alston
Zingiber amaricans Blume (spices)
Zingiber aromaticum Valeton (spices)
Zingiber officinale Roscoe (spices)
Zingiber spectabile Griffith (spices)
Zingiber zerumbet (L.) J.E. Smith (spices)

Composition of essential-oil samples

Abelmoschus moschatus Medikus
Ambrette seed oil

59.1% (E,E)-farnesyl acetate
7.8% ambrettolide
5.6% decyl acetate
4.0% dodecyl acetate
3.8% (Z,E)-farnesyl acetate
3.5% (E,E)-farnesol
1.8% (Z)-tetradec-5-en-14-olide
1.6% tetradecenyl acetate (unknown isomer)
1.4% hexadecanoic acid
1.1% (E,E)-farnesyl propionate
1.0% (Z)-octadec-9-en-18-olide
0.9% oleic acid
0.8% (E,E)-2,4-decadienal
0.7% dodecenyl acetate (unknown isomer)
0.6% 1-decanol
0.5% linoleic acid
0.4% nerolidol (unknown isomer)
0.4% (E,Z)-2,4-decadienal
0.3% 1-dodecanol
0.3% (Z,E)-farnesol
0.3% (E,E)-farnesyl pentanoate
0.3% geranylacetone
0.3% methyl linoleate
0.2% β-farnesene
0.2% decyl propionate
0.2% ethyl linoleate
0.2% hexyl propionate
0.2% octyl butyrate
0.1% octyl-2-methylbutyrate
0.1% 1-octanol
0.1% 2-decanone
0.1% ethyl hexadecanoate
0.1% ethyl oleate
0.1% octadecanoic acid
0.1% methyl oleate
98.2% total
Source: Cravo et al., 1992.

Acacia farnesiana (L.) Willd.
Cassie blossom absolute

47.5% methyl salicylate
17.3% anisaldehyde
9.8% geraniol
6.0% benzaldehyde
3.3% geranyl acetate
2.8% geranial
1.9% 3-methyldec-3-en-1-ol
0.7% (Z)-3-nonen-1-ol
0.7% β-ionone
0.5% myrcene
0.5% 3-methyldec-4-en-1-ol
0.5% benzyl alcohol
0.4% linalool
0.4% benzyl acetate
0.4% α-ionone
0.3% neryl acetate
0.3% (E)-β-ocimene
0.2% β-cyclocitral
0.1% limonene
0.1% (Z)-β-ocimene
0.1% citronellyl acetate
0.1% (E,Z)-2,6-nonadienal
93.7% total
Source: Flath et al., 1983.

Alpinia zerumbet (Pers.) Burtt & Smith
Leaf oil (from Egypt)

17.3% terpinen-4-ol
14.4% 1,8-cineole
11.1% γ-terpinene
10.1% sabinene
5.9% para-cymene
4.9% α-thujene
4.7% α-terpinene
4.3% β-pinene
2.9% linalool
2.7% β-caryophyllene
2.6% α-pinene
2.3% α-terpineol
2.3% cis-sabinene hydrate

1.8% caryophyllene oxide
1.5% myrcene
1.2% trans-sabinene hydrate
1.1% camphor
0.4% α-phellandrene
0.4% nerolidol (unknown isomer)
0.3% camphene
0.3% trans-piperitol
0.3% α-eudesmol
0.2% β-eudesmol
0.2% (Z)-3-hexenol
0.2% γ-eudesmol
0.1% bornyl acetate
0.1% α-humulene
0.1% hexanal
0.1% trans-α-bergamotene
0.1% 1-hexanol
trace (Z)-β-ocimene
trace (E)-β-ocimene
trace terpinolene
93.9% total
Source: De Pooter et al., 1995.

Alpinia zerumbet (Pers.) Burtt & Smith
Rhizome oil (from Egypt)

20.2% terpinen-4-ol
15.9% 1,8-cineole
9.8% sabinene
9.3% γ-terpinene
9.2% fenchyl acetate
4.1% α-terpinene
3.6% β-caryophyllene
2.1% terpinolene
2.0% α-terpineol
1.9% para-cymene
1.8% α-pinene
1.5% cis-sabinene hydrate
1.3% camphene
1.3% bornyl acetate
1.2% α-thujene
1.1% trans-sabinene hydrate
1.0% myrcene
0.8% hexanal
0.7% borneol
0.6% β-pinene
0.6% caryophyllene oxide
0.5% α-phellandrene
0.5% linalool
0.5% γ-cadinene
0.5% α-eudesmol
0.3% α-humulene
0.3% nerolidol (unknown isomer)
0.3% β-eudesmol
0.2% δ-terpineol
0.2% elemol
0.2% γ-eudesmol
0.1% β-bisabolene
0.1% β-farnesene
0.1% trans-α-bergamotene
93.8% total
Source: De Pooter et al., 1995.

Aquilaria malaccensis Lamk
Agar-wood oil

27.0% 2-(2-(4-methoxyphenyl)ethyl)chromone
15.0% 2-(2-phenylethyl)chromone
5.0% oxoagarospirol
3.0% 9,11-eremophiladien-8-one
2.5% 6-methoxy-2-(2-(4-methoxyphenyl)ethyl)chromone
1.5% guaia-1(10),11-dien-15-al
1.5% selina-3,11-dien-9-ol
1.4% kusunol
1.0% selina-2,11-dien-14-ol
1.0% guaia-1(10),11-dien-15-oic acid
0.8% selina-3,11-dien-9-one
0.7% jinkoh-eremol
0.7% selina-4,11-dien-14-al
0.7% dihydrokaranone
0.6% selina-3,11-dien-14-al
0.4% 2-hydroxyguaia-1(10),11-dien-15-oic acid
0.4% β-agarofuran
0.3% guaia-1(10),11-dien-15-ol
0.3% guaia-1(10),11-dien-15,2-olide
0.3% selina-3,11-dien-14-oic acid
0.2% norketoagarofuran
0.2% agarospirol
0.2% sinenofuranol
0.2% selina-4,11-dien-14-oic acid
0.2% 9-hydroxyselina-4,11-dien-14-oic acid
0.2% dehydrojinkoh-eremol
0.1% rotundone
0.1% α-bulnesene
0.1% karanone
0.1% α-guaiene
0.1% bulnesene oxide
0.1% guaia-1(10),11-dien-9-one
0.1% 1,5-epoxy-norketoguaiene
65.7% total
Source: Ishihara et al., 1993.

Blumea balsamifera (L.) DC.
Leaf oil

80.6% l-borneol
1.3% β-eudesmol

1.0% guaiol
0.6% linalool
0.2% β-caryophyllene
83.7% total
Source: Zhu et al., 1995.

Cananga odorata (Lamk) Hook.f. & Thomson
Ylang-ylang oil (from China)

33.0% β-caryophyllene
19.8% γ-muurolene
7.7% α-humulene
5.4% bergamotene (unknown isomer)
5.3% benzyl benzoate
4.8% farnesol (unknown isomer)
3.3% β-farnesene
2.5% geraniol
2.4% para-cresyl methyl ether
1.7% β-cadinene
0.9% farnesyl acetate
0.7% methyl benzoate
0.5% copaene (unknown isomer)
0.4% linalool
0.3% benzyl salicylate
0.1% benzyl acetate
trace geranial
trace methyl chavicol
trace β-pinene
trace α-pinene
88.9% total
Source: Cu, 1988.

Cananga odorata (Lamk) Hook.f. & Thomson
Cananga oil

37.0% β-caryophyllene
12.2% farnesene
10.5% α-caryophyllene
7.6% γ-cadinene
5.4% δ-cadinene
2.9% benzyl benzoate
1.8% geranyl acetate
1.7% linalool
1.1% p-cresyl methyl ehter
1.1% (Z,E)-farnesol
1.0% nerolidol
0.6% geraniol
0.1% benzyl salicylate
83.0% total
Source: Buccellato, 1982.

Cananga odorata (Lamk) Hook.f. & Thomson
Ylang-ylang oil 'Extra'

18.0% farnesene
12.6% benzyl acetate
10.3% linalool
8.9% δ-cadinene
8.4% p-methyl cresyl ether
6.8% β-caryophyllene
4.3% benzyl benzoate
4.0% geranyl acetate
4.0% methyl benzoate
3.1% α-caryophyllene
2.0% γ-cadinene
1.9% benzyl salicylate
0.9% (Z,E)-farnesol
0.5% nerolidol
0.5% benzyl alcohol
0.3% α-pinene
0.3% safrole
0.2% linalyl acetate
0.2% isoeugenol
0.2% geraniol
0.2% eugenol
0.1% α-terpineol
0.1% methyl anthranilate
0.1% methyl salicylate
0.1% p-cresol
88.0% total
Source: Buccellato, 1982.

Cananga odorata (Lamk) Hook.f. & Thomson
Ylang-ylang oil 'Third'

21.0% farnesene
16.3% δ-cadinene
16.3% β-caryophyllene
8.8% α-caryophyllene
7.5% γ-cadinene
5.3% benzyl benzoate
2.0% geranyl acetate
2.0% linalool
1.8% nerolidol
1.7% benzyl salicylate
1.4% (Z,E) farnesol
1.0% p-cresyl methyl ether
0.5% benzyl acetate
0.3% eugenol
0.1% α-pinene
0.1% methyl benzoate
86.1% total
Source: Buccellato, 1982.

Cananga odorata (Lamk) Hook.f. & Thomson
Ylang-ylang absolute

14.9% farnesene
13.2% linalool
11.8% benzyl benzoate
10.8% δ-cadinene
10.0% β-caryophyllene
5.2% benzyl salicylate
4.0% geranyl acetate
3.5% methyl benzoate
3.3% α-caryophyllene
3.0% p-cresyl methyl ether
2.8% benzyl acetate
2.8% γ-cadinene
1.8% (Z,E) farnesol
1.7% geraniol
0.8% α-terpineol
0.8% eugenol
0.7% nerolidol
0.4% safrole
0.3% methyl salicylate
0.1% α-pinene
0.1% methyl anthranilate
92.0% total
Source: Buccellato, 1982.

Cinnamomum camphora (L.) J.S. Presl
Camphor oil, cineole type (from China)

50.0% 1,8-cineole
14.4% α-terpineol
6.9% β-pinene
3.1% bornyl acetate
2.0% linalool
1.7% β-bisabolene
1.7% α-pinene
1.1% para-cymene
0.7% iso-nerolidol (unknown isomer)
0.3% methyl isoeugenol
0.3% borneol
0.3% β-eudesmol
0.3% sabinene
0.3% camphor
0.2% α-copaene
0.2% terpinyl acetate (unknown isomer)
0.2% β-caryophyllene
0.2% safrole
0.2% isogeraniol
0.2% citronellyl acetate
0.1% α-humulene
0.1% citronellol
0.1% methyl eugenol
0.1% terpinen-4-ol
0.1% geranyl acetate
84.8% total
Source: Zhu et al., 1993.

Cinnamomum camphora (L.) J.S. Presl
Camphor oil, borneol type (from China)

81.8% borneol
3.0% camphor
2.0% α-pinene
1.6% 1,8-cineole
1.6% limonene
1.5% camphene
0.9% myrcene
0.9% β-caryophyllene
0.9% linalool
0.8% β-pinene
0.7% α-copaene
0.6% β-bisabolene
0.5% bornyl acetate
0.4% methyl isoeugenol
0.3% sabinene
0.3% α-terpineol
0.2% safrole
0.2% α-thujene
0.2% guaiol
0.2% para-cymene
0.2% γ-terpinene
0.1% β-eudesmol
0.1% α-humulene
0.1% iso-nerolidol (unknown isomer)
0.1% α-phellandrene
0.1% terpinolene
0.1% β-ocimene
0.1% terpinyl acetate (unknown isomer)
99.6% total
Source: Zhu et al., 1993.

Cinnamomum camphora (L.) J.S. Presl
Camphor oil, iso-nerolidol type (from China)

57.7% iso-nerolidol (unknown isomer)
3.6% α-terpineol
2.3% linalool
1.3% terpinen-4-ol
1.1% borneol
1.1% β-caryophyllene
1.0% methyl isoeugenol
0.9% 1,8-cineole
0.5% safrole
0.5% α-phellandrene
0.5% geranyl acetate
0.4% α-humulene

0.3% camphor
0.3% methyl eugenol
0.3% camphene
0.2% β-eudesmol
0.2% limonene
0.2% guaiol
0.1% α-copaene
0.1% terpinyl acetate (unknown isomer)
0.1% α-pinene
0.1% sabinene
0.1% β-pinene
0.1% myrcene
0.1% terpinolene
0.1% citonellyl acetate
73.1% total
Source: Zhu et al., 1993.

Citrus aurantium L. cv. group Bouquetier
Petitgrain bigarade oil

45.9% linalyl acetate
20.2% linalool
5.4% limonene
4.0% α-terpineol
3.9% geranyl acetate
3.0% geraniol
2.6% myrcene
2.5% β-pinene
2.4% (E)-β-ocimene
2.2% neryl acetate
1.8% β-caryophyllene
1.0% nerol
0.8% (Z)-β-ocimene
0.5% (E)-β-farnesene
0.4% sabinene
0.3% terpinolene
0.2% 2-phenylethanol
0.2% α-pinene
0.2% α-humulene
0.2% terpinen-4-ol
0.1% nerolidol (unknown isomer)
0.1% α-terpinyl acetate
0.1% methyl anthranilate
0.1% (Z)-β-farnesene
0.1% geranial
0.1% citronellyl acetate
0.1% δ-cadinene
0.1% α-terpinene
0.1% γ-terpinene
0.1% trans-linalool oxide (5) (furanoid)
0.1% cis-linalool oxide (5) (furanoid)
0.1% para-cymene
0.1% citronellal
0.1% methyl N-methyl anthranilate
trace caryophyllene oxide
trace germacrene D
trace δ-3-carene
trace neral
trace nootkatone
trace valencene
trace α-thujene
trace decanal
trace camphene
trace α-phellandrene
trace octanal
trace perillaldehyde
trace β-elemene
trace δ-cadinol
trace perillene
trace para-1,8-menthadienyl-4 acetate
trace 2,2,6-trimethyl-6-vinyltetrahydropyran
98.9% total
Source: Boelens & Oporto, 1991.

Citrus aurantium L. cv. group Bouquetier
Neroli bigarade oil

39.2% linalool
15.4% limonene
11.8% β-pinene
6.3% (E)-β-ocimene
5.3% linalyl acetate
2.8% (E)-nerolidol
2.3% α-terpineol
2.3% myrcene
2.1% sabinene
1.8% geranyl acetate
1.6% geraniol
1.2% (E,Z)-farnesol
1.0% α-pinene
0.9% neryl acetate
0.6% β-caryophyllene
0.6% nerol
0.5% terpinolene
0.3% α-terpinene
0.3% terpinen-4-ol
0.3% (Z)-β-ocimene
0.3% γ-terpinene
0.2% methyl anthranilate
0.2% 2-phenylethanol
0.2% trans-linalool oxide (5) (furanoid)
0.2% α-terpinyl acetate
0.1% indole
0.1% α-humulene
0.1% (E)-β-farnesene
0.1% (E,E)-α-farnesene

0.1% geranial
0.1% camphene
trace cis-linalool oxide (5) (furanoid)
trace para-cymene
trace (E,Z)-farnesyl acetate
trace hexyl acetate
trace cis-jasmone
trace α-thujene
trace δ-cadinene
trace neral
trace γ-elemene
trace (Z)-methyl jasmonate
97.9% total
Source: Boelens & Boelens, 1997.

Citrus bergamia Risso et Poiteau
Bergamot oil

38.4% limonene
28.1% linalyl acetate
8.6% linalool
8.5% γ-terpinene
7.8% β-pinene
1.4% α-pinene
1.3% sabinene
1.0% myrcene
0.4% bisabolene (unknown isomer)
0.4% geranyl acetate
0.4% β-caryophyllene
0.4% α-thujene
0.4% terpinolene
0.4% geranial
0.3% bergamotene (unknown isomer)
0.3% neryl acetate
0.3% (E)-β-ocimene
0.2% neral
0.2% sesquiterpene hydrocarbons (unknown)
0.2% α-terpinene
0.2% α-terpinyl acetate
0.1% para-cymene
0.1% methyl cinnamate
0.1% esters (unknown structure)
0.1% decanal
0.1% octanal
0.1% α-terpineol
trace camphene
trace nonanal
trace cis-sabinene hydrate
trace α-phellandrene
trace α-humulene
trace linalyl propionate
trace (Z)-β-ocimene
trace terpinen-4-ol
trace citronellol
trace nerol
trace citronellal
trace bornyl acetate
trace citronellyl acetate
trace nonyl acetate
trace undecanal
trace 1-octanol
99.8% total
Source: Dugo et al., 1991.

Corymbia citriodora (Hook.) K.D. Hill & L.A.S. Johnson
Eucalyptus citriodora oil

80.1% citronellal
8.5% isoisopulegol
4.2% citronellol
3.4% isopulegol
0.7% linalool
0.4% β-caryophyllene
0.4% β-pinene
0.1% α-pinene
0.1% spathulenol
0.1% α,para-dimethylstyrene
trace α-terpineol
trace citronellyl acetate
trace myrcene
trace para-cymene
trace limonene
trace terpinolene
trace geraniol
trace 1,8-cineole
trace globulol
trace viridiflorol
98.1% total
Source: Boland et al., 1991.

Cymbopogon citratus (DC.) Stapf
West Indian lemongrass oil

53.6% geranial
36.1% neral
1.2% caryophyllene oxide
0.9% citronellyl acetate
0.7% β-caryophyllene
0.5% linalool
0.5% 6-methyl-5-hepten-2-one
0.5% isopulegol
0.3% limonene
0.3% β-elemene
0.2% geraniol
0.2% camphor
0.1% para-cymene
0.1% terpinolene

0.1% α-terpineol
0.1% citronellal
0.1% geranyl acetate
0.1% α-humulene
0.1% β-bisabolene
0.1% myrcene
0.1% α-phellandrene
0.1% (Z)-β-ocimene
0.1% (E)-β-ocimene
0.1% borneol
0.1% terpinen-4-ol
0.1% citronellol
96.1% total
Source: Rajeswara et al., 1996.

Cymbopogon citratus (DC.) Stapf
West Indian lemongrass oil

39.8% geranial
32.0% neral
3.3% geraniol
2.2% 6-methyl-5-hepten-2-one
1.4% geranic acid
1.3% linalool
1.0% 1,8-cineole
0.9% pulegone
0.8% myrcene
0.7% geranyl acetate
0.6% methyl geranate
0.5% neryl acetate
0.5% citronellol
0.4% 2-undecanone
0.4% trans-carveol
0.4% α-pinene
0.3% isopulegol
0.3% myrtenyl acetate
0.2% geranyl isobutyrate
0.2% limonene
0.2% menthone
0.2% cis-lanalool oxide (furanoid)
0.2% caryophyllene oxide
0.1% α-fenchol
0.1% trans-α-bergamotene
0.1% neric acid
0.1% ar-curcumene
0.1% trans-linalool oxide (furanoid)
0.1% 10-epi-γ-eudesmol
0.1% α-terpinene
trace 3-octanal
trace cis-dihydrocarvone
trace octanal
87.5% total
Source: Idrisi et al., 1993.

Cymbopogon flexuosus (Nees ex Steudel) J.F. Watson
East Indian lemongrass oil

30.5% geraniol
24.1% citronellol
13.6% geranial
10.3% neral
4.0% citronellal
2.2% citronellyl acetate
2.1% geranyl acetate
1.9% limonene
1.3% camphene
1.0% linalool
1.0% γ-cadinene
0.5% myrcene
0.5% β-cubebene
0.4% 6-methyl-5-hepten-2-one
0.4% borneol
0.4% β-caryophyllene
0.3% 4-nonanone
0.3% α-terpineol
0.3% bornyl acetate
0.3% δ-cadinene
0.2% tricyclene
0.2% α-pinene
0.2% β-phellandrene
0.2% decanal
0.2% eugenol
96.4% total
Source: Nath et al., 1993.

Cymbopogon martini (Roxb.) J.F. Watson
Palmarosa oil

75.0% geraniol
12.5% geranyl acetate
2.4% linalool
1.3% β-caryophyllene
1.3% geranyl formate
1.3% geranyl butyrate
1.0% geranyl octanoate
0.5% limonene
0.5% caryophyllene oxide
0.4% prenyl isovalerate
0.3% pentyl hexanoate
0.3% 6,7-geranylepoxide
0.3% geranyl hexanoate
0.2% neryl formate
0.2% prenyl hexanoate
0.1% nerol
0.1% limonen-10-yl-acetate
0.1% 2,3-geranylepoxide

0.1% α-pinene
0.1% myrcene
0.1% γ-terpinene
0.1% geranial
0.1% 1,8-cineole
0.1% 1-hexanol
0.1% geranyl 3-methylbutyrate
0.1% para-mentha-1,8(10)-dien-9-ol
0.1% prenyl octanoate
98.1% total
Source: Sethi et al., 1989.

Cymbopogon winterianus Jowitt

Java citronella oil

34.8% citronellal
23.2% geraniol
11.2% citronellol
5.1% geranyl acetate
3.2% elemol
2.8% limonene
2.5% eugenol
2.3% β-cubebene
2.0% β-elemene
1.9% citronellyl acetate
1.7% γ-cadinene
1.2% δ-cadinene
0.7% linalool
0.7% γ-muurolene
0.7% T-amorphol
0.5% trans-muurolol
0.5% α-muurolene
0.4% (Z)-β-ocimene
0.2% β-caryophyllene
0.2% isoisopulegol
0.2% (E)-β-ocimene
0.2% 10-epi-γ-eudesmol
0.2% α-terpinyl acetate
0.1% α-humulene
0.1% citronellic acid
0.1% decanal
0.1% β-bourbonene
0.1% (Z)-α-farnesol
0.1% myrcene
0.1% methyl eugenol
0.1% 2,6-dimethyl-5-heptenal
0.1% α-copaene
0.1% (E)-α-farnesol
0.1% sabinene
0.1% terpinolene
0.1% α-pinene
0.1% borneol
0.1% α-terpineol
trace camphene
trace terpinen-4-ol
trace 1,8-cineole
trace neryl acetate
trace β-phellandrene
trace tricyclene
trace β-pinene
trace δ-3-carene
trace α-terpinene
trace δ-elemene
trace 6-methyl-5-hepten-2-one
trace (Z)-3-hexenol
97.5% total
Source: Carlin et al., 1988.

Gaultheria procumbens L.

Wintergreen oil

90.0% methyl salicylate
5.0% safrole
2.0% linalool
1.0% 1,8-cineole
0.5% α-pinene
0.5% β-pinene
0.5% camphor
0.2% para-cymene
0.2% eugenol
0.1% camphene
0.1% methyl eugenol
0.1% ethyl salicylate
0.1% methyl 5-hydroxysalicylate
100.3% total
Source: Frey, 1988.

Jasminum grandiflorum L.

Jasmine absolute

26.1% benzyl acetate
13.4% phytol
11.7% benzyl benzoate
11.0% phytyl acetate
8.2% isophytol
4.7% linalool
3.8% indole
2.6% eugenol
2.2% cis-jasmone
2.1% methyl linolenate
2.0% methyl oleate
2.0% (E,E)-α-farnesene
1.6% methyl octadecanoate
1.6% methyl palmitate
1.3% (Z)-3-hexenyl benzoate
1.3% jasmin lactone
1.0% para-cresol
0.8% benzyl alcohol

0.7% N-acetyl methyl anthranilate
0.6% (Z)-methyl jasmonate
0.6% phytone
0.4% 9-dodecen-5-olide
0.2% (E)-methyl jasmonate
0.1% methyl benzoate
0.1% (Z)-3-hexenol
99.9% total
Source: Shaath & Azzo, 1992.

Lavandula angustifolia Miller

Lavender oil

21.5% linalyl acetate
17.8% linalool
8.2% (Z)-β-ocimene
8.0% β-caryophyllene
7.3% lavandulyl acetate
6.4% terpinen-4-ol
6.2% (E)-β-ocimene
2.5% 1-octenyl-3 acetate
2.0% β-farnesene
1.4% 3-octanone
1.3% myrcene
1.2% lavandulol
1.1% α-santalene
1.0% borneol
1.0% α-terpineol
1.0% geranyl acetate
0.9% 1,8-cineole
0.9% germacrene D
0.6% bornyl acetate
0.6% hexyl acetate
0.5% neryl acetate
0.5% 1-octenol-3
0.5% camphor
0.4% geraniol
0.4% limonene
0.4% γ-terpinene
0.4% hexyl butyrate
0.3% α-pinene
0.3% isocaryophyllene oxide
0.3% T-cadinol
0.3% para-cymene
0.3% α-humulene
0.3% γ-cadinene
0.3% butyl butyrate
0.2% nerol
0.2% α-thujene
0.2% camphene
0.2% β-pinene
0.2% cryptone
0.2% 3-octanol
0.2% 3-octyl acetate
0.2% para-cymen-8-ol
0.2% trans-linalool oxide (5) (furanoid)
0.2% cis-linalool oxide (5) (furanoid)
0.2% terpinolene
0.2% α-bergamotene
0.1% δ-3-carene
0.1% cuminaldehyde
0.1% β-bergamotene
0.1% α-terpinene
0.1% sabinene hydrate
0.1% (E,Z)-1,3,5-undecatriene
0.1% butyl tiglate
0.1% linalyl hexanoate
0.1% hexyl tiglate
0.1% hexyl methyl ether
0.1% hexyl isobutyrate
0.1% acetone
0.1% α-phellandrene
0.1% butyl acetate
0.1% sabinene
0.1% α-eka-santalal
trace alloocimene (unknown isomer)
trace 1-hexanol
trace epoxy-linalyl acetate (isomer 1)
trace β-santalene
trace hexyl propionate
trace butyl isobutyrate
trace tricyclene
trace octanal
trace nonanal
trace carvone
trace thymol
trace hexanal
trace caryophyllene oxide
trace cubenol
trace hotrienol
trace 2-hexenal
trace trans-ocimene epoxide
trace butyl benzoate
trace dimethyl disulfide
trace rosefuran
trace cis-linalool oxide (6) (pyranoid)
trace trans-linalool oxide (6) (pyranoid)
trace pentanal
trace prenol
trace (E,Z,Z)-1,3,5,8-undecatetraene
trace butyl propionate
100.0% total
Source: Naef & Morris, 1992.

Lavandula ×intermedia Emeric ex Loisel.
Lavandin oil 'Grosso'

26.2% linalyl acetate
22.5% linalool
12.2% camphor
10.2% 1,8-cineole
3.3% terpinen-4-ol
2.9% borneol
2.7% β-caryophyllene
2.3% lavandulyl acetate
1.5% myrcene
1.2% geranyl acetate
1.2% α-terpineol
1.1% β-farnese
1.1% germacrene D
1.1% (Z)-β-ocimene
0.9% limonene
0.8% lavandulol
0.6% α-pinene
0.5% (E)-β-ocimene
0.4% β-pinene
0.4% γ-terpineol
0.4% γ-terpinene
0.4% β-bisabolol
0.3% camphene
0.3% hexyl butyrate
0.3% terpinolene
0.3% 1-octenyl-3 acetate
0.3% γ-cadinene
0.2% bornyl acetate
0.2% geraniol
0.2% α-santalene
0.2% T-cadinol
0.2% plinol (isomer)
0.2% sabinene hydrate
0.2% α-humulene
0.2% hexyl acetate
0.2% para-cymene
0.2% cis-linalool oxide (5) (furanoid)
0.2% trans-linalool oxide (5) (furanoid)
0.1% sabinene
0.1% 5-methyl-3-heptanone
0.1% neryl acetate
0.1% hexyl tiglate
0.1% α-thujene
0.1% caryophyllene oxide
0.1% 1-octenol-3
0.1% bisabolene (unknown isomer)
0.1% butyl tiglate
0.1% isofenchone
0.1% α-phellandrene
0.1% δ-3-carene
0.1% α-terpinene
0.1% nerol
0.1% hexyl-2-methylbutanoate
0.1% hexyl methyl ether
trace hexyl isobutyrate
trace 3-octanone
trace butyl butyrate
trace p-cymen-8-ol
trace cuminaldehyde
trace 1-hexanol
trace epoxy-linalyl acetate (isomer 2)
trace hexyl propionate
trace lavandulyl butyrate
trace tricyclene
trace octanal
trace carvone
trace fenchone
trace cubenol
trace α-fenchene
trace epoxy-linalyl acetate (isomer 1)
trace 2-hexenal
trace trans-linalool oxide (6) (pyranoid)
trace acetone
trace octyl acetate
trace β-bergamotene
trace undecatriene (unknown isomer)
trace butyl isobutyrate
trace linalyl hexanoate
trace lavandulyl epoxide
99.3% total
Source: Naef & Morris, 1992.

Lavandula latifolia Medikus
Spike lavender oil

41.7% linalool
26.3% 1,8-cineole
12.8% camphor
2.1% β-pinene
1.9% α-bisabolene
1.8% α-pinene
1.4% β-caryophyllene
1.1% limonene
1.1% linalyl acetate
1.0% α-terpineol
0.8% borneol
0.6% camphene
0.6% sabinene
0.6% terpinen-4-ol
0.6% lavandulol
0.4% α-humulene
0.4% δ-cadinene
0.3% bornyl acetate
0.3% trans-linalool oxide (unknown isomer)

0.2% myrcene
0.2% α-terpinene
0.2% (E)-β-ocimene
0.2% γ-terpinene
0.2% terpinolene
0.2% γ-cadinene
0.2% isoborneol
0.2% 1-octenol-3
0.2% cis-linalool oxide (unknown isomer)
0.2% α,p-dimethylstyrene
0.2% 3-octanone
0.1% α-phellandrene
0.1% (Z)-β-ocimene
0.1% geraniol
0.1% 1-octanol
0.1% coumarin
0.1% α-thujene
0.1% nerol
0.1% isoamyl acetate
0.1% eugenol
0.1% caryophyllene oxide
0.1% 1-hexanol
0.1% hexyl acetate
0.1% butyl acetate
0.1% dihydrocoumarin
99.0% total
Source: Boelens, 1986.

Litsea cubeba (Lour.) Persoon
May chang oil (fruit)

26.6% neral
20.5% gernanial
17.5% limonene
7.4% 6-methyl-5-hepten-2-one
4.9% linalool
3.6% α-pinene
3.2% β-pinene
3.0% pulegone
2.3% selinene (unknown isomer)
2.3% α-terpineol
1.4% 2-isopropenyl-3-methyl-4-hydroxy-cyclopentene-2
1.3% camphene
0.9% camphor
0.8% α-humulene
0.7% citronellal
0.1% para-cymene
0.1% geraniol
0.1% piperitone
0.1% pseudo-ionone
96.7% total
Source: Ma et al., 1988.

Melaleuca cajuputi Powell
Cajeput oil, cineole type

41.1% 1,8-cineole
8.7% α-terpineol
6.8% para-cymene
5.9% terpinolene
4.6% γ-terpinene
4.1% limonene
3.6% linalool
3.2% α-pinene
2.5% β-caryophyllene
1.6% α-humulene
1.5% terpinen-4-ol
1.5% β-selinene
1.5% α-selinene
1.2% guaiol
0.9% myrcene
0.8% β-pinene
0.7% α-eudesmol
0.7% β-eudesmol
0.6% α-terpinene
0.6% γ-eudesmol
0.5% α-phellandrene
0.5% γ-gurjunene
0.4% geraniol
0.4% cadina-1,4-diene
0.3% α-ylangene
0.3% β-elemene
0.3% caryophyllene oxide
0.3% α-farnesene
0.3% β-guaiene
0.2% α,p-dimethylstyrene
trace β-phellandrene
trace camphene
trace sabinene
trace δ-3-carene
trace (Z)-β-ocimene
trace (E)-β-ocimene
trace δ-cadinene
trace γ-cadinene
trace α-copaene
trace δ-elemene
trace γ-elemene
trace elemol
trace T-cadinol
trace δ-cadinol
trace α-cadinol
trace β-sesquiphellandrene
trace calamenene
trace thujopsene
trace bulnesol
trace monoterpene alcohols
trace α-maaliene

95.8% total
Source: Motl et al., 1990.

Melaleuca quinquenervia (Cav.) S.T. Blake
Niaouli oil

25.0% (E)-nerolidol
19.0% 1,8-cineole
19.0% viridiflorol
5.5% α-terpineol
5.5% ledene
5.1% terpinen-4-ol
4.1% β-caryophyllene
3.8% limonene
3.4% α-pinene
2.4% ledol
1.7% γ-terpinene
0.9% β-pinene
0.8% caryophyllene oxide
0.8% terpinolene
0.4% para-cymene
0.4% benzaldehyde
0.3% myrcene
0.3% α-terpinene
0.3% α-gurjunene
0.3% allo-aromadendrene
0.2% δ-cadinol
0.2% linalool
0.1% α-humulene
0.1% 4-selinenol-11
0.1% methyl benzoate
0.1% sabinene
0.1% neral
0.1% β-selinene
0.1% δ-cadinene
trace γ-cadinene
trace δ-3-carene
trace aromadendrene
trace α-cubebene
99.6% total
Source: Ramanoelina et al., 1994.

Michelia champaca L.
Flower absolute

25.0% 2-phenylethanol
13.0% methyl linoleate
4.5% methyl anthranilate
4.0% benzyl acetate
3.4% β-lonone
3.0% methyl palmitate
2.9% indole
2.0% linalool
2.0% 2-phenylethyl acetate
2.0% oximes of ionones
1.6% α-farnesene
1.6% α-ionone
1.4% dehydro-β-ionone
1.3% phenylacetonitrile
1.1% dehydro β-ionol
1.0% methyl benzoate
0.8% benzyl alcohol
0.6% methyl cis-(Z)-jasmonate
0.5% phenylacetaldoxime
0.3% β-ionol
0.2% eugenol
0.2% cis-linalool oxide (6) (pyranoid)
0.1% photoisomer of β-ionone
72.5% total
Source: Kaiser, 1989.

Ocimum gratissimum L.
Leaf oil, thymol type

46.7% thymol
22.9% γ-terpinene
5.8% p-cymene
3.1% myrcene
3.0% α-thujene
3.0% α-terpinene
2.0% β-caryophyllene
1.8% cis-β-ocimene
1.1% terpinenen-4-ol
1.0% α-pinene
0.9% β-selinene
0.9% α,para-dimethylstyrene
0.9% linonene
0.6% carvacrol
0.5% sabinene
0.4% β-pinene
0.4% α-copaene
0.4% trans-sabinene hydrate
0.3% oct-1-en-3-ol
0.3% α-phellandrene
0.3% trans-β-ocimene
0.3% eugenol
0.3% 8-cadinene
0.3% β-caryophyllene epoxide
0.3% 1,8-cineole
0.2% γ-cadinene
0.2% α-humulene
0.2% linalool
0.2% δ-carene
0.1% trans-hex-2-enal
0.1% camphene
0.1% 3-octanone
0.1% terpinolene

0.1% cis-sabinene hydrate
0.1% α-terpineol
0.1% β-elemene
0.1% trans-methylisoeugenol
0.1% germacrene-D
trace trans-p-menth-2-en-1-ol
trace δ-terpineol
trace methylcinnamate
trace methyleugenol
trace trans-β-farnesene
trace α-farnesene
trace β-bisabolene
99.2% total
Source: Ntezurubanza et al., 1987.

Ocimum gratissimum L.
Leaf oil, eugenol type

40.3% eugenol
12.0% 1,8-cineole
5.4% unknown
3.8% α-terpineole
3.2% γ-terpinene
2.7% β-caryophyllene
2.6% unknown
1.5% citronellal
1.5% α-pinene
1.0% unknown
0.9% safrole
0.8% myrcene
0.6% camphor
0.5% β-pinene
0.4% α-terpinene
0.4% linalyl acetate
0.2% p-cymene
0.2% terpinolene
0.2% linalool
78.2% total
Source: De Medici et al., 1992.

Pelargonium L'Herit. cv. group Rosat
Geranium oil, Bourbon

20.6% citronellol
18.1% geraniol
9.9% linalool
9.5% isomenthone
7.4% citronellyl formate
5.8% guania-6,9-diene
5.6% geranyl formate
2.0% sesquiterpene hydrocarbons (unknown)
1.3% β-caryohyllene
1.2% geranyl propionate
1.2% geranyl tiglate
1.0% menthone
1.0% geranyl butyrate
0.9% citronellyl acetate
0.8% α-pinene
0.8% α-terpineol
0.8% nerol
0.7% sesquiterpenes, oxygen-containing
0.6% cis-rose oxide
0.6% 2-phenylethyl tiglate
0.5% δ-cadinene
0.5% citronellyl butyrate
0.3% germacrene D
0.3% trans-rose oxide
0.3% citronellyl tiglate
91.7% total
Source: Southwell et al., 1995.

Pimenta racemosa (Miller) J.W. Moore
Bay leaf oil

57.0% eugenol
8.2% myrcene
7.8% chavicol
6.0% methyl eugenol
4.0% β-caryophyllene
3.0% limonene
1.9% linalool
1.4% 1,8-cineole
0.9% 1-octenol-3
0.8% (E)-β-ocimene
0.8% α-humulene
0.7% δ-cadinene
0.6% 3-octanone
0.5% para-cymene
0.5% terpinen-4-ol
0.5% α-pinene
0.4% 3-octanol
0.4% α-copaene
0.3% α-terpineol
0.3% α-selinene
0.3% α-farnesen
0.3% α-phellandrene
0.3% eugenyl acetate
0.2% α-amorphene
0.2% globulol
0.2% terpinolene
0.2% β-selinene
0.2% α-cadinol
0.2% α,p-dimethylstyrene
0.1% allo-aromadendrene
0.1% geranial
0.1% α-terpinene
0.1% γ-terpinene
0.1% γ-cadinene

0.1% β-elemene
0.1% (Z)-β-ocimene
0.1% β-chamigrene
0.1% camphene
0.1% geraniol
0.1% spathulenol
0.1% γ-gurjunene
0.1% β-pinene
0.1% aromadendrene
0.1% cinnamic aldehyde
trace methyl chavicol
trace calamenene
trace α-muurolene
trace α-thujene
trace sabinene
trace camphor
trace β-cadinene
trace p-cymene-8-ol
trace α-cubebene
trace γ-cadinol
trace γ-muurolol
98.9% total
Source: Tucker et al., 1991.

Pogostemon cablin (Blanco) Benth.
Patchouli oil (from Java)

26.7% patchouli alcohol
16.7% α-bulnesene
13.5% α-guaiene
8.8% seychellene
4.5% α-patchoulene
4.2% β-caryophyllene
2.4% δ-cadinene
2.3% pogostol
2.0% β-patchoulene
0.9% caryophyllene oxide
0.8% norpatchoulenol
0.7% β-elemene
0.4% α-gurjunene
0.3% β-pinene
0.3% 1,10-epoxy-α-bulnesene
0.2% cycloseychellene
0.1% α-pinene
0.1% 1,5-epoxy-α-guaiene
87.7% total
Source: Lawrence, 1990.

Rosa L. cv. group Damascena
Rose oil, Bulgaria

32.0% citronellol
19.0% alkanes & alkenes
15.7% geraniol
8.7% nerol
2.7% linalool
2.3% methyl eugenol
1.6% ethanol
1.2% 2-phenylethanol
1.0% (E,E)-farnesol
0.7% α-terpineol
0.7% geranyl acetate
0.6% eugenol
0.5% citronellyl acetate
0.5% β-caryophyllene
0.4% cis-rose oxide
0.3% terpinen-4-ol
0.2% α-humulene
0.2% α-pinene
0.2% dibutyl phthalate
0.2% trans-geranic acid
0.2% benzyl tiglate
0.2% (E)-nerolidol
0.2% 1-hexanol
0.2% trans-rose oxide
0.2% α-guaiene
0.2% (Z,E)-farnesol
0.1% γ-cadinene
0.1% p-cymene-8-ol
0.1% geranylacetone
0.1% 2-phenylethyl isobutyrate
0.1% β-damascenone
0.1% 2-phenylethyl benzoate
0.1% myrcene
0.1% nerol oxide
0.1% methyl geranate
0.1% methanol
0.1% neryl acetate
0.1% benzyl benzoate
0.1% 2-phenylethyl acetate
0.1% 2-methylbutanol
0.1% 3-methylbutanol
0.1% (E)-3-hexenol-1
trace β-pinene
trace limonene
trace (E)-β-ocimene
trace 2-phenylethyl 2-methylbutyrate
trace acetaldehyde
trace trans-linalool oxide (unknown isomer)
trace nonanal
trace geranial
trace 1,8-cineole
trace heptanal
trace 6-methyl-5-hepten-2-one
trace 2-undecanone
trace ethyl dodecanoate
trace 2-pentadecanone
trace γ-terpinene

trace terpinolene
trace benzaldehyde
trace ethyl benzoate
trace 6-methyl-5-hepten-2-ol
trace 2-tridecanone
trace farnesene (unknown isomer)
trace α,p-dimethylstyrene
trace pentanal
trace 1-pentanol
trace 1-heptanol
trace α-terpinene
trace para-cymene
trace (Z)-β-ocimene
trace decanal
trace undecanal
trace neral
trace ylangene
trace acids and esters
trace hexanal
trace menthol
trace 1-decanol
trace (E)-anethol
trace 1,1-diethoxy ethane
trace geranic acid
trace citronellic acid
trace zingiberene
trace benzyl alcohol
trace 1-octanol
trace menthone
trace isomenthone
trace 2-methylbutanal
trace 3-methylbutanal
trace methyl salicylate
trace rosefuran
trace menthyl acetate
trace 2-butanol
trace 2-methylpropanol
trace acetone
trace benzyl methyl ether
trace prenol
trace methyl cis-geranate
trace 1-butanol
trace citronellyl hexanoate
trace p-1-menthenal-9
92.1% total
Source: Kovats, 1987.

Santalum album L.
Sandalwood oil (fresh)

50.0% cis-α-santalol
20.9% cis-β-santalol
4.1% epi-β-santalol
3.9% (Z)-trans-α-bergamotol
2.9% α-santalal
1.7% cis-lanceol
1.5% trans-β-santalol
1.4% β-santalene
1.2% spirosantalol
1.1% cis-nuciferol
1.0% epi-β-santalene
0.8% α-santalene
0.6% β-bisabolol
0.6% trans-α-santalol
0.6% β-santalal
0.4% dihyro-α-santalol
0.3% ar-curcumene
0.3% α-bisabolol
0.1% β-curcumene
0.1% trans-α-bergamotene
0.1% (Z)-trans-α-bergamotal
0.1% β-bisabolene
0.1% α-eka-santalal
0.1% (E)-nerolidol
trace γ-curcumene
trace santene
trace β-eka-santalal
93.8% total
Source: Brunke & Hammerschmidt, 1988.

Vetiveria zizanioides (L.) Nash
Vetiver oil

50.0% vetiverol
10.0% α-vetivol
10.0% β-vetivol
10.0% γ-vetivene
5.0% α-vetivone
5.0% β-vetivone
1.0% 1,10-dihydro-α-vetivone
1.0% vetiselinene
1.0% vetiselinenol
1.0% α-vetispirene
1.0% β-betispirene
1.0% vetivenic acid
1.0% khusimone
1.0% khusimol
0.5% vetivalene
0.1% vetiazulene
98.6% total
Source: Garnero, 1972.

Table on standard physical properties of some essential oils

Most of the data presented here have been issued by the International Standardization Organization (ISO). ISO standards are determined in accordance with standard procedures. The procedures used to determine the parameters in this table are stipulated in the following standards:

Relative density: ISO 279 – 1981: Determination of relative density at 20 °C.
Refractive index: ISO 280 – 1976: Determination of refractive index.
Optical rotation: ISO 592 – 1981: Determinatioin of optical rotation.
Miscibility in ethanol: ISO 875 – 1981: Determination of miscibility in ethanol.

In the last column the number of the standard referring to the essential oil in question is given. If available, the ISO standard with the year of its publication is given. ISO/DIS refers to a standard that is currently under review by the ISO Essential Oils Committee. If no ISO standard was available for an essential oil, standard data issued by the Essential Oils Association of the United States (EOA) are presented. EOA data are generally comparable to ISO data, but measurements are taken following different procedures.

Species oil	Relative density	Refractive index	Optical rotation	Miscibility in ethanol	ISO/EOA
Abelmoschus moschatus ambrette seed oil	0.898–0.920	1.468–1.485	–2.5° to +3°	passes test	EOA 147
Cananga odorata cananga oil	0.906–0.923	1.495–1.503	–30° to –15°	partially (95%)	ISO 3523 '76
Cananga odorata ylang-ylang oil 'Extra', Madagascar	0.950–0.965	1.501–1.509	–45° to –36°		ISO 3063 '83
Cananga odorata ylang-ylang oil 'Third', Madagascar	0.906–0.921	1.506–1.513	–63° to –49°		ISO 3063 '83
Cinnamomum camphora white camphor oil	0.855–0.875	1.467–1.472	+16° to +28°	1:1 (95%)	EOA 98
Cinnamomum camphora yellow camphor oil	0.955–0.980	1.496–1.501	+1° to +5°	1:0.5 (90%)	EOA 99
Cinnamomum camphora brown camphor oil	1.064–1.075	1.510–1.550	0° to +3°	1:2 (90%)	EOA 69
Citrus aurantium petitgrain bigarade oil	0.886–0.898	1.456–1.472	–6° to +1°	1:5 (70%)	ISO 8910 '87
Citrus aurantium neroli bigarade oil, Italy	0.866–0.879	1.469–1.474	+2.5° to +11.5°	1:2 (80%)	ISO 3517 '75
Citrus aurantium cold pressed peel oil	0.840–0.861	1.472–1.476	+88° to +98°	1:8 (90%)	ISO 9844 '91
Citrus bergamia bergamot oil	0.876–0.884	1.465–1.470	+15° to +32°	1:1 (85%)	ISO/DIS 3520 '96
Corymbia citriodora eucalyptus citriodora oil	0.860–0.870	1.450–1.456	–1° to +3°	1:2 (80%)	ISO/DIS 3044 '94
Cymbopogon citratus West Indian lemongrass oil	0.872–0.897	1.483–1.489	–3° to +1°	soluble when fresh (70%)	ISO 3217 '74
Cymbopogon flexuosus East Indian lemongrass oil	0.855–0.905	1.483–1.489	–3° to +1°	1:3 (70%)	ISO 4718 '98
Cymbopogon martini palmarosa oil	0.880–0.894	1.471–1.478	+1.4° to +3°	1:2 (70%)	ISO 4727 '88

Cymbopogon winterianus Java citronella oil	0.880–0.895	1.466–1.473	–5° to 0°	1:2 (80%)	ISO 3848 '76
Lavandula angustifolia lavender oil	0.880–0.890	1.458–1.464	–11.5° to –7°	1:2 (75%)	ISO 3515 '87
Lavandula angustifolia lavender oil 'Maillette'	0.880–0.890	1.455–1.460	–12.5° to –9.5°	1:3 (70%)	ISO 3515 '87
Lavandula ×intermedia lavandin oil 'Abrialii'	0.885–0.897	1.459–1.466	–7° to –2°	1:4 (70%)	ISO 3054 '87
Lavandula ×intermedia lavandin oil 'Grosso'	0.891–0.899	1.458–1.462	–7° to –3.5°	1:3 (70%)	ISO/DIS 8902 '97
Lavandula latifolia spike lavender oil, Spain	0.894–0.917	1.461–1.468	–7° to +2°	1:3 (70%)	ISO 4719 '83
Litsea cubeba litsea cubeba oil	0.880–0.892	1.480–1.490	+3° to +12°	1:3 (70%)	ISO/DIS 3214 '98
Melaleuca alternifolia tea tree oil, terpinen-4-ol type	0.885–0.906	1.475–1.482	+5° to +15°	1:2 (85%)	ISO 4730 '96
Pelargonium cv. group Rosat geranium oil, Bourbon	0.884–0.892	1.462–1.468	–14° to –8°	1:3 (70%)	ISO 4731 '78
Pimenta racemosa bay leaf oil	0.943–0.984	1.505–1.517	up to –3°		ISO 3045 '74
Pogostemon cablin patchouli oil	0.955–0.983	1.505–1.512	–66° to –40°	1:10 (90%)	ISO 3757 '78
Rosa cv. group Damascena rose oil, Bulgaria	0.848–0.861	1.453–1.464	–5 to –2		ISO 9842 '91
Santalum album sandalwood oil	0.968–0.983	1.503–1.508	–21° to –15°	1:5 (70%)	ISO 3518 '79
Vetiveria zizanioides vetiver oil, Bourbon	0.990–1.015	1.522–1.530	+19° to +32°	1:2 (80%)	ISO 4716 '87
Vetiveria zizanioides vetiver oil, Java	0.980–1.018	1.520–1.530	+17° to +32°	1:2 (80%)	ISO 4716 '87

Sources: Bauer, Garbe & Surburg, 1997; ISO Standards.

Literature

Allured Publishing Corporation, 1998. Allured's flavor and fragrance materials. Carol Stream, IL, United States. 482 pp.

Arctander, S., 1960. Perfume and flavour materials of natural origin. S. Arctander, Elizabeth, NJ, United States. 736 pp.

Arnaudo, J.F., 1991. The taste of nature. Industrial methods of natural products extraction. Biolandes, Labrit, France. 30 pp.

Atal, C.K. & Kapur, B.M., 1982. Cultivation and utilization of aromatic plants. Regional Research Laboratory, Jammu-Tawi, India. 815 pp.

Axtell, B.L. & Fairman, R.M., 1992. Minor oil crops. Food and Agriculture Organization of the United Nations, Rome, Italy. 241 pp.

Baerheim Svendsen, A. & Scheffer, J.J.C., 1985. Essential oils and aromatic plants. Martinus Nijhoff/Dr. W. Junk Publishers, Dordrecht, the Netherlands. 246 pp.

Baçer, K.H.C. (Editor), 1995. Proceedings of the 13th International Congress of Flavour, Fragrances and Essential Oils, 15–19 October, 1995, Istanbul, Turkey. 3 volumes. AREP, Istanbul, Turkey. 93, 420, 394 pp.

Bartholome, E., Biekert, E. & Hellmann, H., 1984. Ullmans Encyklopaedie der technischen Chemie [Ullmans encyclopedia of technical chemistry]. 4th Edition, Vol. 20. Verlag Chemie, Weinheim, Germany.

Bauer, K., Garbe, D. & Surburg, 1997. Common fragrance and flavor materials: preparation, properties and uses. 3rd Edition. VCH, Weinheim, Germany. 278 pp.

Bhattacharyya, S.C., Sen, N. & Sethi, K.L. (Editors), 1989. Proceedings of the 11th International Congress of Essential Oils, Fragrances and Flavours, 12–16 November, 1989, New Delhi, India. 5 volumes. Oxford & IBH Publishing, New Delhi, India. 156 + 19, 76, 133, 270, 150 pp.

Boelens, M.H., 1986. The essential oil of spike lavender Lavendula latifolia Vill. (L. spica DC). Perfumer & Flavorist 11(5): 46–63.

Boelens, M.H., 1991. A critical review of the chemical composition of Citrus oils. Perfumer & Flavorist 7: 17–34.

Boelens, M.H., 1995. Chemical and sensory evaluation of trace compounds in naturals. In: Başer, K.H.C. (Editor): Proceedings of the 13th International Conference on Flavours, Fragrances and Essential Oils held in Istanbul, Turkey, 15–19 October 1995. Vol. 3. AREP Publishers, Istanbul, Turkey. pp. 177–185.

Boelens, M.H. & Boelens, H.H., 1997. Differences in chemical and sensory properties of orange flower and rose oils obtained from hydrodistillation and from supercritical CO2 extraction. Perfumer & Flavorist 22(3): 31–35.

Boelens, M.H. & Oporto, A., 1991. Natural isolates from Seville bitter orange tree. Perfumer & Flavorist 16(6): 1–7.

Boelens, M.H., Valverde, F., Sesquerios, L. & Jimenez, R., 1990. Ten years of hydrodiffusion oils. Perfumer and Flavorist 15(5): 11–14.

Boland, D.J., Brophy, J.J. & House, A.P.N., 1991. Eucalyptus leaf oils: use, chemistry, distillation and marketing. Inkata Press, Melbourne, Australia.

Brunke, E.J. (Editor), 1986. Progress in essential oil research. Proceedings of the International Symposium on Essential Oils. Holzminden/Neuhaus, Germany, September 18–21, 1985. Walter de Gruyter, Berlin, Germany. 668 pp.

Brunke, E.J. & Hammerschmidt, F.J., 1988. Constituents of East Indian sandalwood oil – an eighty year long 'stability test' (concentration in fresh oil). Dragoco Report 4: 107–133.

Buccellato, F., 1982. Ylang survey. Perfumer and Flavorist 7(4): 9–12.

Carlin, J.T., Kramer, S. & Ho Chi-Tang, 1988. Comparison of commercial citronella oils from various origins. In: Lawrence, B.M., Mookherjee, B.D. & Willis, B.J. (Editors): Flavors and fragrances: a world perspective. Proceedings of the 10th International Congress of Essential Oils, Fragrances and Flavors, Washington, DC, United States, 16–20 November 1986. Elsevier, Amsterdam, the Netherlands. pp. 495–504.

Chadha, K.L. & Rajendra Gupta (Editors), 1995. Advances in horticulture. Vol. 11. Medicinal and aromatic plants. ??? pp.

Chomchalow, N. & Henle, H.V. (Editors), 1993. Medicinal and aromatic plants in Asia. Proceedings. RAPA Publication 1993/19. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. 196 pp.

Conolly, J.D. & Hill, R.A., 1991. Dictionary of terpenoids. 3 volumes. Chapman & Hall, London, United Kingdom. 1460, 629 pp.

Craker, L.E. & Simon, J.E., 1986–1989. Herbs, spices and medicinal plants: recent advances in botany, horticulture, and pharmacology. 4 volumes. Oryx Press, Phoenix, Arizona, United states.

Cravo, L. Perineau, F., Gaset, A. & Bessiere, J.M., 1992. Study of the chemical composition of the essential oil, oleoresin and its volatile product obtained from ambrette (Abelmoschus moschatus Moench) seeds. Flavour and Fragrance Journal 7: 65–67.

Cu, J.-Q., 1988. Yunnan – the kingdom of essential oil plants. In: Lawrence, B.M., Mookherjee, B.D. & Willis, B.J. (Editors): Flavors and fragrances: a world perspective. Proceedings of the 10th International Congress of Essential Oils, Fragrances and Flavors, Washington, D.C., United States, 16–20 November 1986. Elsevier, Amsterdam, the Netherlands. pp. 231–241.

Curtis, T. & Williams, D.G., 1994. Introduction to perfumery. Ellis Horwood, New York, United States. 752 pp.

De Medici, D., Pieretti, S., Salvatore, G., Nicoletti, M. & Rasoanaivo, P., 1992. Chemical analysis of essential oils of Malagasy medicinal plants by gas chromatography and NMR spectroscopy. Flavour and Fragrance Journal 7: 275–281.

De Pooter, H.L., Aboutabl. E.A. & El-Shabrawy, A.O., 1995. Chemical composition and antimicrobial activity of essential oil of leaf, stem and rhizome of Alpinia speciosa (J.C. Wendl.) K. Schum. grown in Egypt. Flavour and Fragrance Journal 10: 63–67.

Dhar, K.L., Thappa, R.K. & Agarwal, S.G., 1993. Newer trends in essential oils and flavours. Tata McGraw-Hill, New Delhi, India. 375 pp.

Dugo, G., Cotroneo, A., Verzera, A., Donato, M.G., Del Duce, R. & Licandro, G.,

1991. Genuineness characters of the calabrian bergamot essential oil. In: Proceedings 11th International Congress of Essential Oils, Fragrances and Flavours, 12–16 November 1989, New Delhi, India. Vol. 4: 245–264. Flavour and Fragrance Journal 6: 39–56.

Duke, J.A. & DuCellier, J.L.. 1993. CRC Handbook of alternative cash crops. CRC, Boca Raton, United States. 536 pp.

Fahn, A. 1979. Secretory tissues in plants. Academic Press, London, United Kingdom. 302 pp.

Flath, R.A. et al., 1983. Volatile compounds of Acacia sp. blossoms. Journal of Agricultural and Food Chemistry 31: 1167–1170.

Formacek, V. & Kubeczka, K.-H., 1982. Essential oils analysis by capillary gas chromatography & Carbon-13 NMR spectra. John Wiley, Chchester, United Kingdom. 373 pp.

Frey, C., 1988. Dectection of synthetic flavorant addition to some essential oils by selected ion monitoring GC/MS (estimated peak area percentages). In: Lawrence, B.M., Mookherjee, B.D. & Willis, B.J. (Editors): Flavors and fragrances: a world perspective. Proceedings of the 10th International Congress of Essential Oils, Fragrances and Flavors, Washington, D.C., United States, 16–20 November 1986. Elsevier, Amsterdam, the Netherlands. pp. 517–524.

Garnero, J., 1972. A survey of the vetiver oil components. Rivista Italiana Eppos 54: 315.

Gildemeister, E. & Hoffmann, F., 1931. Die ätherischen Öle [The essential oils]. 3 volumes. Verlag der Schimmel, Miltitz bei Leipzig, Germany. 959, 864, 1072 pp.

Gildemeister E. & Hoffmann, F., 1956–1966. Die ätherischen Öle [The essential oils]. 4th Edition, 8 volumes. Akademie Verlag, Berlin, Germany.

Glöss, W. (Publisher), 1995. Fragrance guide. Fragrances on the international market. H&R Edition. Glöss Verlag, Hamburg, Germany. 272 pp.

Groom, N., 1997. The new perfume handbook. 2nd Edition. Blackie Academic & Professional, London, United Kingdom. 435 pp.

Guenther, E., 1948–1952. The essential oils. 6 volumes. Van Nostrand, Toronto, Canada.

Hardman, R., 1973. Spices and herbs: their families, secretory tissues and pharmaceutical aspects. In: Nabney, J. & Matthews, W.S.A. (Editors): Spices. Proceedings of the Conference on Spices held in London, April 10–14, 1972. Tropical Products Institute, London, United Kingdom. pp. 23–35.

Harper, R., Land, D.G., Griffith, N.M. & Bate-Smith, E.C., 1968. Odor qualities: a glossary of usage. British Journal of Psychology 59: 231.

Hay, R.K.M. & Waterman, P.G. (Editors), 1993. Volatile crops: their biology, biochemistry and production. Longman, Harlow, United Kingdom. 185 pp.

Husain, A., 1994. Essential oil plants and their cultivation. Central Institute of Medicinal and Aromatic Plants, Lucknow, India. 292 pp.

Idrisi, A.I., Bellakhdar, J., Canigueral, S., Iglesias, J. & Vila, R., 1993. Composition de l'huile essentielle de la citronelle (Cymbopogon citratus (DC) Stapf) acclimatisée au Maroc [Composition of the essential oil of citronella grass (C. citratus (DC) Stapf) adapted to the climate of Morocco]. Plantes Medicinales et Phytothérapie 26: 264–277.

Ishihara, M., Tsuneya, T. & Uneyama, K., 1993. Components of the volatile concentrate of agarwood. Journal of Essential Oil Research 5: 283–289.

ISO Standards. ISO standards (e.g. on essential oils) are published regularly and individually by the International Organization for Standardization, Geneva, Switzerland. For the standards mentioned in the 'Table on standard physical properties of some essential oils' the years of publication are indicated.

Jantan, I. & Goh, S.H., 1992. Essential oils of Cinnamomum species from Peninsular Malaysia. Journal of Essential Oil Research 4: 161–171.

Kaiser, R., 1989. New volatile constituents of the flower concrete of Michelia champaca L. In: Proceedings 11th International Congress of Essential Oils, Fragrances and Flavours, 12–16 November 1989, New Delhi, India. Vol. 4: 1–13.

Kaiser, R., 1991. Trapping, investigation and reconstitution of flower scents. In: Müller, P.M. & Lamparsky, D. (Editors): Perfumes: art, science and technology. Blackie Academic & Professional, London, United Kingdom. pp. 213–250.

Kaiser, R., 1993. The scent of orchids. Elsevier, Amsterdam, the Netherlands. 259 pp.

Kapoor, J.N., 1991. Attars of India, a unique aroma. Perfumer and Flavorist 16(1): 21–24.

Kovats, E., 1987. Composition of essential oils Part 7. Bulgarian oil of rose (Rosa damascena Mill.). Journal of Chromatography 406: 185–222.

Lawrence, B.M., 1985. A review of the world production of essential oils (1984). Perfumer & Flavorist 10(5): 1–16.

Lawrence, B.M., 1990. Comparative chemical composition of patchouli oil. Perfumer & Flavorist 15(2): 77.

Lawrence, B.M., 1995. The isolation of aromatic materials from natural plant products. In: Tuley de Silva, K. (Editor): A manual on the essential oil industry. United Nations Industrial Development Organization (UNIDO), Vienna, Austria. pp. 57–154

Lawrence, B.M., Mookherjee, B.D. & Willis, B.J. (Editors), 1988. Flavours and fragrances: a world perspective. Proceedings of the 10th International Congress of Essential Oils, Fragrances and Flavors, 16–20 November, 1986, Washington, D.C., United States. Elsevier, Amsterdam, the Netherlands. 1104 pp.

Leung, A.Y. & Foster, S., 1996. Encyclopedia of common natural ingredients used in food, drugs and cosmetics. 2nd Edition. John Wiley & Sons, New York, United States. 649 pp.

Lis-Balchin, M., 1997. Essential oils and 'aromatherapy': their modern role in healing. Journal of the Royal Society of Health 117 (5): 324–329.

Ma, X.-Y., Huang, X.-H., Hua S.-M. & Chen, Y.-Z., 1988. A study of essential oil of Litsea cubeba (Lour.) Pers. Proceedings of the International Conference on Essential Oils, Flavours, Fragrances and Cosmetics, 9–13 October 1988, Beijing. pp. 378–379.

Maarse, H. (Editor), 1991. Volatile compounds in foods and beverages. Marcel Dekker, New York, United States. 764 pp.

Mookerjee, B.D. & Mussinan C.J. (Editors), 1979. Essential oils. Allured Publishing, Wheaton, United States. 272 pp.

Motl, O., Hodačová, J. & Ubik, K., 1990. Composition of Vietnamese cajuput essential oil. Flavour and Fragrance Journal 5: 39–42.

Müller, P.M. & Lamparsky, D. (Editors), 1994. Perfumes: art, science & technology. Blacky Academic & Professional, London, United Kingdom. 658 pp.

Müller, J. & Bräuer, H., 1992. The H&R book of perfume. Glöss Verlag, Hamburg, Germany. 214 pp.

Naef, R. & Morris, A.F., 1992. Lavender et lavandin - une analyse comparative [Lavender and lavandin - a comparative analysis]. Rivista Italiana Eppos (special edition): 364–377.

Nath, S.C., Saha, B.N., Bordoloi, D.N., Mathur, R.K. & Leclercq, P.A., 1993. The chemical composition of the essential oil of Cymbopogon flexuosus (Steud.) Wats. growing in northeast India. Journal of Essential Oil Research 6: 85–87.

Ntezurubanza, L., Scheffer, J.J.C. & Baerheim Svendsen, A., 1987. Composition of the essential oil of Ocimum gratissimum grown in Rwanda. Planta Medica 35: 421–423.

Ohloff, G., 1990. Riechstoffe un Gerüchsinn [Scent and fragrances]. Springer Verlag, Berlin, Germany. English translation published in 1994 by Springer Verlag. 238 pp.

Palevitch, D., Simon, J.E. & Mathé, A. (Editors), 1992. First World Congress on Medicinal and Aromatic Plants for Human Wellfare. Acta Horticulturae No 330–333. 298, 386, 285, 314 pp.

Patterson, R.L.S., Charlwood, B.V., McLeod, G. & Williams, A.A.W. (Editors), 1992. Bioformation of flavours. Royal Society of Chemistry, Cambridge, United Kingdom. 212 pp.

Porter, K.E., 1992. Distillation. Icheme, Rugby, United Kingdom. 112 pp.

Rajeswara, B.R., et al., 1996. Yield and chemical composition of the essential oils of three cymbopogon species suffering from iron chlorosis. Flavour and Fragrance Journal 11: 289–293.

Ramanoelina, P.A.R., Viano, J., Bianchini, J.P. & Gaydou, E.M., 1994. Occurrence of various chemotypes in niaouli (Melaleuca quinquenervia) essential oils from Madagascar using multivariate statistical analysis. Journal of Agricultural and Food Chemistry 42: 1177–1182.

Roshchina, V.V. & Roshchina, V.D., 1993. The excretory function of higher plants. Springer Verlag, Berlin, Germany. 314 pp.

Schügerl, K., 1994. Solvent extraction in biotechnology: recovery of primary and secondary metabolites. Springer Verlag, Berlin, Germany. 213 pp.

Sethi, K.L., Maheswari, M.L. & Gupta, R., 1989. Genetic diversity and development of high oil yielding palmarosa strains. In: Proceedings 11th International Congress of essential oils, fragrances and flavours, 12–16 November, 1989, New Delhi, India. Vol. 3: 89–96.

Shaath, N.A. & Azzo, R., 1992. Egyptian jasmine. Perfumer and Flavorist 17(5): 49–55.

Southwell, I.A., Stiff, I.A. & Curtis, A., 1995. An Australian geranium oil. Perfumer and Flavorist 20 (4): 11–14.

Steinmetz, E.F., 1957. Codex vegetabilis. Steinmetz, Amsterdam, the Netherlands. 142 pp.

Theimer, E.T. (Editor), 1982. Fragrance chemistry: the science of smell. Academic Press, New York, United States. 635 pp.

Teisseire, P.J., 1994. Chemistry of fragrant substances. VCH Publishers, New York, United States. 458 pp.

Tucker, A.O., et al., 1991. Volatile leaf oils of Caribbean Myrtaceae. I. Three varieties of Pimenta racemosa (Miller) J. Moore of the Dominican Republic and the commercial bay oil. Journal of Essential Oil Research 3: 323–329.
Tuley de Silva, K. (Editor), 1995. A manual on the essential oil industry. United Nations Industrial Development Organization, Vienna, Austria. 232 pp.
Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. 600 pp.
Wijesekara, R.O.B. (Editor), n.d. Practical manual on the essential oil industry. United Nations Industrial Development Organization, Viena, Austria. 173 pp.
Zhu, L.-F., Li, Y.-H., Li, B.-L., Lu, B.-Y., Xia, N.-H. & Zhang, W.-L., 1993. Aromatic plants and essential constituents. Hai Feng Publishing, Hong Kong, China. 300 pp.
Zhu, L.-F., Li, Y.-H., Li, B.-L., Lu, B.-Y. & Zhang, W.-L., 1995. Aromatic plants and essential constituents. Supplement 1. Hai Feng Publishing, Hong Kong, China. 250 pp.

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Acronyms of organizations

- CAB(I): Commonwealth Agricultural Bureaux International (Wallingford, United Kingdom; New York, United States).
- CITES: Convention on International Trade in Endangered Species of Wild Fauna and Flora (Lausanne, Switzerland).
- CSIRO: Commonwealth Scientific and Industrial Research Organization (Canberra, Australia).
- DGIS: Directorate-General for International Cooperation of the Netherlands Ministry of Foreign Affairs (Den Haag, the Netherlands).
- EDC: Centre for Education and Development of Chromatography (Hanoi, Vietnam).
- EOA: Essential Oil Association of the United States.
- FAO: Food and Agriculture Organization of the United Nations (Rome, Italy).
- FDA: Food and Drug Administration (Rockville, Maryland, United States).
- FEMA: Flavor and Extract Manufacturers' Association (Washington, D.C., United States).
- FRIM: Forest Research Institute Malaysia (Kepong, Malaysia).
- IBPGR: see IPGRI.
- IEBR: Institute of Ecology and Biological Resources (Hanoi, Vietnam).
- IFEAT: International Federation of Essential Oils and Aroma Traders, (London, United Kingdom).
- IFRA: International Fragrance Association (Geneva, Switzerland).
- INRA: Institut National de la Recherche Agronomique (Antibes, France).
- IOFI: International Organization of Flavour Industries (Geneva, Switzerland).
- IPGRI: International Plant Genetic Resources Institute (Rome, Italy).
- ISO: International Standardization Organization (Geneva, Switzerland).
- IUFRO: International Union of Forestry Research Organizations (Vienna, Austria).
- LIPI: Indonesian Institute of Sciences (Jakarta, Indonesia).
- PCARRD: Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (Los Baños, the Philippines).
- PROSEA: Plant Resources of South-East Asia (Bogor, Indonesia).
- RDCB: Research and Development Centre for Biology (Bogor, Indonesia).
- RIFM: Research Institute for Fragrance Materials (IFRA, Geneva, Switzerland).
- RISMC: Research Institute for Spice and Medicinal Crops (Bogor, Indonesia).
- TISTR: Thailand Institute of Scientific and Technological Research (Bangkok, Thailand).
- UNITECH: Papua New Guinea University of Technology (Lae, Papua New Guinea).

- UPLB: University of the Philippines at Los Baños (Los Baños, the Philippines).
- UPM: Universiti Putra Malaysia (Serdang, Malaysia).
- WAU: Wageningen Agricultural University (Wageningen, the Netherlands).

Glossary

abaxial: on the side facing away from the axis or stem (dorsal)

abortifacient: inducing abortion

absolute: a highly concentrated, alcohol-soluble liquid, normally obtained by alcoholic extraction of concretes or pomades and considered to reflect most accurately the taste and odour of the original material

accession: in germplasm collections: plant material of a particular collection, usually indicated with a number

accessory buds: those additional to the axillary and normal buds; more than one bud in an axil

accrescent: increasing in size with age

achene: a small dry indehiscent one-seeded fruit

acicular: needle-shaped; with a sharp point

acid value: a measure of the content of free acid present in an aromatic material, which tends to increase with increasing age of products such as essential oils and esters, particularly esters of lower and terpene alcohols

actinomorphic: radially symmetrical; applied to flowers which can be bisected in more than one vertical plane

aculeate: furnished with prickles; prickly

acumen: the point of an acuminate leaf; the drip-tip

acuminate: ending in a narrowed, tapering point with concave sides

acute: sharp; ending in a point with straight or slightly convex sides

adaxial: on the side facing the axis (ventral)

adherent: the union of parts usually separate

adnate: united with another part; with unlike parts fused, e.g. ovary and calyx tube

adpressed (appressed): lying flat for the whole length of the organ

adulterate: falsify by admixture of inferior ingredients

adventitious: not in the usual place, e.g. roots on stems, or buds produced in other than terminal or axillary positions on stems

agarbattis (joss stick): incense stick consisting of a blend of aromatic plant matter wrapped around a thin length of bamboo, impregnated with a perfume compound; in high-quality agarbattis the base material is sufficiently fragrant not to require perfuming

agroforestry: land-use systems in which trees or shrubs are grown in association with crops (agricultural crops or pastures) in a spatial arrangement or a rotation and in which there are both ecological and economic interactions between the trees and the other components of the system

air layering: a form of layering in which soil (rooting medium) is brought to the branch to be layered; the ball of soil in a polyethene cover is wrapped around the girdled branch; after adventitious roots grow out above the girdle, the layer can be separated

albumen: the nutritive material stored within the seed, and in many cases surrounding the embryo (endosperm)

aliphatic compounds: acyclic organic compounds; the chain of C-atoms in these compounds may be straight or branched and some of the bands between C-atoms may be unsaturated

alkaloid: large group of organic bases containing nitrogen and usually oxygen that occur for the most part in the form of salts with acids; usually optically and biologically active

alternate: leaves, etc., inserted at different levels along the stem, as distinct from opposite or whorled

alveolate: marked as though honeycombed

amplexicaul: stem-clasping, when the base of a sessile leaf or a stipule is dilated at the base, and embraces the stem

anastomosis: cross connection of branches or roots; union of one vein or parenchyma band with another, the connection forming a reticulation

androecium: the male element; the stamens as a unit of the flower

androgynophore: a column on which stamens and carpels are borne

annual: a plant which completes its life cycle in one year

annular: used of any organs disposed in a circle
anterior: of time, previous; of place, position in front, or turned away from the axis
anthelmintic: a drug or agent that destroys or causes expulsion of intestinal worms
anther: the part of the stamen containing the pollen
antheriferous: bearing anthers
anthesis: the time the flower is expanded, or, more strictly, the time when pollination may take place
antioxidant: a substance that opposes oxidation or inhibits reactions promoted by oxygen or peroxides; many of these substances are used as preservatives in various products
antiseptic: inhibits or retards or prevents the growth and reproduction or arrests the development of bacteria and other micro-organisms that cause infection or other deleterious processes
antispasmodic: an agent that prevents or relieves spasms or a remedy for spasms
apetalous: without petals
apex (plural apices): the tip or summit of an organ
aphrodisiac: a food or drug stimulating sexual desire
apical: at the apex of any structure
apiculate: ending abruptly in a short point
apocarpous: with the carpels free from each other
apomixis: reproduction by seed formed without sexual fusion (apomictic)
appendage: a part added to another; attached secondary or subsidiary part, sometimes projecting or hanging
appendix (botany): a name given to appendages of any kind, e.g. in *Araceae* the sterile top part of the spadix
appressed (adpressed): lying flat for the whole length of the organ
arbuscular: shrubby, and branched like a tree
architectural model: model describing the branching habit of a tree as determined by the pattern of activity of axes, the pattern including timing, positioning and fate (e.g. terminating in an inflorescence) of active axes
areolate: with irregular squares or angular spaces marked out on a surface, e.g. of a fruit; with small cells or cavities
areole: an irregular square or angular space marked out on a surface, e.g. of a fruit; a small cell or cavity
aril: an expansion of the funicle enveloping the seed, arising from the placenta; sometimes occurring as a pulpy cover (arillus)
arillate: possessing an aril
aristate: awned
armed: bearing some form of spines
aromatherapy: the treatment of disorders in humans by the use of essential oils; essential oils are usually used in diluted form as massage oils or preparations for the bath, or in products acting as odour carriers for the purported psychological benefits of essential oils when smelled
aromatic compounds: see benzene derivatives
arthritis: inflammation of a joint or joints
articulate: jointed, or with places where separation takes place naturally
ascending: curving or sloping upwards
astringent: an agent or substance causing constriction of the skin, mucous membranes or raw or exposed tissues; as such, ethanol is used in skin-toning lotions and aluminium chlorohydrate in anti-perspirants
attar: liquid perfume traditional in India; it carries the scent of an aromatic plant in a base of sandalwood or sesame oil
attenuate: gradually tapering
auct.: auctorum (Latin); of authors
auct., non: auctorum, non (Latin); of authors, not ... (author name); used after a scientific name when this name is erroneously applied by several authors to material actually belonging to a different species than the species described by the mentioned author
auricle: a small lobe or ear
auriculate: eared, having auricles
awn: a bristle-like appendage, especially occurring on the glumes of grasses
axial: in the direction of the axis; in longitudinal direction
axil: the upper angle between the leaf and the stem
axillary: arising from the axil
axis: the main or central line of development of a plant or organ
bark: the tissue external to the vascular cambium collectively, being the secondary phloem, cortex and periderm
basifixed: attached or fixed by the base
basionym: the synonym of a scientific name that supplies the epithet for the correct name
batteuse: industrial equipment for washing concretes with alcohol to produce absolutes
beak: a long, prominent and substantial point, applied particularly to prolongations of fruits
bearded: awned; having tufts of hairs
benzene derivatives (benzenoids): chemical compounds containing a characteristic benzene ring, often represented as a C_6 ring with 3 dou-

ble bonds alternating with single bonds between the C-atoms

berry: a juicy indehiscent fruit with the seeds immersed in pulp; usually several-seeded without a stony layer surrounding the seeds

biennial: a plant which flowers, fruits and dies in its second year or season

bifid: forked, divided in two but not to the base

bilabiate: two-lipped

bipinnate: when the primary divisions (pinnae) of a pinnate leaf are themselves pinnate

biseriate: arranged in two rows

bisexual: having both sexes present and functional in the same flower

blade: the expanded part, e.g. of a leaf or petal

blennorrhoea: an excessive secretion and discharge of mucus

body note: the note or combination of notes by which the odour of an essential oil is characterized; on a smelling strip body notes appear after evaporation of monoterpenes and other highly volatile compounds

bole: the main trunk of a tree, generally from the base up to the first main branch

brachyblast: a short reproductive branch

bract: a reduced leaf subtending a flower, flower stalk or the whole or part of an inflorescence

bracteole: a secondary bract on the pedicel or close under the flower

bristle: a stiff hair or a hair-like stiff slender body

bronchitis: inflammation of the bronchial tubes

bud: the nascent state of a flower or branch; often applied to those primordial vegetative or reproductive branches that are enclosed in a prophyllum and have a resting stage

bullate: surface much blistered or puckered

bunch: cluster, growing together

bush: a low thick shrub without a distinct trunk

buttress: the enlargement of the base of trunks of tropical trees that ranges from a small spur or swelling to massive structures, partly root, partly stem, reaching as high as 10 m up the stem, thin and flat to thick, twisted or anastomose

caducous: falling off

callus: small hard outgrowth at the base of spikelets in some grasses; tissue that forms over cut or damaged plant surface

calorific value: the heat produced by the combustion of a unit weight of a fuel

calyx: the outer envelope of the flower, consisting of sepals, free or united

cambium (plural: cambia): a layer of nascent tissue between the wood and bark, adding elements to both

campanulate: bell-shaped

canaliculate: channeled, with a longitudinal groove

canopy: the uppermost leafy layer of a tree, forest or crop

capitate: headed, like the head of a pin in some stigmas, or collected into compact headlike clusters as in some inflorescences

capsule: a dry dehiscent fruit composed of two or more carpels and either splitting when ripe into valves, or opening by slits or pores

carminative: expelling gas from the stomach and intestines

carpel: one of the foliar units of a compound pistil or ovary; a simple pistil has only one carpel

cartilaginous: hard and tough

caryopsis: the fruit of a grass, in which the outer layer (testa) of the seed proper is fused to the ovary wall

cataphyll: reduced or scale-like leaf present in certain seedlings on the lower stem nodes and sometimes elsewhere on the seedling stem

caudate: with a tail-like appendage

cauline: belonging to the stem or arising from it

chartaceous: papery

chemotype: taxon which is morphologically similar to another one but with different chemical content

chromosome: a structural unit in the nucleus which carries the genes in a linear constant order; the number is typically constant in any species

ciliate: with a fringe of hairs along the edge

ciliolate: fringed with small hairs

cincinnus: a monochasial cymose inflorescence with branches alternating from one side of the vertical axis to the other and normally curved to one side

clavate: club-shaped or thickened towards the end

claw: the basal, narrow part of a petal or sepal

cleistogamous: pollination and fertilization taking place within the unopened flower

clone: a group of plants originating by vegetative propagation from a single plant and therefore of the same genotype

cohobation: re-use of distillation waters for the purpose of recovering dissolved essential oil

colleter: a multicellular glandular hair

column (botany): a cylindrical body, e.g. a tube of connate stamen filaments or the central axis of a fruit

coma: the hairs at the end of some seeds; a tuft of leafy bracts or leaves at the top of an inflorescence (e.g. pineapple) *compatibility*: in floral biology: capable of cross- or self-fertilization; in plant propagation: stock-scion combinations resulting in a lasting union

compound: in botany, of two or more similar parts in one organ, as in compound leaf or compound fruit; in chemistry, a substance consisting of 2 or more elements combined chemically in fixed proportions; in perfumery, a perfume concentrate in which the ingredients of a perfume formula are mixed together

concave: hollow

concolourous: similarly coloured on both sides or throughout; of the same colour as a specified structure

concrescent: growing together

concrete: a fatty or waxy aromatic product obtained from a natural source by extraction with a pure, volatile hydrocarbon solvent, a mixture of solvents or carbon dioxide; they are mainly used as raw material for production of absolutes

condenser: in distillation that part of a still in which the hot vapours from a distillation vessel are condensed to liquid by cooling, usually by cold water circulating round a coiled part of the vapour pipe known as 'worm'

cone: the fruit of a pine or fir tree (gymnosperms), largely made up of imbricated scales

conical: having the shape of a cone (cone-shaped)

connate: united or joined

connective (botany): tissue between the pollen sacs of an anther

conspecific: belonging to the same species

contorted: twisted or bent

convex: having a more or less rounded surface

coppice: a small wood which is regularly cut at stated intervals, the new growth arising from the stools

cordate: heart-shaped, as seen at the base of a leaf, etc., which is deeply notched

cordiform: heart-shaped

core: central part; the seeds and integuments of a pome, such as an apple; pith in dicotyledonous plants

coriaceous: of leathery texture

corolla: the inner envelope of the flower consisting of free or united petals

cortex: the bark or rind

corymb: a flat-topped indeterminate inflorescence in which the branches or pedicels sprout from different points, but attain approximately the same level, with the outer flowers opening first

corymbose: flowers arranged to resemble a corymb

cotyledon: seed-leaf, the primary leaf; dicotylous embryos have two cotyledons and monocotylous embryos have one

cover crop: a close-growing crop primarily grown for the purpose of protecting and improving soil between periods of regular crop production or between trees or vines in orchards and plantations

crenate: the margin notched with blunt or rounded teeth

crenulate: slightly crenate, with small teeth

crest: an elevation or ridge upon the summit of an organ

cross-pollination: the transfer of pollen from one flower to the stigma of a flower of another plant which is not of the same clone

crown: the aerial expanse of a tree, not including the trunk; corona; a short rootstock with leaves; the base of a tufted, herbaceous, perennial grass

culm: the stem of grasses and sedges

cultigen: a plant species or race that has arisen or is known only in cultivation

cultivar (cv., plural cvs): an agricultural or horticultural variety that has originated and persisted under cultivation, as distinct from a botanical variety; a cultivar name should always be written with an initial capital letter and given single quotation marks (e.g. banana 'Gros Michel')

cuneate: wedge-shaped; triangular, with the narrow end at the point of attachment, as the bases of leaves or petals

cupular: furnished with or subtended by a cupule

cupule: a small cup-like structure; the cup of such fruits as the acorn, consisting of an involucre composed of adherent bracts

cusp: a sharp, rigid but small point

cuspidate: abruptly tipped with a sharp rigid point

cuticle: the outermost skin of plants, consisting of a thin continuous fatty film

cutting: a portion of a plant, used for vegetative propagation

cyme: a determinate inflorescence, often flat-topped, in which each growing point ends in a flower and the central flowers open first

cymose: bearing cymes or inflorescences related to cymes

damping-off: a disease of seeds or seedlings caused by fungi which cause various effects, from failure to germinate to the dying off of the seedling

deciduous: shedding, applied to leaves, petals, etc.

declinate: bent or curved downward or forward

decoction: a medicinal preparation made by boiling parts of a plant in water

decompound: several times divided or compounded
decumbent: reclining or lying on the ground, but with the summit ascending
decurrent: extending down and adnate to the petiole or stem, as occurs in some leaves
decussate: of leaves, arranged in opposite pairs on the stem, with each pair perpendicular to the preceding pair
deflexed (reflexed): abruptly recurved; bent downwards or backwards
dehiscent: opening spontaneously when ripe, e.g. of capsules, anthers
deltoid: shaped like an equal-sided triangle
density: the ratio of mass to volume of a substance (see also: specific gravity)
dentate: margin prominently toothed with the pointed teeth directed outwards
denticulate: minutely toothed
determinate: of inflorescences, when the terminal or central flower of an inflorescence opens first and the prolongation of the axis is arrested; of shoot growth, when extension growth takes the form of a flush, i.e. only the previously formed leaf primordia unfold; for pulses also used to indicate bush-shaped plants with short duration flowering in one plane
dextrorse: twining to the right (clockwise)
diaphoretic: an agent inducing sweating, having the power to increase perspiration
dichasium (plural dichasia): a cymose inflorescence with 2 equal or nearly equal lateral branches arising below the terminal flower, this pattern being repeated or not (compound and simple dichasium respectively)
dichotomous: forked, parted by pairs
dicotyledon: angiosperm with two cotyledons or seed-leaves
didynamous: with the stamens in two pairs, two long and two short ones
dieback: the dying off of parts of the aboveground structure of the plant, generally from the top downward
digestibility: the percentage of a foodstuff taken into the digestive tract that is absorbed into the body
digitate: a compound leaf whose leaflets diverge from the same point like the fingers of a hand
dilated: expanded into a flat structure
dimorphic: of two forms, as may occur with branches, etc.
dioecious: with unisexual flowers and with the staminate and pistillate flowers on different plants (dioecy)
diploid: with two sets (genomes) of chromosomes, as occurs in somatic or body cells; usually written $2n$, having twice the basic chromosome number of the haploid germ cells
discolourous: dissimilarly coloured on both sides or throughout; of a different colour as a specified structure
disjunct: separated
disk: a fleshy or elevated development of the receptacle within the calyx, corolla or stamens, often lobed and nectariferous
dispersal: the various ways by which seeds are scattered, e.g. by wind, water or animals
distal: situated farthest from the place of attachment
distichous: regularly arranged in two opposite rows on either side of an axis
distillation: the process of transforming (fractions of) a liquid or solid into the vapour state, and condensing the vapour back to liquid or solid, named the distillate
diuretic: tending to increase the flow of urine
dormancy: a term used to denote the inability of a resting plant or plant part (e.g. the seed, bulb, tuber, or in tree crops usually the buds) to grow or to leaf out, even under favourable environmental conditions
dorsal: back; referring to the back or outer surface of a part or organ (abaxial)
dorsifixed: attached by the back, as in the case of the attachment of a filament to an anther
double-flowered: petals monstrously increased at the expense of other organs, especially the stamens
downy: covered with very short and weak soft hairs
drupaceous: resembling a drupe, whether actually a drupe or not
drupe: a fleshy one-seeded indehiscent fruit with the seed enclosed in a strong endocarp
dry-out: the final notes perceptible from an aromatic material or perfume after the body notes have evaporated
dysmenorrhoea: painful menstruation
dyspepsia: a condition of disturbed digestion
ecotype: a biotype resulting from selection in a particular habitat
eglandular: without glands
ellipsoid: a solid which is elliptic in outline
elliptical: oval in outline but widest about the middle
emarginate: notched at the extremity
emetic: an agent that induces vomiting
emmenagogue: substance promoting flow of menstrual discharge

endemic: exclusively native to a specified or comparatively small region; also used as a noun for a taxon thus distributed

endo-: prefix, referring to the inside or the inner surface or part

endocarp: the innermost layer of the pericarp or fruit wall

endosperm: the starchy or oily nutritive material stored within some seeds, sometimes referred to as albumen; it is triploid, having arisen from the triple fusion of a sperm nucleus and the two polar nuclei of the embryo sac

energy value: the heat produced by the combustion of a unit weight of a fuel or food (= calorific value)

enfleurage: the process of transferring the volatile compounds responsible for the scent of picked flowers to a fixed oil or fat spread out on a glass plate; enfleurage is successful only with flowers that continue to produce aroma compounds for several hours after picking, such as jasmine and tuberose

entire (botany): with an even margin without teeth, lobes, etc.

epicalyx: an involucre of bracts below the flower, resembling an extra calyx

epidermis: the true cellular skin or covering of a plant below the cuticle

epigeal: above the ground; in epigeal germination the cotyledons are raised above the ground

epigynous: on the pistil, apparently above the ovary

epipetalous: borne upon or placed before the petals

epiphyte: a plant that grows on another plant but without deriving nourishment from it

epithet: the second part of the scientific name of a species, the first part denoting the genus to which the species belongs

erect: directed towards summit, not decumbent

erecto-patent: between spreading and erect

essential oil: a volatile product, obtained from a natural source, which agrees with that source in odour and name; in a narrow sense only volatile products obtained by steam or water distillation are called essential oils

evapotranspiration: loss of water from the soil by evaporation from the surface and by transpiration from the plants growing thereon

evergreen: bearing foliage all year long; a plant that changes its leaves gradually

ex situ: in an artificial environment or unnatural habitat

exocarp: the outer layer of the pericarp or fruit wall

expectorant: an agent tending to promote discharge of mucus from the respiratory tract

expression: any process for the removal of essential oil from the outer rind of a citrus fruit, involving scarification and compression of the peel

exsert, exserted: protrude beyond, as stamens beyond the tube of the corolla

exstipulate: without stipules

extra-axillary: beyond or outside the axil

extraction: any process for separating aroma compounds from animal or plant matter using a volatile solvent; the product is called a concrete; the composition, and hence odour quality, of an aromatic extract depends strongly on the nature of the solvent used

extrorse: directed outward, as the dehiscence of an anther

falcate: sickle-shaped

fallow: land resting from cropping, often covered by natural vegetation or planted with fast growing herbs, shrubs or trees (fallow crop)

fascicle: a cluster of flowers, leaves, etc., arising from the same point

fasciculate: connected or drawn into a fascicle

febrifuge: an agent serving to reduce fever

fermentation: a chemical change accompanied by effervescence and suggestive of changes produced in organic materials by yeasts

ferrugineous: rust-coloured

fertile (botany): capable of completing fertilization and producing seed; producing seed capable of germination; having functional sexual organs

fertilization (biology): union of the gametes (egg and sperm) to form a zygote

fibre: any long, narrow cell of wood or bark other than vessel or parenchym elements

fibrous: composed of or including fibres

filament: thread; the stalk supporting the anther

filiform: slender; threadlike

fimbriate: fringed

fissured: provided with fissures (cracks of considerable length and depth), e.g. in the bark of some trees

fixed oil: a non-volatile oil, chemically a triglyceride of fatty acids; many fixed oils from plants have faint odours, even when purified, showing that they contain traces of volatile compounds

flavonoid: water-soluble phenolic compounds, consisting of 2 aromatic rings joint together with a 3-carbon unit

fleshy: succulent

floret: a small flower, one of a cluster as in grasses or *Compositae*; a grass floret typically consists of a lemma, palea, 2 lodicules, 3 stamens and a pistil with 2 plumose stigmas

flowering branch: a leafy or leafless segmented axis that bears one or more inflorescences
flush: a brief period of rapid shoot growth, with unfolding of the leaf primordia which had accumulated during the previous quiescent period
fluted: of a bole, with rounded grooves and folds
fodder: something fed to domesticated animals, especially coarse, dried food from plants (hay, straw, leaves)
foliaceous: leaf-like
foliolate: 2-, 3-, 4- etc., with 2-, 3-, 4- leaflets
follicle: a dry, unicarpellate fruit, dehiscing by the ventral suture to which the seeds are attached
forage: grassland and fodder plants suitable as feed for herbivores, usually with lower nutrient concentration and digestibility than concentrates such as grain
fougère: a French word meaning fern; fougère-type perfumes are based on coumarin in combination with oak-moss, and with lavender accentuated in the top note; their odour has no relation with that of ferns
fractionation, fractional distillation: a distillation process in which a fractionating column is interposed between the distillation vessel and the condenser; during fractionation of a homogeneous mixture of volatile components of different boiling points, components with a lower boiling point move up the column faster than components with a higher boiling point and the components distil over in sequence
free: neither adhering nor united
fringed: fimbriate; with hair-like appendages along the margin
fruit: the ripened ovary with adnate parts
fugaceous: withering or falling off rapidly or early
fungicide: an agent that destroys fungi or inhibits their growth
funicle (funiculus): the little cord which attaches the ovule or seed to the placenta
fusiform: spindle-shaped; tapering towards each end from a swollen centre
gamete: a unisexual protoplasmic body, incapable of giving rise to another individual until after conjugation with another gamete
gamopetalous: with united petals either throughout their length or at the base
gamosepalous: with united sepals either throughout their length or at the base
gas-liquid chromatography (GLC): a technique for the separation of the constituents of liquid or gaseous mixtures; in combination with mass spectroscopy it is a powerful tool for the qualitative and quantitative analysis of complex mixtures of chemical compounds such as essential oils or perfumery products
gastralgia: pain in the stomach especially of a neuralgic type
gene: the unit of inheritance located on the chromosome
geniculate: abruptly bent so as to resemble the knee-joint
genome: a set of chromosomes as contained within the gamete and corresponding to the haploid chromosome number of the species
genotype: the genetic makeup of an organism comprising the sum total of its genes, both dominant and recessive; a group of organisms with the same genetic makeup
genus (plural genera): the smallest natural group containing distinct species
geometrical isomerism (cis-trans isomerism): a form of stereoisomerism in which the orientation of structural elements on each side of a double bond in the molecule of one isomer is at a 180° angle to that of the other isomer
germplasm: the genetic material that provides the physical basis of heredity
girth: a measure around a body
glabrate: destitute of pubescence and of any roughness
glabrescent: becoming glabrous or nearly so
glabrous: devoid of hairs
glandular: having or bearing secreting organs or glands
glaucous: pale bluish-green, or with a whitish bloom which rubs off
globose: spherical or nearly so
glomerule: a condensed head of almost sessile flowers; a cluster of heads in a common involucre
glucoside: compound that is an acetal derivative of sugars and that on hydrolysis yields glucose
glume (plural glumes): the chaffy or membranous two-ranked members of the inflorescence of grasses and similar plants; lower glume and upper glume, two sterile bracts at the base of a grass spikelet
glycosides: compounds that are acetal derivatives of sugars and that on hydrolysis yield one or more molecules of a sugar and often a non-carbohydrate
gonorrhoea: a venereal disease characterized by inflammation of the mucous membrane of the genitourinary tract and a discharge of mucus and pus
graft: a union of different individuals by apposition, the rooted plant being termed the stock, the portion inserted the scion

grafting: the process of inserting a scion, which consists of a piece of stem and two or more buds of the plant to be propagated, into another plant (rootstock) with the intention that it will unite and grow
grain (botany): a general term for cereals, those grasses cultivated for food; the caryopsis or the fruit of cereals
granulose (granular): composed of or covered with grain-like minute particles
green manure: green leafy material applied to and mostly worked into the soil to enrich the soil with nutrients and organic matter
gregarious: growing in associated groups or clusters but not matted; at the same time
gynoecium: the female part or pistil of a flower, consisting, when complete, of one or more ovaries with their styles and stigmas
gynophore: a stalk supporting the gynoecium formed by elongation of the receptacle
habit: external appearance or way of growth of a plant
habitat: the kind of locality in which a plant grows
halophyte: a plant that grows naturally in soils having a high content of salts
haploid: having a single set (genome) of chromosomes in a cell or an individual, corresponding to the chromosome number (n) in a gamete
harvest-index: the total harvestable produce as a fraction of the total biomass produced by the crop in a given year
hastate: with more or less triangular basal lobes diverging laterally
head: a dense inflorescence of small crowded often stalkless flowers (a capitulum)
headspace: the space in a container between the contents and the closure; in perfumery, the volatile compounds evaporated by flowers, representing their true odour
hemi-: prefix, meaning half
herb: any vascular plant which is not woody
herbaceous: with the texture, colour and properties of a herb; not woody
hermaphrodite: bisexual; in flowers, with stamens and pistil in the same flower
hesperidium: a superior, polycarpellary, syncarpous berry, pulpy within, and externally covered with a tough rind, e.g. citrus fruits
heterogamous: with two or more kinds or forms of flowers
heterogeneous: lacking in uniformity; exhibiting variability
heteromorphic: varying in number or form
heterostylous: having styles of two or more distinct forms or of different lengths
hexaploid: having six sets of chromosomes ($6n$)
hilum: the scar left on a seed indicating its point of attachment
hirsute: with rather coarse stiff hairs
hispid: covered with long rigid hairs or bristles
homogeneous: uniform as to kind; showing no variability
homologous: of one type
husk: the outer covering of certain fruits or seeds
hyaline: almost transparent
hybrid: the first generation offspring of a cross between two individuals of different species or taxa
hybridization: the crossing of individuals of different species or taxa
hypanthium: a cup-like receptacle usually derived from the fusion of the floral envelopes and androecium on which are seemingly borne the calyx, corolla and stamens
hypocotyl: the young stem below the cotyledons
hypogeal: below ground; in hypogeal germination the cotyledons remain below ground within the testa
hypoglycemia: abnormal decrease of sugar in the blood
idioblast: a cell differing markedly in form and contents from other constituents of the same tissue, like crystalliferous cells, oil and mucilage cells
imbricate: overlapping like tiles; in a flower bud when one sepal or petal is wholly external and one wholly internal and the others overlapping at the edges only
imparipinnate: of leaves, pinnate with an unpaired terminal leaflet
impressed: marked with slight depressions
in situ: in the natural environment
in vitro: outside the living body and in an artificial environment
incised: cut deeply
incompatibility: in floral biology: not capable of cross- or self-fertilization; in plant propagation: not capable to make stock–scion combinations resulting in a lasting union
indehiscent: not opening when ripe
indented: forced inward to form a depression
indeterminate: of inflorescences, a sequence in which the terminal flowers are the last to open, so that the floral axis may be prolonged indefinitely by the terminal meristem; of shoot growth: when the shoot apex forms and unfolds leaves during extension growth, so that shoot growth can continue indefinitely

indigenous: native to a particular area or region
indumentum: a covering, as of hairs, scales, etc.
inferior: beneath, lower, below; an inferior ovary is one which is situated below the sepals, petals and stamens
inflexed: bent or curved inward toward the centre
inflorescence: the arrangement and mode of development of the flowers on the floral axis; the branch that bears the flowers, including all its bracts and branches
infructescence: a ripened inflorescence in the fruiting stage
inner bark: the secondary phloem; the living part of the tissue outside the cambium
insecticidal: destroying or controlling insects
insecticide: an agent that destroys insects
internode: the portion of the stem (culm) between two nodes
introrse: turned inward, towards the axis, as the dehiscence of an anther
involucel: a secondary partial involucre
involucral: belonging to an involucre
involucre: a ring of bracts (involucral bracts) surrounding several flowers or their supports, as in the heads of *Compositae* or the umbels in *Umbelliferae*
involute: having the edges of the leaves rolled inwards
irregular flower: in which parts of the calyx or corolla are dissimilar in size and shape; asymmetrical or zygomorphic
isozymes: multiple distinct molecular forms of an enzyme that differ in net electrical charge; important to the investigation of the molecular basis for cellular differentiation and morphogenesis, and increasingly used to clarify genotypic relationships
joint; jointed: an articulation (e.g. a node); articulated
joss stick: see agarbattis
jugate: connected or yoked together; e.g. in leaves 1–n-jugate: with 1–n pairs of leaflets
juvenile phase (stage): the period between germination and the first signs of flowering, during which vegetative processes preclude flower initiation even under the most favourable conditions
keel (carina): a ridge like the keel of a boat; the two anterior and united petals of a papilionaceous corolla; the principal vein of a sepal or glume
kernel: the nucellus of an ovule or of a seed, that is, the whole body within the coats
labellum: lip; the lowest petal of an orchid; petaloid anterior staminode in *Zingiberaceae*
lac insect: a scale insect (*Laccifer lacca*, synonym: *Kerria lacca*) that produces lac, a resinous gold-coloured substance used for lacquerware
lacerate: torn; irregularly cleft or cut
laciniate: slashed, cut into narrow lobes
lamellate: made up of thin plates
lamina: see blade
lanate: with woolly hairs
lanceolate: lance-shaped; much longer than broad, being widest at the base and tapering to the apex
landrace: a locally developed kind of cultivar, without formal recognition, and usually much more variable than an official registered cultivar and from which usually several cultivars can be selected
lanose: woolly
lateral: on or at the side
latex: a juice, usually white and sometimes sticky, exuding from broken surfaces of some plants
lax: loose, distant
leaflet: one part of a compound leaf
lemma: the lower of the two glumes which surround each floret in the spikelet of grasses
lenticel: lenticular masses of loose cells protruding through fissures in the periderm on stems, fruits and roots, usually arising beneath individual stomata and their main function is gaseous exchange
lenticular: shaped like a double-convex lens
leucorrhoea: a discharge of whitish mucus and pus from the female genitals
liana: a woody climbing vine
lignotuber: a woody swelling, partly or completely underground, at the base of certain plants and containing numerous cortical buds, as in many eucalypts
ligulate: possessing an elongated flattened strap-shaped structure or ligule
ligule: an elongated flattened strap-shaped structure; a membranous outgrowth on the upper surface of a grass leaf at the junction of the sheath and the blade which may be presented by a ridge or by a line of hairs; in palms it is a distal projection of the leaf sheath, often coriaceous
limb: the expanded part of a tubular corolla, as distinct from the tube or throat; the lamina of a leaf or of a petal; the branch of a tree
linear: long and narrow with parallel sides
lingulate: tongue-shaped
lobe: any division of an organ or specially rounded division
lobed: divided, but not to the base

locular: divided by internal partitions into compartments as in anthers and ovaries

locule: the cavity of an ovary or anther

loculicidal: the cavity of a pericarp dehiscent by the back, the dorsal suture

lodicule: one of the small, usually thin, delicate and transparent structures inserted usually in a single whorl of 3, immediately below the stamens in the grass flower

longitudinal: lengthwise

maceration: a process of softening plant matter by soaking; in perfumery it denotes the extraction of odorous plant material by soaking it in hot, melted fat

macronutrients: chemical elements of which relatively large quantities are essential for the growth of a plant (such as N, P, Ca, Mg)

Malesia: the biogeographical region including Malaysia, Indonesia, the Philippines, Singapore, Brunei and Papua New Guinea

mangrove: a brackish-water coastal swamp of tropical and subtropical areas that is partly inundated by tidal flow

marcotting: air layering, a form of layering in which soil (rooting medium) is brought to the branch to be layered; the ball of soil in a polyethene cover is wrapped around the girdled branch; after adventitious roots grow out above the girdle, the layer can be separated

mass spectroscopy: a technique of analysis in which the molecules of a pure compound are subjected to bombardment with high energy electrons; the molecules of the sample are fragmented and separated according to their masses, producing a graphical 'fragmentation pattern'; the molecular structure of the compound can be derived from this pattern

membranaceous (membranous): thin and semi-transparant, like a fine membrane

mericarp: one of the separate halves or parts of a fruit, as in *Umbelliferae*

meristem: undifferentiated tissue of the growing point whose cells are capable of dividing and developing into various organs and tissues

merous: 4-, 5- etc., with 4, 5 etc. parts or numbers of sepals, petals etc.

mesocarp: the middle layer of the pericarp or fruit wall which is often fleshy or succulent

mesophyll: the interior parenchyma of a leaf

midrib: the main vein of a leaf which is a continuation of the petiole

miscibility: the capability of liquids of being mixed to form a homogeneous substance (see also: solubility)

monadelphous: of stamens, united into one group by their filaments

monocarp: a plant that flowers and fruits only once during its lifetime; the single carpel of an apocarpous fruit

monochasium: a cymose inflorescence where a pattern of a single lateral branch arising below the terminal flower is repeated

monocotyledon: angiosperm having a single cotyledon or seed-leaf

monoculture: the cultivation during an extended period of time of a single product to the exclusion of other possible uses of the land

monoecious: with unisexual flowers, but male and female flowers borne on the same plant

monoterpene: a terpene of molecular formula $C_{10}H_{16}$, e.g. limonene, myrcene and phellandrene; most monoterpenes are readily oxidized to coarse-smelling products, so essential oils containing them must be carefully preserved to minimize this tendency

monotypic: consisting of a single element, e.g. of a genus consisting of only one species

mucilage (mucilaginous): a gelatinous substance that is similar to gum but that swells in water without dissolving and forms a slimy mass

mucro: a sharp terminal point

mucronate: ending abruptly in a short stiff point

mulch: plant or non-living materials used to cover the soil surface with the object of protecting it from the impact of rainfall, controlling weeds, temperature and evaporation

muricate: rough, with short and hard tubercular excrescences

mycorrhiza: a symbiotic association of roots with a fungal mycelium which may form a layer outside the root (ectotrophic) or within the outer root tissue (endotrophic)

narcotic: a drug that in moderate doses dulls the senses, relieves pain and induces profound sleep, but in excessive doses causes stupor, coma or convulsions

naturalized: introduced into a new area and established there, giving the impression of wild growth

nectar: a sweet fluid extruded from various parts of the plant (e.g. by the flower to attract pollinators)

nectary: a group of modified subepidermal cells in flowers or leaves (extrafloral) secreting nectar

nematode: small elongated cylindrical worm-like micro-organism, free-living in soil or water, or parasitic in animals or plants

nerve: a strand of strengthening and/or conducting tissue running through a leaf, which starts from the midrib and diverges or branches throughout the blade

neuralgia: an acute paroxysmal pain radiating along the course of one or more nerves

neuter: sexless, neither male or female; having neither functional stamens nor pistils

node: the point on the stem or branch at which a leaf or lateral shoot is borne

nucellar: belonging to the body of the ovule or macrosporangium containing the embryo sac or macrospore

nucellus: the nutritive tissue in an ovule

nut: a one- to many-seeded indehiscent fruit with a hard dry pericarp or shell

nutlet: a little nut

ob-: prefix, indication inverse or opposite condition (obtriangular, obcordate, etc.)

oblanceolate: reverse of lanceolate

oblique: slanting; of unequal sides

oblong: longer than broad, with the sides parallel or almost so

oblongoid: a solid object which is oblong in section

obovate: reverse of ovate

obovoid: a solid object which is obovate in section

obtuse: blunt or rounded at the end

offset (offshoot, rhizome cutting): a lateral shoot used for propagation

oil cell (anatomy): a parenchymatous idioblast filled with oil

oil gland: a glandular cell which secretes oil

oleoresin: a natural plant product consisting of a viscous mixture of essentially essential oil and non-volatile solids

olfaction: the process of smelling

operculum: a lid or cover which separates by a transverse line of division

opposite: of leaves and branches when two are borne at the same node on opposite sides of the stem

optical activity (optical rotation): in organic chemistry, the property of a compound, containing an asymmetric carbon atom, of rotating the plane of polarized light, clockwise in the case of dextrorotatory (abbreviated d-) compounds, and counterclockwise in the case of laevorotatory (abbreviated l-) compounds; in perfumery d- and l-compounds may have different odours, e.g. d- and l-limonene

optical isomerism: isomerism in which the molecular structures of the molecules are mirror-images of one another; optical isomers have the same structural formula, but their molecules can not be superimposed

optical rotation: see optical activity

orbicular: flat with a more or less circular outline

oriental: in perfumery, a heavy and long-lasting perfume; ambergris-like and/or spicy notes combined with woody and balsamic tonalities are typical of this perfume family; middle notes are generally floral, top notes tend to be contrastingly fresh and light

orifice: an opening by which spores, etc., escape; ostiole

orthotropic: having a more or less vertical direction of growth

outer bark: the periderm or rhytidome; the non-living layer of fibrous or corky tissue outside the cambium in woody plants which may be shed or retained

ovary: that part of the pistil, usually the enlarged base, which contains the ovules and eventually becomes the fruit

ovate: egg-shaped in outline or in section; a flat surface which is scarcely twice as long as broad with the widest portion below the middle

ovoid: a solid object which is egg-shaped (ovate in section)

ovule: the immature seed (egg) in the ovary before fertilization

palea: the upper of two membranous bracts enclosing the flower in grasses

palmate: of leaflets, leaf-lobes or veins, with the different elements arising from the same point

palmatifid: cut about half way down in a palmate manner = palmately lobed

palmatilobed: lobed in palmate manner

panicle: an indeterminate branched racemose inflorescence

paniculate: resembling a panicle

pantropical: distributed throughout the tropics

papillate: having minute nipple-like protuberances

papillose: covered with minute nipple-like protuberances

pappus: the various tufts of hairs on achenes or fruits; the limb of the calyx of *Compositae* florets

papyraceous: papery, like paper

parasitic: deriving nourishment from some other organism

paratracheal: applied to wood-elements arranged about the vessels

parenchyma: ground tissue composed of thin-walled, relatively undifferentiated cells, e.g. the pith and mesophyll

paripinnate: a pinnate leaf with all leaflets in pairs

partite (parted): cleft, but not quite to the base
patent: spreading out widely
pedicel: the stalk of an individual flower
pedicellate: furnished with a pedicel
peduncle: the stalk of an inflorescence or partial inflorescence
pedunculate: furnished with a peduncle
pellucid: translucent
peltate: of a leaf, with the stalk attached to the lower surface, not at the edge
pendent, pendulous: drooping; hanging down from its support
penninerved: pinnately veined, parallel veins arise at an angle from a midvein (as in a banana leaf)
pentamerous: having five parts in a flower-whorl
perennial: a plant living for many years and usually flowering each year
perfect flower: a flower possessing both male and female organs
perfume: a harmonious composition prepared from natural or synthetic aromatic materials having aesthetic appeal alone, or after incorporation in an end-product
perianth: the floral leaves as a whole, including both sepals and petals if both are present
pericarp: the wall of the ripened ovary or fruit whose layers may be fused into one, or may be more or less divisible into exocarp, mesocarp and endocarp
persistent: remaining attached; not falling off, not deciduous; applies to organs that remain in place after they have fulfilled their natural functions
petal: a member of the inner series of perianth segments (corolla) which are often brightly coloured
petaloid: petal-like
petiolate: having a petiole
petiole: the stalk of a leaf
petiolule: the stalk of a leaflet
phenology: the complex annual course of flushing, quiescence, flowering, fruiting and leaf fall in a given environment
phenotype: the physical or external appearance of an organism as distinguished from its genetic constitution (genotype); a group of organisms with similar physical or external make-up
phloem: the principal food-conducting tissue of vascular plants; the bast element of a vascular bundle and basically composed of sieve elements, parenchyma cells, fibres and sclereids
photoperiod: length of day favouring optimum functioning of an organism
photosensitive: sensitive to the action of radiant energy such as light
phylogenetic: based on natural evolutionary and genealogic relationships
phytosanitary: of or relating to health or health measures of plants
pilose: hairy with rather long soft hairs
pinna (plural pinnae): a primary division or leaflet of a pinnate leaf
pinnate: arranged in pairs along each side of a common axis
pinnatifid: pinnately divided about halfway to the midrib
pinnatisect: pinnately divided down to the midrib
pistil: the female part of a flower (gynoecium) of one or more carpels, consisting, when complete, of one or more ovaries, styles and stigmas
pistillate: a unisexual flower with pistil, but no stamens
pistillode: a sterile, often reduced pistil
placenta: the part of the ovary to which the ovules are attached
placentation: the way in which the placentae are arranged in the ovary
plagiotropic: having an oblique or horizontal direction of growth
ploidy: degree or repetition of the basic number of chromosomes
plumose: featherlike with fine hairs
plumule: the primary bud of an embryo or germinating seed
pod: a dry fruit composed of a single carpel and dehiscing by sutures, like in legumes; a general term for a dry dehiscent fruit
pollarding: cutting a tree back to the trunk to promote the growth of a dense head of foliage
pollen: spores or grains borne by the anthers containing the male element (gametophyte)
pollination: the transfer of pollen from the dehiscing anther to the receptive stigma
polyembryonic: with more than a single embryo in an ovule
polygamous: with unisexual and bisexual flowers in the same plant
polymorphic, polymorphous: with several or various forms; variable as to habit
polyploid: with more than two sets (genomes) of chromosomes in the somatic cells
pomade (pommade): the highly fragrant, essential-oil-soaked fat resulting from enfleurage, usually used for absolute production
posterior: next to or towards the main axis
poultice: a soft, usually heated and sometimes medicated mass spread on cloth and applied to sores or other lesions

prickle: a sharp, relatively stout outgrowth from the outer layers
primary vegetation: the original, undisturbed plant cover
procumbent: lying along the ground; in wood anatomy also of ray parenchyma cells with their longest dimension in radial direction
propagule: a part of a plant that becomes detached and grows into a new plant
prostrate: lying flat on the ground
protandrous: of flowers, shedding pollen before the stigma is receptive
protogynous: of flowers, the stigma is receptive before the pollen is shed; of inflorescences, the female flowers mature before the male ones
protuberance: projection, an extension beyond the normal surface
proximal: the part nearest the axis (as opposed to distal)
pruinose (pruinous): having a waxy powdery secretion on the surface, a bloom
pruning: cutting off the superfluous branches or shoots of a plant for better shape or more fruitful growth
puberulent: covered with down or fine hairs
puberulous: minutely pubescent
pubescent: covered with soft short hairs
pulp: the soft fleshy part of the fruit; mechanically ground or chemically digested wood used in manufacturing paper and allied products
pulvinus: a minute gland or swollen petiole base
punctate: marked with dots or translucent glands
pungent: bearing a sharp point; causing a sharp or irritating sensation
pyriform: resembling a pear in shape
quadrangular: four-cornered or four-edged
qualitative short-day plant: to flower, the plant needs short days (often with quantitative response); if the daylength surpasses a certain value (the critical daylength) the plant does not flower
quantitative short-day plant: plant flowers sooner under short-day conditions, but short days are not absolutely necessary to flower
raceme: an unbranched elongated indeterminate inflorescence with stalked flowers opening from the base upwards
racemose: raceme-like
rachilla: a diminutive or secondary axis, e.g. the branch that bears a flower or the stalk of the spikelet in grasses
rachis (plural rachides): the principal axis of an inflorescence or a compound leaf beyond the peduncle or petiole
radical: arising from the root, or its crown
radicle: the first root of an embryo or germinating seed
rain forest: a tropical forest receiving an annual rainfall of at least 1800 mm, characterized by lofty evergreen trees forming a continuous canopy below which terrestrial herbs and shrubs are poorly developed
ray: the radiating branch of an umbel; the outer floret of an inflorescence of the compositae with straplike perianth which differs from those in the centre or disk
receptacle (botany): the flat, concave or convex part of the axis from which the parts of the flower arise
reconstitution: the reproduction of an aromatic material of natural origin; it involves identification of the components of the natural product, followed by close matching of the results of the analysis using mainly cheaper synthetic aroma chemicals to produce an essentially convincing representation of costly natural products; some products, e.g. bergamot oil, have been reconstituted with astonishing success, while other odours, e.g. those of cassie oil and ylang-ylang oil are more difficult to reproduce
rectification: a second distillation of an essential oil with the purpose of removing non-volatile matter
recurved: bent or curved downward or backward
reflexed: abruptly bent or turned downward or backward
reforestation: the planting of a formerly forested area with forest trees
refractive index: the ratio of the sine of the angle of incidence to the sine of the angle of refraction when a beam of light passes from a vacuum (or the atmosphere) into the medium studied; this ratio is equivalent to the ratio of the velocity of light in free space to that in the medium
refrigerant: a medication for reducing body heat
regular: of a radially symmetrical flower; actinomorphic
reniform: kidney-shaped
resin: solid to soft semisolid amorphous fusible flammable substance obtained as exudate or as an extract of plants
resinoid: prepared by solvent extracting exudates, highly lignified plant material, or animal substances; incorrectly but commonly used when describing the physical condition of absolutes
reticulate: netted, as when the smallest veins of a leaf are connected together like the meshes of a net

retrorse: turned or directed backward or downward (opposed to antrorse)
revolute: of leaves with the margins, rolled downwards towards the midrib
rhizome: an underground stem which is distinguished from a root by the presence of nodes, buds, and leaves or scales
rhombic: shaped like a rhomb, an equilateral oblique-angled figure
rind: the tough outer layer of the fruit
root sucker: a shoot originating from adventitious buds on the roots
rootstock: see rhizome; a stock for grafting consisting of a root and part of the main axis
rosehip: the fruit of the rose, a cynarrhodium, fleshy, hollow, and enclosing achenes
rosette: a cluster of leaves or other organs in a circular form
rostrum: a beak-like extension
rotund: rounded in outline, somewhat orbicular, but a little inclined towards oblong
rudimentary: of organs, imperfectly developed and non-functional
rugose: wrinkled
rugulose: somewhat wrinkled
ruminate: of endosperm, mottled in appearance, due to the infolding of a dark inner layer of the seed-coat into the paler coloured endosperm
saccate: pouched
sagittate: shaped like an arrowhead; of a leaf base with two acute straight lobes directed downwards
saponin: a glycoside with soap properties
saprophyte: a plant which derives its food from dead organic matter
sapwood: the outer layers of wood adjacent to the bark which in the living tree contain living cells and reserve materials
sarcotesta: the fleshy outer seed-coat
scabrid, scabrous: rough to the touch
scale: a thin scarious body, often a degenerate leaf or a trichome of epidermal origin
scandent: climbing
scarification: of seed, the cutting or softening of the wall of a hard seed to hasten germination
schizocarp: a dry fruit formed from a syncarpous ovary which splits into one-seeded portions, mericarps or 'split fruits'
scrub: vegetation whose growth is stunted because of lack of water coupled with strong transpiration
secondary vegetation: a plant cover that has been disturbed by natural causes or by man
secondary venation: the collection of veins of a leaf blade branching off from midrib in pinnately veined leaves, or from the main veins in palmately veined ones
section (botany): a taxonomic rank between the genus and the species accomodating a single or several related species
seed: the reproductive unit formed from a fertilized ovule, consisting of embryo and seed-coat, and, in some cases, also endosperm
seedling: the juvenile plant, grown from a seed
segment: one of the divisions into which a plant organ, as a leaf or a calyx, may be cleft; the division of a palmate or costapalmate leaf
self-compatible: capable of fertilization and setting seed after self-pollination
self-fertile: capable of fertilization and setting seed after self-pollination
self-pollination: pollination with pollen from the same flower or from other flowers of plants of the same clone
self-sterile: failure to complete fertilization and obtain seed after self-pollination
semi-: prefix, meaning half or incompletely, e.g. semi-inferior
sepal: a member of the outer series of perianth segments
sepaloid: sepal-like
septate: divided by one or more partitions
septum (plural septa): a partition or cross-wall
sericeous: silky
serrate: toothed like a saw, with regular pointed teeth pointing forwards
serrulate: serrate with minute teeth
sesquiterpene: a terpene of molecular formula C_8H_{24}, e.g. caryophyllene and farnesene
sessile: without a stalk
seta (plural setae): a bristle-like body
setose: set with bristles or bristle-like elements
shaggy: villous
sheath: a tubular structure surrounding an organ or part, as the lower part of the leaf clasping the stem in grasses
shoot: the ascending axis, when segmented into dissimilar members it becomes a stem
shrub: a woody plant which branches from the base, all branches being equivalent (see also tree)
simple (botany): not compound, as in leaves with a single blade
sinuate: with a deep wavy margin
sinuous: wavy
sinusitis: inflammation of a sinus (cavity)
slash: a cut or stroke along the stem of a tree to reveal exudates and colours of bark and sapwood

solubility: the weight of a solute required to saturate 100 g of a solvent at a given temperature
solvent extraction: see extraction
spadix: a flower spike with a fleshy or thickened axis, as in aroids and some palms
spat(h)ulate: spoon-shaped
spathe: a large bract enclosing a spadix, or two or more bracts enclosing a flower cluster
spatheole: small spathe
specific gravity: ratio of the weight of a volume of material to the weight of an equal volume of water at a specified temperature
spherical: globular
spicate: spike-like
spiciform: with the form of a spike
spicule: a fine, fleshy or brittle, needlelike spine
spike: a simple indeterminate inflorescence with sessile flowers along a single axis
spikelet: a secondary spike, one of the units of which the inflorescence is made in grasses, consisting of one or more florets on a thin axis, subtended by a common pair of glumes
spine: a short, stiff, straight, sharp-pointed, hard structure usually arising from the wood of a stem
spinescent: ending in a spine or sharp point
spinose, spinous: having spines
spiral: as though wound round an axis
spur (botany): a hollow and slender extension of some part of the flower, usually nectariferous; a small reproductive shoot
squamose: scaly
stamen: one of the male reproductive organs of a flower; a unit of the androecium
staminate: a flower bearing stamens but no pistil
staminode: an abortive or rudimentary stamen without or with an imperfect anther
steam distillation: distillation using steam injected under pressure into a distillation vessel
stellate: star-shaped, as of hairs with radiating branches, or of petals arranged in the form of a star
stem: the main ascending axis of a plant; in bamboos usually named culm, in other plant groups occasionally
stereoisomerism: isomerism in which 2 or more compounds have the same molecular and structural formula, but differ in the spatial arrangement of the atoms in their molecules (see also: geometrical or cis-trans isomerism and optical isomerism)
sterile: failing to complete fertilization and produce seed as a result of defective pollen or ovules; not producing seed capable of germination; lacking functional sexual organs (sterility)
stigma: the portion of the pistil which receives the pollen
still: an apparatus for distillation
stipe: the stalk supporting a carpel or gynoecium
stipitate: borne on a stipe or short stalk
stipule: a scale-like or leaf-like appendage at the base of a petiole
stolon: a trailing stem usually above the ground which is capable of producing roots and shoots at its nodes
stoloniferous: bearing a stolon or stolons
stoma (plural stomata): a breathing pore or aperture in the epidermis
stomachic: a digestive tonic stimulating the action of the stomach
stone: the hard endocarp of a drupe containing the seed or seeds
strain: a group of individuals of a common origin, usually a more narrowly defined group than a cultivar
striate: marked with fine longitudinal parallel lines, as grooves or ridges
strigose: with short stiff hairs lying close along the surface
stump: seedling with trimmed roots and shoot and used as planting stock; also the part of a tree remaining attached to the root after the trunk is cut
style: the part of the pistil connecting the ovary with the stigma
sub-: prefix, meaning somewhat or slightly (e.g. subacute), or below (e.g. subterranean) or less than, imperfectly
subfamily: a taxonomic rank between the family and the tribe denoting a part of a family
subglobose: nearly globular
subspecies: a subdivision of a species, in rank between a variety and a species
subulate: awl-shaped, sharply pointed
succulent: juicy, fleshy
sucker: a shoot, usually originating from adventitious buds on the roots or basal stem parts, which does not fit in the architectural model, but is capable of repeating the model
sudorific: causing or inducing sweat
sulcate: grooved or furrowed
superior: of an ovary, with the perianth inserted below or around its base, the ovary being attached at its base only
supra-axillary: growing above an axil
sympetalous: with united petals
sympodial: of a stem in which the growing point either terminates in an inflorescence or dies,

growth being continued by a new lateral growing point

syncarp: a multiple or fleshy aggregate fruit, including fruit produced from a more or less entire inflorescence (as in *Artocarpus, Ananas, Morus*)

syncarpous: of an ovary composed of two or more united carpels

tail (botany): any long and slender prolongation

tangential: lengthwise, in a plane at right angles to the radius but not passing through the pith (cf. radial)

taproot: the primary descending root, forming a direct continuation of the radicle

taxon (plural taxa): a term applied to any taxonomic unit irrespective of its classification level, e.g. variety, species, genus, etc.

taxonomy: the study of principles and practice of classifying living organisms (systematics)

tendril: a thread-like climbing organ formed from the whole or part of a stem, leaf or petiole

tepal: a segment of a perianth, applied when no distinction between sepals and petals can be made

terete: cylindrical; circular in transverse section

terminal: borne at the end or apex

terpene: an unsaturated hydrocarbon of molecular formula $(C_5H_8)n$; in monoterpenes n=2, in sesquiterpenes n=3; the term terpene is often used to refer to a terpenoid

terpenoid: a chemical compound derived from a terpene

terrestrial: on or in the ground

tertiary venation: generally the collection of the smallest veins of a leaf blade

testa: the outer coat of the seed

tetraploid: having four times ($4n$) the basic number of chromosomes or twice the diploid number ($2n$)

thorn: a woody sharp-pointed structure formed from a modified branch

throat: of a corolla, the orifice of a gamopetalous corolla

thyrse (thyrsus): a compound inflorescence composed of a panicle (indeterminate axis) with the secondary and ultimate axes cymose (determinate)

tiller: a shoot from the axils of the lower leaves, e.g. in some grasses and palms (making such shoots: tillering)

timber: any wood other than fuelwood

tissue culture: a body of tissue growing in a culture medium outside the organism

tomentellous: minutely tomentose

tomentose: densely covered with short soft hairs

tomentum: pubescence

tonic: medicinal preparation believed to have the power of restoring normal activity

top note: the first odour impression given by an aromatic material when smelled

tree: a perennial woody plant with a single evident trunk (see also shrub)

triad: a group composed of 3 elements; a special group of 2 lateral staminate and a central pistillate flower, structurally a short cincinnus

tribe (plural tribae): a taxonomic rank between the family and the genus

trichome: any hair, bristle or scale-like outgrowth of the epidermis

trifid: cleft in three parts

trifoliate: three-leaved

trifoliolate: with three leaflets

trigonous: three-angled, with plane faces

truncate: cut off more or less squarely at the end

trunk: the main stem of a tree apart from its limbs and roots

tuber: the swollen portion of an underground stem or root which acts as a storage organ and propagule; it is usually of one year's duration, those of successive years not arising directly from the old ones nor bearing any constant relation to them

tuberculate: covered with warty protuberances

tuberous: producing tubers or resembling a tuber

tufted: growing in tufts (caespitose)

turgid: swollen, but not with air

umbel: an indeterminate, often flat-topped inflorescence whose divergent peduncles (rays) and pedicels arise from a common point; in a compound umbel each ray itself bears an umbellet or umbellule (small umbel)

umbellule: diminutive of umbel

unarmed: devoid of thorns, spines or prickles

uncinate: hooked

undershrub: any low shrub; partially herbaceous shrub, the ends of the branches perishing during the winter

undulate: wavy, said for instance of a leaf margin if the waves run in a plane at right angles to the plane of the leaf blade

unifoliolate: with one leaflet only, but in origin a compound leaf

uniseriate: in one horizontal row or series

unisexual: of one sex, having stamens or pistils only

urceolate: urn-shaped

vacuum distillation: distillation in equipment from which most air has been removed; this reduces the pressure acting on the material to be distilled, with the result that it will boil and distil at a lower temperature; it is used to distil liquids containing compounds that decompose at high temperature

valve: one of the parts produced by a dehiscing capsule

variegated: irregularly coloured in patches, blotched

variety: a botanical variety which is a subdivision of a species; an agricultural or horticultural variety is referred to as a cultivar

vein: a strand of vascular tissue in a flat organ, such as a leaf

velutinous: see velvety

velvety: with a coating of fine soft hairs; the same as tomentose but denser so that the surface resembles (and feels like) velvet

venation: the arrangement of the veins in a leaf

ventral: facing the central axis (adaxial), opposed to dorsal (abaxial)

vermifuge: a drug serving to destroy or expel parasitic worms of the intestine

verrucose: warty

versatile (botany): turning freely on its support, as anthers on their filaments

verticil: whorl

verticillaster: a false whorl, composed of a pair of opposed cymes, as in *Labiatae*

verticillate: in a whorl with several elements arising at the same node

vesicular: bladder-like

vestigial: small and imperfectly developed

viability: ability to live, grow and develop

villose (villous): with long weak hairs

vine: a plant having a stem that is too slender to hold itself erect and therefore supports itself by climbing over an object

viscid: sticky

viscous: glutinous, or very sticky

volatile: a volatile substance is one that evaporates at room temperature; it is an essential property of odorous materials

warty: covered with firm roundish excrescences

water distillation: a form of distillation in which an aromatic plant material is treated with boiling water to release, vaporize and subsequently condense the essential oil it contains; neroli oil is water distilled from citrus flowers to prevent clumping of the petals, which would occur under steam distillation

waterlogged: flooded with water, generally for a period of at least a few weeks

wax: waxes are mixtures of esters of higher alcohols and higher fatty acids; waxes are used as stiffening agents in the manufacture of cosmetics; natural plant waxes are removed from concretes to produce absolutes

whorl: arrangement with more than two organs of the same kind arising at the same level

wind-break: one to several rows of closely spaced, preferably low branching trees planted to protect adjacent areas from strong winds

wing: any membraneous expansion attached to an organ; a lateral petal of a papilionaceous corolla

wood: the hard, compact, fibrous substance between pith and bark

woolly: clothed with long and tortuous or matted hairs

xylem: the main water-conducting tissue in vascular plants which extends throughout the body of the plant and is also involved in transport of minerals, food storage and support; primary xylem is derived from the procambium, secondary xylem (e.g. the wood of trees and shrubs) from the vascular cambium; xylem is composed of tracheary elements: tracheids and (in angiosperms) vessel elements; both are elongated hollow cells, with thickened, usually heavily lignified walls, and lacking protoplasts when mature; they are joined end to end to form a continuous conducting tube

zygomorphic: irregular and divisible into equal halves in one plane only

Sources of illustrations

Abelmoschus moschatus: Chang, C.E., 1977. Malvaceae. In: Li, H.L. et al. (Editors): Flora of Taiwan. Vol. 3. Epoch Publishing Company, Taipei, Taiwan. Fig. 782, p. 712. Redrawn and adapted by P. Verheij-Hayes.

Acacia farnesiana: Stewart, J.L., Dunsdon, A.J., Hellin, J.J. & Hughes, C.E., 1992. Wood biomass estimation of Central American dry zone species. Tropical Forestry Papers No 26. Oxford Forestry Institute, Department of Plant Sciences, University of Oxford, United Kingdom. p. 6. Redrawn and adapted by P. Verheij-Hayes.

Alpinia zerumbet: Burtt, B.L. & Smith, R.M., 1972. Key species in the taxonomic history of Zingiberaceae. Notes from the Royal Botanic Garden Edinburgh 31. Fig. 10, p. 206 (bracteole, cincinnus with 2 flowers, dissected corolla tube); Wu, T.L., Tsai, H.T., Tong, S.Q, Chen, P.S. & Li, H.W., 1981. Flora reipublicae popularis Sinicae. Vol. 16(2). Science Press, Peking, China. Fig. 27, p. 87 (habit, inflorescence). Redrawn and adapted by P. Verheij-Hayes.

Aquilaria malaccensis: Baillon, H., 1875. Thymelaeaceae. Histoire des plantes [History of the plants]. Vol. 6. Librairie Hachette, Paris, France. Figs. 67, 68, 69, p. 100 (flower, sections through flower and fruit); Gilg, E., 1894. Studien über die Verwandtschaftsverhältnisse der Thymelaeales und über die anatomische Methode [Studies about the relationships in Thymelaeales and on the anatomical method]. Botanische Jahrbücher 18: 488–574, Fig. 8, p. 506 (flowering branch); Roxburgh, W., 1854. On the genus Aquilaria, with remarks by H.T. Colebrooke. Transactions of the Linnean Society, London 21: 199–206, Fig. 21, p. 203 (fruit). Redrawn and adapted by P. Verheij-Hayes.

Blumea balsamifera: Backer, C.A. & van Slooten, D.F., 1924. Geïllustreerd handboek der Javaansche theeonkruiden en hunne betekenis voor de cultuur [Illustrated handbook of weeds of Javanese tea plantations and their significance for tea-growing]. Ruygrok, Batavia, Dutch East Indies. Fig. 222, p. 222 (flowering branch); Li, H.L., 1978. Compositae. In: Li, H.L. et al. (Editors): Flora of Taiwan. Vol. 4. Epoch Publishing Company, Taipei, Taiwan. Fig. 1206, p. 809 (section through flower head, florets). Redrawn and adapted by P. Verheij-Hayes.

Cananga odorata: Verdcourt, B., 1971. Annonaceae. Cananga. In: Milne-Redhead, E. & Polhill, R.M. (Editors): Flora of tropical East Africa. Crown Agents for Oversea Governments and Administrations, London, United Kingdom. Fig. 15, p. 65. Redrawn and adapted by P. Verheij-Hayes.

Cinnamomum camphora: Chang, C.E., 1976. Lauraceae. In: Li, H.L. et al. (Editors): Flora of Taiwan. Vol. 2. Epoch Publishing Company, Taipei, Taiwan. Fig. 355, p. 412. Redrawn and adapted by P. Verheij-Hayes.

Citrus aurantium: Purseglove, J.W., 1968. Tropical crops. Dicotyledons. Vol. 2. Longman, London, United Kingdom. Fig. 77, p. 503. Redrawn and adapted by P. Verheij-Hayes.

Citrus bergamia: Original drawing by P. Verheij-Hayes after living material. Material deposited in herbarium WAG under number PJ 8198.

Clausena anisum-olens: Brown, W.H., 1921 (reprint 1953). Minor products of Philippine forests. Vol. 2. Department of Agriculture and Natural Resources, Bureau of Forestry, Bulletin No 22. Bureau of Printing, Manila, the Philippines. Fig. 71, p. 215 (fruiting branch); Molino, J.-F., 1994. Révision du genre Clausena Burm.f. (Rutaceae) [Revision of the genus Clausena (Rutaceae)]. Bulletin du Muséum National d'Histoire Naturelle, section B, Adansonia 16. Fig. 6, p. 139 (pistils). Redrawn and adapted by P. Verheij-Hayes.

Corymbia citriodora: Original drawing by P. Verheij-Hayes after a photograph by Gerald D. Carr (flowering branches) and herbarium material (J.S. Larmour 2656 present in WAG) (ripe fruits).

Cymbopogon citratus: Stapf, O., 1906. The oil-grasses of India and Ceylon. Kew Bulletin 1906: 297–363. Plate opposite p. 297. Redrawn and adapted by P. Verheij-Hayes.

Cymbopogon flexuosus: Soenarko, S., 1977. The genus Cymbopogon Sprengel (Gramineae). Reinwardtia 9: 225–375. Fig. 39B, p. 366 (inflorescence branch, glume); Weiss, E.A., 1997. Essential oil crops. CAB International, Wallingford, United Kingdom. Fig. 4.8, p. 87 (photograph of habit). Redrawn and adapted by P. Verheij-Hayes.

Cymbopogon martini: Matthew, K.M., 1982. Illustrations on the flora of the Tamilnadu Carnatic. The Rapinat Herbarium, St. Joseph's College, Tiruchirapalli, India. Fig. 836 & 837. Redrawn and adapted by P. Verheij-Hayes.

Cymbopogon winterianus: Hsu, C.C., 1975. Taiwan grasses. Taiwan Provincial Education Association, Taipei, Taiwan. p. 664 (inflorescence part, spikelet pair); Purseglove, J.W., 1972. Tropical crops. Monocotyledons 1. Longman Group Limited, London, United Kingdom. Fig. 17, p. 138 (habit). Redrawn and adapted by P. Verheij-Hayes.

Gaultheria leucocarpa: Li, H.L., 1978. Ericaceae. In: Li, H.L. et al. (Editors): Flora of Taiwan. Vol. 4. Epoch Publishing Company, Taipei, Taiwan. Fig. 899, p. 18 (flower, stamen, sections); Sleumer, H., 1966. Ericaceae. In: van Steenis, C.G.G.J. (Editor): Flora Malesiana, Series 1. Vol. 6. Wolters-Noordhoff Publishing, Groningen, the Netherlands. Fig. 67, p. 693 (flowering and fruiting branch). Redrawn and adapted by P. Verheij-Hayes.

Jasminum grandiflorum: Herklots, G., 1976. Flowering tropical climbers. Dawson & Science History Publications, Folkestone, United Kingdom. Fig. 202, p. 140 (flowering branch), fig. 203, p. 141 (leaf). Redrawn and adapted by P. Verheij-Hayes.

Lavandula: Bonnier, G., Douin, R., & Poinsot, J., 1990. La grande flore en couleurs de Gaston Bonnier [The large flora in colours of Gaston Bonnier]. 2nd ed. (Palese, R. & Aeschiman, D., Editors). Vol. 2. Editions Belin, Paris, France. Fig. 468 (flowering branches of *L. angustifolia* and *L. stoechas*). Hensen, K.J.W., 1974. Het Lavendula-sortiment [The Lavendula assortment]. Groen 30: 184–190 (inflorescence and corollas *L. angustifolia*). Redrawn and adapted by P. Verheij-Hayes.

Litsea cubeba: Chang, C.E., 1976. Lauraceae. In: Li, H.L. et al. (Editors): Flora of Taiwan. Vol. 2. Epoch Publishing Company, Taipei, Taiwan. Fig. 366, p. 440. Redrawn and adapted by P. Verheij-Hayes.

Melaleuca cajuputi: Greshoff, M., 1894. Schetsen nuttige Indische planten [Sketches of useful Indonesian plants]. Eerste Serie (1–50). Koloniaal Museum, Extra Bulletin. J.H. de Bussy, Amsterdam, the Netherlands. Fig. 41, p. 176. Redrawn and adapted by P. Verheij-Hayes.

Melaleuca quinquenervia: Little, E.L., 1982. Common fuelwood crops: a handbook for their identification. Communi-Tech, Morgantown, United States. Fig. 92, p. 191. Redrawn and adapted by P. Verheij-Hayes.

Michelia champaca: Dasuki, U.A., 1998. Michelia L. In: Sosef, M.S.M., Hong, L.T. & Prawirohatmodjo, S. (Editors): Plant Resources of South-East Asia No 5(3). Timber trees: Lesser-known timbers. Backhuys Publishers, Leiden, the Netherlands. p. 377.

Ocimum gratissimum: Backer, C.A., 1936. Handbook for the cultivation of sugar-cane and manufacturing of cane-sugar in Java. Vol. 7(16). Atlas of the weed flora of Javanese sugar-cane fields. Indonesian Sugar Experiment Station, Pasuruan, Indonesia. Fig. 546. Redrawn and adapted by P. Verheij-Hayes.

Pelargonium L'Hérit. cv. group Rosat: Moore, H.E., 1955. Pelargoniums in cultivation. Baileya 3: 5–25, 41–45, 71–97. Fig. 13, p. 23. Redrawn and adapted by P. Verheij-Hayes.

Pimenta racemosa: Landrum, L.R., 1986. Campomanesia, Pimenta, Blepharocalyx, Legrandia, Acca, Myrrhinium, and Luma (Myrtaceae). Flora Neotropica: monograph 45. New York Botanical Garden, New York, United States. Fig. 33, p. 108 (flower); Little, E.L. & Wadsworth, F.H., 1964. Common trees of Puerto Rico and the Virgin Islands. Agriculture Handbook No 249. United States Department of Agriculture, Washington, D.C., United States. Fig. 194, p. 415 (flowering branch, fruiting branch). Redrawn and adapted by P. Verheij-Hayes.

Pogostemon cablin: Brown, W.H., 1957. Useful plants of the Philippines. Vol. 3. Department of Agriculture and Natural Resources. Technical Bulletin No 10. Bureau of Printing, Manila, the Philippines. (reprint of the 1943 edition). Fig. 110, p. 295 (flowering branch); Raza Bhatti, G. & Ingrouille, M., 1997. Systematics of Pogostemon (Labiatae). Bulletin of the Natural History Museum London (Botany) 27: 77–147, Fig. 5(b), p. 93 (calyx, corolla, bract). Redrawn and adapted by P. Verheij-Hayes.

Rosa L. cv. group Damascena: Bois, E. & Trechslin, A.M., 1964. Rozen [Roses]. Dutch edition by De Langhe, J.E. Artis, Brussels, Belgium. Plate 2, p. 9. Redrawn and adapted by P. Verheij-Hayes.

Santalum album: Koorders, S.H. & Valeton, T., 1913–1918. Atlas der Baumarten von Java [Atlas of the tree species of Java]. Trap, Leiden, the Netherlands. Fig. 254. Redrawn and adapted by P. Verheij-Hayes.

Vetiveria zizanioides: Cope, T.A., 1982. Poaceae. In: Nasir, E. & Ali, S.I. (Editors): Flora of Pakistan, No 143. Department of Botany, University of Karachi, Karachi, Pakistan. Fig. 34, p. 307 (inflorescence, part of inflorescence branch); Matthew, K.M., 1982. Illustrations on the flora of the Tamilnadu Carnatic. The Rapinat Herbarium, Tiruchirapalli, India. Fig. 955 (base of leafy culm, ligule); National Research Council, 1993. Vetiver grass: a thin green line against erosion. National Academy Press, Washington D.C., United States. p. 74 (habit). Redrawn and adapted by P. Verheij-Hayes.

Index of scientific plant names

Page numbers printed in bold refer to main treatment.

Index of vernacular plant names

Page numbers printed in bold refer to main treatment. For transcriptions of Vietnamese names, see at the end of the index.

Transcriptions of Vietnamese characters

[aa] = â	[ar] = ả	[ax] = ã	[ej] = ẹ	[oo] = ô	[ow] = ơ	[uj] = ụ	[uwx] = ữ
[aaf] = ầ	[as] = á	[ee] = ê	[er] = ẻ	[oof] = ồ	[owf] = ờ	[ur] = ủ	[ux] = ũ
[aaj] = ậ	[aw] = ă	[eef] = ề	[es] = é	[ooj] = ộ	[ooj] = ợ	[us] = ú	
[aar] = ẩ	[awf] = ằ	[eej] = ệ	[ex] = ẽ	[oor] = ổ	[owr] = ở	[uw] = ư	
[aas] = ấ	[awj] = ặ	[eer] = ể	[if] = ì	[oos] = ố	[ows] = ớ	[uwf] = ừ	
[aax] = ẫ	[awr] = ẳ	[ees] = ế	[is] = í	[oox] = ỗ	[owx] = ỡ	[uwj] = ự	
[af] = à	[aws] = ắ	[eex] = ễ	[of] = ò	[or] = ỏ	[ox] = õ	[uwr] = ử	
[aj] = ạ	[awx] = ẵ	[ef] = è	[oj] = ọ	[os] = ó	[uf] = ù	[uws] = ứ	

The Prosea Foundation
(Plant Resources of South-East Asia)

Name, location, legal status and structure

- Prosea is a Foundation under Indonesian law, with an international charter, domiciled in Bogor. It is an autonomous, non-profit, international agency, governed by a Board of Trustees. It seeks linkage with existing regional and international organizations;
- Prosea is an international programme focusing on the documentation of information on plant resources of South- East Asia;
- Prosea consists of a Network Office in Bogor (Indonesia) coordinating 6 Country Offices in South-East Asia, and a Publication Office in Wageningen (the Netherlands).

Participating institutions

- Forest Research Institute of Malaysia (FRIM), Karung Berkunci 201, Jalan FRIM Kepong, 52109 Kuala Lumpur, Malaysia;
- Indonesian Institute of Sciences (LIPI), Sasana Widya Sarwono, Jalan Gatot Subroto 10, Jakarta 12710, Indonesia;
- Institute of Ecology and Biological Resources (IEBR), Nghia Do, Cau Giay, Hanoi, Vietnam;
- Papua New Guinea University of Technology (UNITECH), Private Mail Bag, Lae 411, Papua New Guinea;
- Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD), Los Baños, Laguna, the Philippines;
- Thailand Institute of Scientific and Technological Research (TISTR), 196 Phahonyothin Road, Chatuchak, Bangkok 10900, Thailand;
- Wageningen Agricultural University (WAU), Costerweg 50, 6701 BH Wageningen, the Netherlands.

Objectives

- to document and make available the existing wealth of information on the plant resources of South-East Asia for education, extension work, research and industry;
- to make operational a computerized data bank on the plant resources of South-East Asia;
- to publish the results in the form of an illustrated, multi-volume handbook in English;
- to promote the dissemination of the information gathered.

Target groups

- those professionally concerned with plant resources in South-East Asia and working in education, extension work, research and commercial production (direct users);
- those in South-East Asia depending directly on plant resources, obtaining relevant information through extension (indirect users).

Activities

- the establishment and operation of data bases;
- the publication of books;
- the sponsorship, support and organization of training courses;
- research into topics relevant to Prosea's purpose;
- the publication and dissemination of reports and the research results.

Implementation

The programme period has been tentatively divided into 3 phases:
- preliminary phase (1985–1986): publication of 'Plant Resources of South-East Asia, Proposal for a Handbook' (1986);
- preparatory phase (1987–1990): establishing cooperation with South-East Asia through internationalization, documentation, consultation and publication; reaching agreement on the scientific, organizational and financial structure of Prosea;
- implementation phase (1991–2000): compiling, editing and publishing of the handbook; making operational the computerized data bank with the texts and additional information; promoting the dissemination of the information obtained.

Documentation

A documentation system has been developed for information storage and retrieval called Prosea Data Bank. It consists of 7 data bases:
- BASELIST: primarily a checklist of more than 6200 plant species;
- CATALOG: references to secondary literature;
- PREPHASE: references to literature from South-East Asia;
- ORGANYM: references to institutions and their research activities;
- PERSONYM: references to specialists;
- TEXTFILE: all Prosea publications and additional information;
- PHOTPHILE: photographs of useful plants of South-East Asia.

Publication

The handbook in blue cover (hardbound) is distributed by Backhuys Publishers, Leiden, the Netherlands (formerly by Pudoc, Wageningen, the Netherlands). The handbook in green cover (paperback) is distributed in two price-classes: a low-price paperback, distributed by Prosea South-East Asia for all developing countries; a medium-price paperback, distributed by Backhuys

Publishers, Leiden, the Netherlands, for developed countries (becoming available two years after publication of the hardbound edition). The bibliographies are distributed by Prosea South-East Asia.

The handbook

- No 1. Pulses. L.J.G. van der Maesen and Sadikin Somaatmadja (Editors). Pudoc, Wageningen. 1989/ESCAP CGPRT Centre, Bogor. 1990 (out of print)/Prosea, Bogor. 1992.
- No 2. Edible fruits and nuts. E.W.M. Verheij and R.E. Coronel (Editors). Pudoc, Wageningen. 1991/Prosea, Bogor. 1992.
- No 3. Dye and tannin-producing plants. R.H.M.J. Lemmens and N. Wulijarni-Soetjipto (Editors). Pudoc, Wageningen. 1991/Prosea, Bogor. 1992.
- No 4. Forages. L. 't Mannetje and R.M. Jones (Editors). Pudoc, Wageningen. 1992/Prosea, Bogor. 1992.
- No 5(1). Timber trees. Major commercial timbers. I. Soerianegara and R.H.M.J. Lemmens (Editors). Pudoc, Wageningen. 1993/Prosea, Bogor. 1994.
- No 5(2). Timber trees. Minor commercial timbers. R.H.M.J. Lemmens, I. Soerianegara and Wong Wing Chong (Editors). Backhuys Publishers, Leiden. 1995/Prosea, Bogor. 1995.
- No 5(3). Timber trees. Lesser-known timbers. M.S.M. Sosef, L.T. Hong and S. Prawirohatmodjo (Editors). Backhuys Publishers, Leiden. 1998/Prosea, Bogor. 1998.
- No 6. Rattans. J. Dransfield and N. Manokaran (Editors). Pudoc, Wageningen. 1993/Prosea, Bogor. 1994.
- No 7. Bamboos. S. Dransfield and E.A. Widjaja (Editors). Backhuys Publishers, Leiden. 1995/Prosea, Bogor. 1995.
- No 8. Vegetables. J.S. Siemonsma and Kasem Piluek (Editors). Pudoc, Wageningen. 1993/Prosea, Bogor. 1994.
- No 9. Plants yielding non-seed carbohydrates. M. Flach and F. Rumawas (Editors). Backhuys Publishers, Leiden. 1996/Prosea, Bogor. 1996.
- No 10. Cereals. G.J.H. Grubben and Soetjipto Partohardjono (Editors). Backhuys Publishers, Leiden. 1996/Prosea, Bogor. 1996.
- No 11. Auxiliary plants. I. Faridah Hanum and L.J.G. van der Maesen (Editors). Backhuys Publishers, Leiden. 1997/Prosea, Bogor. 1997.
- No 12(1). Medicinal and poisonous plants 1. L.S. de Padua, N. Bunyapraphatsara and R.H.M.J. Lemmens (Editors). (expected publication date 1999).
- No 12(2). Medicinal and poisonous plants 2.
- No 12(3). Medicinal and poisonous plants 3.
- No 13. Spices. C.C. de Guzman and J.S. Siemonsma (Editors). (expected publication date 1999).
- No 14. Vegetable oils and fats.
- No 15(1). Cryptogams. Algae. W.F. Prud'homme van Reine and G.C. Trono Jr (Editors). (expected publication date 1999).
- No 15(2). Cryptogams. Ferns.
- No 15(3). Cryptogams. Fungi.
- No 16. Stimulants. H.A.M. van der Vossen and M. Wessel (Editors). (expected publication date 1999).
- No 17. Fibre plants.
- No 18. Plants producing exudates.

- No 19. Essential-oil plants. L.P.A. Oyen and Nguyen Xuan Dung (Editors). Backhuys Publishers, Leiden. 1999/Prosea, Bogor. 1999.
- No 20. Ornamental plants.

Bibliographies

- Bibliography 1: Pulses. Edition 1. N. Wulijarni-Soetjipto and J.S. Siemonsma (Editors). Prosea, Bogor. 1990.
- Bibliography 2: Edible fruits and nuts. Edition 1. Part 1 and part 2. N. Wulijarni-Soetjipto and J.S. Siemonsma (Editors). Prosea, Bogor/Pudoc, Wageningen. 1993.
- Bibliography 3: Dye and tannin-producing plants. Edition 1. N. Wulijarni-Soetjipto and J.S. Siemonsma (Editors). Prosea, Bogor/Pudoc, Wageningen. 1991.
- Bibliography 4: Forages. Edition 1. N. Wulijarni- Soetjipto (Editor). Prosea, Bogor/Pudoc, Wageningen. 1994.
- Bibliography 5(1): Timber trees: Major commercial timbers. Edition 1. Part 1 and part 2. Sarkat Danimihardja and Soedarsono Riswan (Editors). Prosea, Bogor/Pudoc, Wageningen. 1994.
- Biliography 5(2): Timber trees: Minor commercial timbers. Edition 1. Sarkat Danimihardja and Djunaedi Gandawidjaja (Editors). Prosea, Bogor. 1996.
- Bibliography 5(3): Timber trees: Lesser-known timbers. Edition 1. Sarkat Danimihardjo and Djunaedi Gandawidjaja (Editors). Prosea, Bogor. 1998.
- Bibliography 6: Rattans. Edition 1. N. Wulijarni- Soetjipto and Sarkat Danimihardja (Editors). Prosea, Bogor. 1995.
- Bibliography 7: Bamboos. Edition 1. N. Wulijarni- Soetjipto and Sarkat Danimihardja (Editors). Prosea, Bogor. 1996.
- Bibliography 8: Vegetables. Edition 1. Part 1 and part 2. Sarkat Danimihardja and M.H. van den Bergh (Editors). Prosea, Bogor. 1995.
- Bibliography 11: Auxiliary plants. Edition 1. Sarkat Danimihardja and Djunaedi Gandawidjaja (Editors). Prosea, Bogor. 1997.

Miscellaneous

- A Selection. E. Westphal and P.C.M. Jansen (Editors). Pudoc, Wageningen. 1989/Prosea, Bogor. 1993.
- Basic list of species and commodity grouping. Version 1. R.H.M.J. Lemmens, P.C.M. Jansen, J.S. Siemonsma, F.M. Stavast (Editors). Prosea Project, Wageningen. 1989. (out of print).
- Basic list of species and commodity grouping. Final version. P.C.M. Jansen, R.H.M.J. Lemmens, L.P.A. Oyen, J.S. Siemonsma, F.M. Stavast and J.L.C.H. van Valkenburg (Editors). Pudoc, Wageningen. 1991/Prosea, Bogor. 1993.
- Proceedings of the First Prosea International Symposium, May 22–25, 1989. Jakarta, Indonesia. J.S. Siemonsma and N. Wulijarni-Soetjipto (Editors). Pudoc, Wageningen. 1989. (out of print).
- Proceedings of the Second Prosea International Workshop, November 7–9, 1994. Jakarta and Cisarua, Indonesia. Rusdy E. Nasution and N. Wulijarni-Soetjipto (Editors). Prosea, Bogor. 1995.

In brief, Prosea is

- an international programme, focused on plant resources of South-East Asia;
- interdisciplinary, covering the fields of agriculture, forestry, horticulture and botany;
- a research programme, making knowledge available for education and extension;
- ecologically focused on promoting plant resources for sustainable tropical land-use systems;
- committed to conservation of biodiversity;
- committed to rural development through diversification of resources and application of farmers' knowledge.

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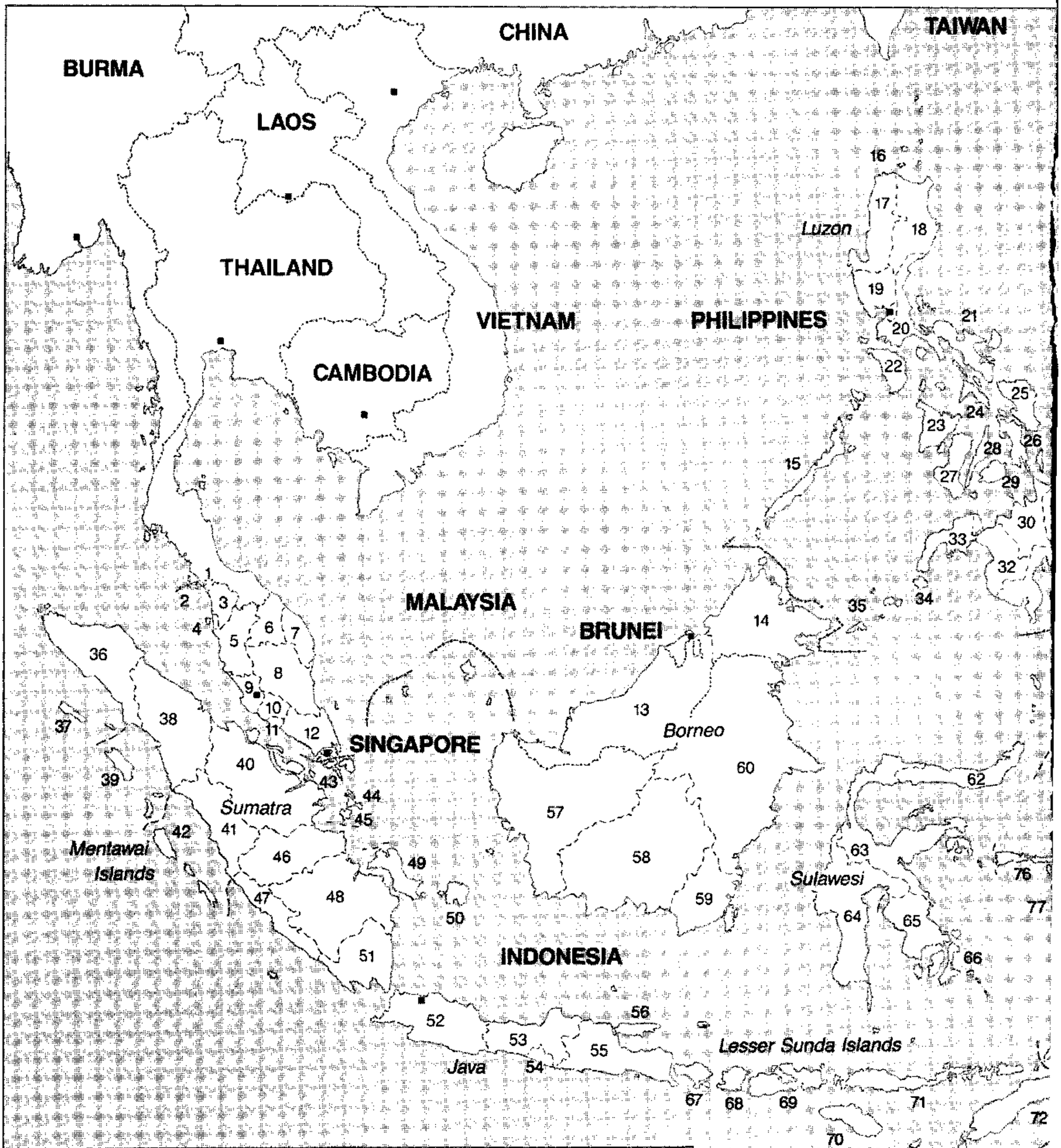
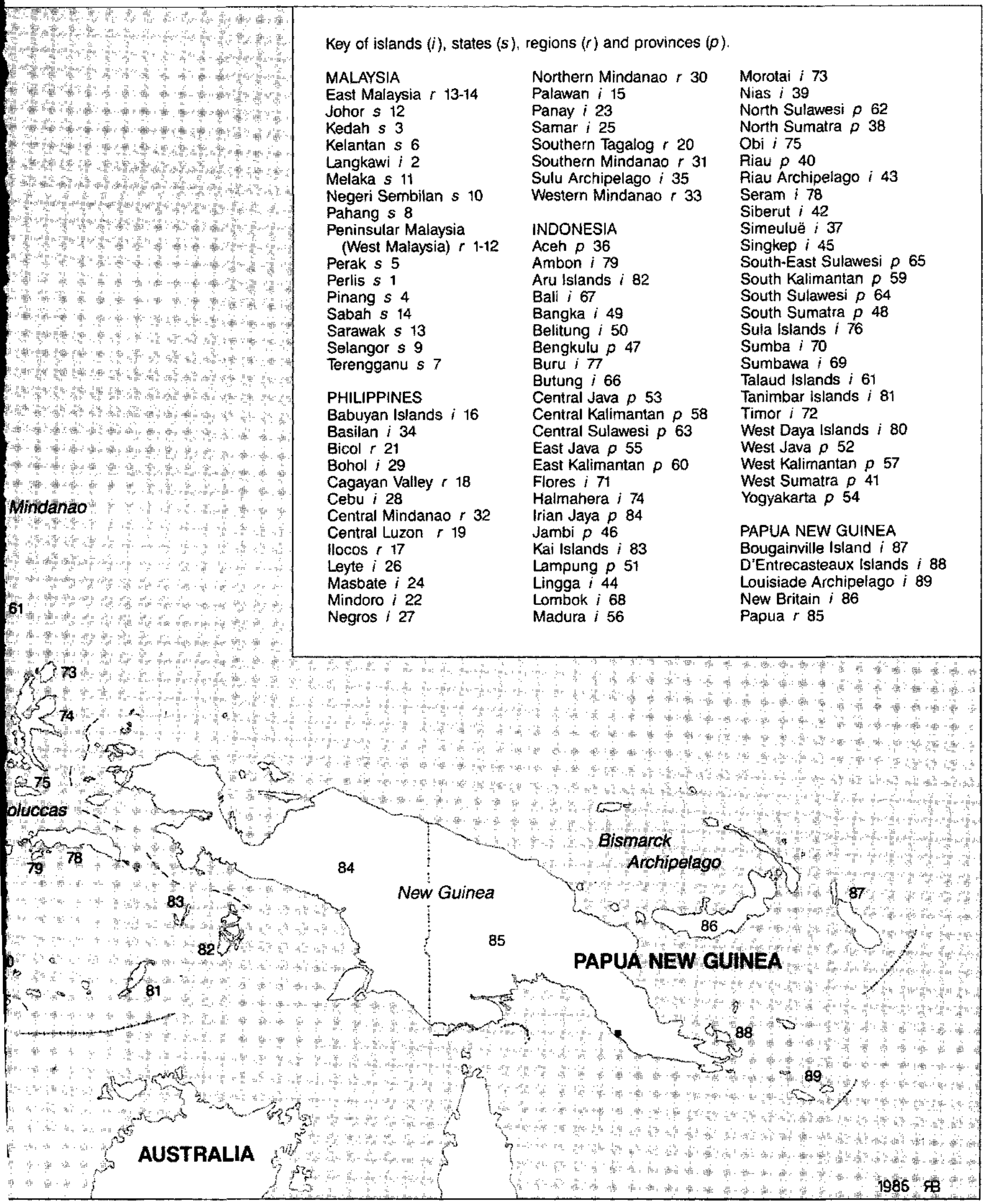


MAP OF SOUTH-EAST ASIA FOR PROSEA

Names of countries in capital letters and islands in lower case; numbers refer to the key.


Key of islands (*i*), states (*s*), regions (*r*) and provinces (*p*).
MALAYSIA
East Malaysia *r* 13-14
Johor *s* 12
Kedah *s* 3
Kelantan *s* 6
Langkawi *i* 2
Melaka *s* 11
Negeri Sembilan *s* 10
Pahang *s* 8
Peninsular Malaysia (West Malaysia) *r* 1-12
Perak *s* 5
Perlis *s* 1
Pinang *s* 4
Sabah *s* 14
Sarawak *s* 13
Selangor *s* 9
Terengganu *s* 7
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AUSTRALIA
1986 FB