Plant Resources of South-East Asia

No 13

Spices

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Foreword

Prosea volume 13 'Spices' focuses on the aromatic plants and their parts, fresh or dried, whole or ground, that are primarily used to impart flavour and fragrance to foods and drinks. The volume is closely related to Prosea volume 19 'Essential-oil plants' that deals with aromatic plants whose main use is for the extraction and use of essential oils.

Ample attention is given to the important and well-known spices from the Orient. No agricultural commodity has played a greater role in the history of 'East meeting West' than the oriental spices; more than any other commodity they are linked to the colonial history of South-East Asia.

In addition the volume deals with the rich assortment of Mediterranean aromatic herbs that are increasingly being grown on a small scale in South-East Asia. Contrary to what happened in the South-East Asian vegetable sector, where a few introduced highland vegetables of temperate origin account for the bulk of the production, the temperate aromatic herbs are only slowly and very gradually being adopted in the region. This is surely related to the fact that the production and marketing of spices and their derivatives are very complex: the species involved are numerous but the economic significance of individual species is marginal.

This volume gives a balanced coverage of the information available on an important group of plant resources for South-East Asia. On the other hand, if the volume reflects the present state of knowledge, one can only conclude that the 'spices' form an ill-known commodity group, which has so far benefited little from the contributions of crop science. Perhaps this will change under the influence of the growing demand for natural and organic products geared towards wholesome living, and the increasing clamour to dispense with synthetic flavours and artificial food colouring.

Like all Prosea publications, this volume is the result of the efforts of an international team of scientists, supported by the Prosea network. The network of Country Offices in South-East Asia played an important role in tracing potential authors, in collecting and checking vernacular names, in compiling national statistics on areas and production, and in scanning local literature that may not be internationally known. It is impressive to see how much cooperation this approach could muster.

In conclusion, I wish to express my appreciation to the Board and personnel of the Prosea Foundation for making this new volume a reality.

Jakarta, August 1999

Dr. Ir. H. Soefjan Tsauri, M. Sc., APU
Chairman
Indonesian Institute of Sciences (LIPI)

1 Introduction

1.1 Definition and species diversity

1.1.1 Definition of spices

Definitions of spices abound in the literature. According to the International Organization for Standardization (ISO), the term 'spices and condiments' refers to 'vegetable products or mixture thereof, without any extraneous matter, that are used for flavouring, seasoning and imparting aroma to foods' (ISO 676). The term is applicable to the 'product either in the whole form or in the ground form'. The ISO lists a total of 109 spices. The United States Food and Drug Administration (FDA), in the Code of Federal Regulations on food labelling, defines spices as 'any aromatic vegetable substance in the whole, broken or ground form (except for those substances which have been traditionally regarded as foods, such as onions, garlic, celery); whose significant function in food is seasoning rather than nutrition; that is true to name; and from which no portion of any volatile oil or other flavouring principle has been removed' (Farrel, 1985). On the other hand, the American Spice Trade Association (ASTA) defines spices broadly as 'the products of dried plants, essentially used for seasoning food'. This specification appears to emphasize the fact that for the most part spice products are traded internationally in the dried form. However, spices can also be used fresh, particularly in areas of production. The International Trade Centre UNCTAD/GATT (1982) market report on spices defined this commodity 'as various strongly flavoured or aromatic substances of vegetable origin obtained from tropical or other plants, commonly used as condiments or employed for other purposes on account of their fragrance and preservative qualities'. This definition includes the utilization of spices other than for the flavouring of food.

It is common in the literature to encounter the term 'herbs and spices', as if inseparable twins, but suggesting a clear distinction between the two. In the food industry, the herbs are considered as 'soft-stemmed plants, the whole herbaceous tops of which are gathered and may be used either fresh or dried in the seasoning of food'. Most temperate flavouring plants fall in this category. On the other hand, the term 'spices' covers 'all other dried aromatic vegetable products used in food seasoning, usually of tropical or subtropical origin'. In contrast to the herbs, spices refer generally to only parts of the plant such as barks, rhizomes, flower buds, fruits, seeds and other parts of fruits (aril).

The distinction between spices and herbs presents some difficulty when applied to some members of each category. Bay-laurel, although of Mediterranean origin, is botanically a tree but is often classified as a culinary herb. So is rosemary which eventually develops a woody stem. Ginger and turmeric are

herbaceous perennials but on account of their rhizomes fall under the term spices. Anise, caraway, coriander, cumin, dill and fennel are known in the international trade as sources of spice seeds, not herb seeds. Thus, the distinction is rather imprecise.
In this volume the term 'spice' is used in a wide sense, covering all aromatic plants and their parts, fresh or dried, whole or ground, used to impart flavour, fragrance and sometimes colour to foods and drinks.

1.1.2 Choice of species

The spices form a large and diverse commodity group. In addition to the classifications based on taxonomic families, properties and plant parts used, many subgroups have been proposed, such as tropical spices, spice seeds, herbs, aromatic vegetables, tree spices, leafy spices, pungent spices, phenolic spices, aromatic barks, and coloured spices, but the combination of chemistry, morphology and agronomy has so far not led to a comprehensive, satisfactory classification (Prakash, 1990).
In this volume, 61 important spices are described in 50 papers (Chapter 2).
Summary data are presented on 65 minor species (Chapter 3). About 150 plant resources with another primary use but also used as a spice, are listed in Chapter 4, with a reference to the Prosea volume where they are or will be treated in more detail.
The selection of species for this volume primarily reflects the commodity grouping adopted for the Prosea handbook (Jansen et al., 1991), which somewhat arbitrarily subdivides the aromatic plants into 'spices' (Prosea 13) and 'essential-oil plants' (Prosea 19). The 'spices' are those species in which the direct use of the whole or ground, fresh or dried plant parts preponderates over the use of the essential oils. The 'essential-oil plants' are those species in which the extraction and use of essential oils is more important than the direct use of the plants. 'Spices' are predominantly used in the flavour industry, whereas 'essential-oil plants' are applied in the fragrance industry as well.
The selection of species is further influenced by diffuse boundaries with some other commodity groups, especially 'vegetables', 'edible fruits and nuts' and 'medicinal and poisonous plants'. Mauritius papeda (*Citrus hystrix* DC.) and tamarind (*Tamarindus indica* L.) are dealt with in Prosea 2: 'Edible fruits and nuts'. Saffron (*Crocus sativus* L.) is described in Prosea 3: 'Dye and tannin-producing plants'. Garlic (*Allium sativum* L.), onion (*A. cepa* L.), chives (*A. schoenoprasum* L.), celery (*Apium graveolens* L.), and capsicum pepper (*Capsicum* L.) are detailed in Prosea 8: 'Vegetables'. Calamus (*Acorus calamus* L.), poppy (*Papaver somniferum* L.) and mint (*Mentha* L.) are described in Prosea 12: 'Medicinal and poisonous plants'. Sesame (*Sesamum* L.) appears in Prosea 14: 'Vegetable oils and fats'.
In view of the above-mentioned choices, it may seem inconsistent that *Citrus amblycarpa* (Hassk.) Ochse (similar in use to *C. hystrix*, described in Prosea 2) and *Capsicum pubescens* Ruiz & Pavón (*Capsicum annuum* L. and *C. frutescens* L., capsicum pepper, are described in Prosea 8) are included in this volume under Minor spices, but this was done to make good earlier omissions. *Citrus amblycarpa* was overlooked during the compilation of Prosea 2. As for *Capsicum pubescens*, it was only recently realized (Grubben & Anggoro H.P.,

1996) that a sizeable production of this South American capsicum pepper exists around the West Javanese city of Lembang.
It was decided to pay some attention in this volume to natural sweeteners and flavour enhancers, as they do not fit well into the Prosea commodity grouping. They are briefly described in general terms in section 1.10.

1.1.3 Origin and geographic distribution

It is estimated that in the course of time and on a worldwide scale, 400–500 plant species have been used as a spice. For South-East Asia the number is close to 275 species. Among the 126 'primary use' spices described in this volume, about half of the species is mainly cultivated, and about half is still mainly collected from the wild.
Most of the important tropical spices (cardamom, cinnamon, clove, ginger, nutmeg, pepper and turmeric) have their origin in the Orient. The only major spices native to the American tropics are pimento and vanilla (capsicum pepper being considered a vegetable).
Up to the 16th Century, the spice trade was centred on India, Sri Lanka, China and Indonesia. Subsequent introduction into other parts of the world has led to diversification of production areas, so that nowadays Zanzibar and Madagascar are important producers of clove, Guatemala produces first-quality cardamom, Grenada the finest nutmeg and mace, and Brazil good-quality pepper.
The spices originating from the American tropics have also been introduced into other regions, and the best quality vanilla is grown in the Indian Ocean Islands of Madagascar and Réunion, in the Pacific Island of Tonga, and in Indonesia.
The Mediterranean area (southern Europe, northern Africa, Middle East) is the home of most of the temperate species (coriander, cumin, dill, fennel, fenugreek, laurel, mustard, oregano, rosemary, sage, sweet basil and thyme). The cold temperate regions have produced only a few such as caraway, horseradish and tarragon.
Most culinary herbs have become widely distributed, although in these crops too certain provenances (local selections and/or specific ecological conditions) are known for their top-of-the-line or special-purpose qualities (Indian dill, Dalmatian sage). Some culinary herbs introduced into South-East Asia have succeeded in becoming part of local cuisine, others occupy small niches at higher elevations, satisfying the demand of a foreign clientele (international hotels) or catering to a local clientele acquiring a taste for foreign cuisine (international fast-food chains).
The increased interest in exotic cuisine through contacts with migrant communities and international travel helps the introduction of new crops. Vietnamese refugees in the United States not only brought along their traditional spices such as *Eryngium foetidum* L. and *Perilla frutescens* (L.) Britton, but also generated a local market and initiated local production.

1.2 Importance of spices

1.2.1 Historical aspects

No commodity has played a more pivotal role in the development of modern civilization than the spices (Parry, 1969; Rosengarten, 1973). In a period when Europe had no knowledge of sugar, tea, coffee, chocolate, potatoes or tobacco, Oriental spices already supplied flavour and pungency to bland foods and drinks, and fragrancy to mask a multitude of unpleasant odours. So indispensable were spices, both politically and economically, as well as culturally, that monarchs sent expeditions in search of them, merchants risked life and fortune to trade in them, wars were fought over them, populations were enslaved, the globe was explored, and revolutionary changes were brought about by the ruthless competition.

The earliest cultivation and trading of aromatic herbs probably took place in Mesopotamia, the cradle of civilization and agriculture. Initially, selected herbs would be planted near habitations for family use, but with the development of an agrarian society, some farmers specialize in the production of these aromatic plants. As contacts between communities, countries and people grew, spices were among the first products exchanged and traded. During the reign of Charlemagne in the 9th Century, the cultivation and use of Mediterranean aromatic herbs greatly expanded in Europe.

Transport over long distances was greatly facilitated by the discovery that aromatic plants retained most of their flavour after drying. To ancient people, spices were so necessary in food, medicine and religious rituals, that they were in short supply and merchants went far in search of aromatics. Camel trains travelled across Asia, but also sea communication between Asiatic countries intensified. Arabia prospered as the great monopolistic carrier of goods between East and West.

Since the beginning of our era 2000 years ago, trade between eastern Mediterranean ports increased in importance. In the early centuries merchants thrived in Alexandria, and later during the Middle Ages in Venice, which controlled the flow of spices from the east through the Mediterranean into Europe.

Gradually the spice merchants in western European countries organized themselves in guilds, which sought direct access to the eastern lands of spices, to free themselves from the monopoly of Mediterranean traders. Portugal, Spain, the Netherlands and England all established sea routes to India and the Far East, and the English and the Dutch in particular founded powerful trading companies. The Dutch East India Company was long successful in securing its monopoly in the Spice Islands by aggressive policies. This ultimately led to the smuggling of spice plants out of those islands into areas beyond the control of the Dutch, marking the beginning of the era of free commerce. The spice trade became highly competitive, comparable to the food industry in general.

The Second World War had a devastating effect upon spice production and trade. Strict rationing of spices became necessary, and this had two important effects. First of all it led to many eastern spices being introduced and tried out in the western hemisphere after the war. Secondly, it gave a strong impetus to the manufacture of artificial and imitation spices.

Advances in organic chemistry have resulted in 5000 or so aroma chemicals.

The synthetics strongly outnumber the naturals. The synthetic compounds have allowed cheap fragrance materials to be produced, which greatly extended their use into everyday products such as soaps, detergents and air fresheners. However, the total eclipse of natural materials predicted for the end of the 20th Century has not happened because of changes in life-style: increased concern for the environment and health has renewed interest in natural aroma products and other natural food additives.

1.2.2 Main product forms and uses

Main product forms

The principal way in which spices are used is directly, in the form of a fresh or dried, whole or ground, vegetable product. The aromatic principles of spices are mainly situated in their essential oils, which can be isolated from the spice by hydrodistillation, steam distillation, hydrodiffusion, expression or solvent extraction. Essential-oil contents of spices vary from as low as 0.1% to as high as 18%. Spice oils have a number of advantages over ground spices in processed foods: no debris and bacterial or fungal contamination, concentrated flavour, better control over flavour strength, usually colourless, less bulky, stable in storage. However, distilled oils can be regarded as artefacts. In many cases, the spice oil does not fully reproduce the natural taste and odour of the spice. For instance, the characteristic bite of pepper and ginger is absent, the characteristic yellow colour of turmeric is lost. Another product of modern spice processing are oleoresins. Oleoresins consist of non-volatile compounds and volatile essential oils, and they contain the flavour constituents in concentrated form. Oleoresins are obtained by extraction with solvents and subsequent removal of the solvent. Spices contain on average 10% oleoresin (variation 3–30%). Oleoresins can be used as direct substitute for the dried spices. Ginger, pepper and turmeric oleoresins are of greater value than their essential oils because of the taste and colour compounds. However, some argue that even oleoresins often fail to reproduce the natural flavour (Greenhalgh, 1982).

Uses

Spices, spice oils and spice oleoresins are important products of the flavour and fragrance industry: they are indispensable in the food and beverage manufacturing industry, the perfumery and cosmetic industry and the pharmaceutical industry.

Spices are first and foremost indispensable in the culinary art. They give taste, smell and sometimes colour to our dishes through their addition to the foods and beverages before, during or after their preparation. It is the spices that make food dishes into original creations, into artistic experiences related to the history, the culture and the geography of a country (e.g. curry powder in India, houng-liu (five-spice powder) in Chinese/Vietnamese cuisine, pizza herbs in Italy, the 'fines herbes' in French cuisine).

Curry powder has many recipes. It usually contains capsicum pepper, coriander, cumin, pepper and turmeric, but other components may be black cumin, cardamom, caraway, cinnamon, fenugreek, ginger, mace, mustard, nutmeg and poppy. Houng-liu (five-spice powder) contains Chinese cassia, clove, fennel, pepper and star anise; it combines well with pork, chicken and duck. Countries or regions are not only associated with particular spiced dishes or drinks but also by other aromatic products (e.g. kretek or clove-cigarettes in Indonesia).

The food manufacturing industry depends on spices to flavour the great variety of products. Spices proper are still most important, but the use of spice oils and spice oleoresins is increasing.

Oleoresins are finding wide application in the canning and frozen-food industries, and in the baking and processed meat industries. The beverage industry is making wide use of spices proper and their essential oils for a great variety of liquors and cordials.

The perfumery and cosmetic industries use the oils of many spices in the blending with chemical substances for perfumes and cosmetics, including personal care products such as soaps and toothpastes. Spice oils are also popular in fringe medicine applications (e.g. aromatherapy).

In traditional medicine, aromatic plants are important in driving out diseases. However, modern developments have largely destroyed the ancient beliefs in the medicinal value of spices. Modern pharmacopoeias are cautious in attributing medicinal effects to spices. Spices impart a pleasant taste to disagreeable medicines and may aid the effect of the chief ingredient. The principal use for spices in medicine lie in their adjuvant and alleviative qualities, e.g. analgesic, anthelminthic, aphrodisiac, carminative, expectorant, purgative, stomachic, tonic. Some definitely have antibiotic (bactericidal, mycocidal) properties. This has increased interest in the commercial exploitation of aromatic plants for food preservation and crop protection.

1.2.3 Economic aspects

The production and marketing of spices and their derivatives are characterized by the great complexity of the global network; the species involved are numerous, while the economic significance of most individual species is limited.

The fact that more than 70% of natural and synthetic flavours and fragrances are consumed by 15% of the world population, suggests there is considerable potential for growth (Verlet, 1993).

Spices

Spices in fresh form are traded in large quantities within the countries of production. In organization and structure such trade is similar to the fresh-vegetable trade.

Most spices enter international trade in the crude dried form. Further processing beyond drying is increasingly undertaken in the producing countries, but final refinement is almost invariably done in the country of consumption for quality reasons (retention of aroma, avoiding adulteration).

The annual world import of spices increased in both quantity and value from 1970 to 1995. It rose from an average of 220 000 t during the period 1970–1975 to 500 000 t during the years 1993–1995, and in value from US$ 300 million to US$ 1.75 billion. The future growth rate in terms of volume is estimated to be between 3% and 4% annually.

Pepper is the most important spice in world trade, cornering over 30% of the total quantity imported in 1991–1993 (Table 1). This is followed by capsicum pepper with a 22% share while the spice seeds rank third (mustard is not included in these statistics). Perennial tropical spices dominate the world import scene.

Table 1. Average world import of spices[1] 1991–1993.

Species	Quantity	
	t	%
Piper nigrum (black, white, green pepper)	155 000	33.8
Capsicum spp. (capsicum pepper, paprika)	100 000	21.8
Spice seeds[2]	75 000	16.3
Cinnamomom spp. (cinnamon, cassia)	33 000	7.2
Curcuma longa (turmeric)	30 000	6.5
Zingiber officinale (ginger)	18 000	3.9
Myristica fragrans (nutmeg, mace)	14 000	3.0
Elettaria cardamomum (cardamom)	14 000	3.0
Syzygium aromaticum (clove)	10 000	2.2
Mixtures (curry powder)	6 000	1.3
Vanilla planifolia (vanilla)	2 000	0.4
Pimenta dioica (pimento)	2 000	0.4
Crocus sativus (saffron)	50	0.0
Total	459 050	100.0

Source: ITC UNCTAD/WTO, 1996.
[1] Table does not consider all spices, e.g. mustard
[2] Anise, caraway, coriander, cumin, dill, fennel

The three largest importing countries of spices during the years 1992–1996 belong to the group of highly industrialized ones (Table 2), with the United States topping the list, and Japan ranking second. Almost half of the list of leading importers are European countries. The developing countries are meagerly represented. In South-East Asia Singapore and Malaysia are important importers. On the other hand, the developing countries form the bulk of spice exporters, with Indonesia as the leading one (Table 2). Singapore, which ranks second, does not produce spices but serves as entrepôt for this commodity. Most of the European countries and the United States are important re-exporters of spices too. A majority of the countries listed as leading exporters are in Asia. South-East Asia contributes considerably to world exports.

World production and import statistics specific for the culinary herbs of traditional Western usage are often not available or difficult to obtain. The most recent available data for this commodity can be derived from the market study published by the International Trade Centre UNCTAD/GATT in 1991 on the most traded culinary herbs in Western Europe. Table 3 shows an overall annual market size of 17 100 t in 1989–1990 for the most popular culinary herbs in the region. Parsley has the largest market size, about 20% of the total volume.

Table 2. Major spice-importing and exporting countries from 1992–1996.

Importer	**Annual value** (million US$)	**Exporter**	**Annual value** (million US$)
United States	326.9	Indonesia	174.5
Japan	165.1	Singapore	161.6
Germany	132.2	China	151.8
Singapore	114.9	Spain	76.3
France	69.2	Germany	64.8
Netherlands	68.0	Netherlands	58.6
United Kingdom	61.2	Madagascar[1)]	56.1
United Arab Emirates[1)]	58.1	Brazil	47.4
Spain	57.6	Sri Lanka[1)]	43.0
Hong Kong	51.2	United States	41.6
Saudi Arabia[1)]	48.0	Guatemala[1)]	40.9
Canada	45.4	Malaysia	40.5
Malaysia	38.3	Turkey[1)]	40.4
Mexico[1)]	36.1	France	33.7
Bangladesh[1)]	31.9	United Kingdom	19.0
Belgium/Luxembourg	28.7	Hungary[1)]	18.2
Italy	25.0	Costa Rica[1)]	17.1
Republic of Korea	24.5	Thailand[1)]	14.3
Switzerland	16.7	Morocco[1)]	13.7
Pakistan	16.2	Pakistan	12.3
Austria	15.5	Mexico[1)]	10.9
Brazil[1)]	15.4	South Africa[1)]	10.2
Sweden	15.1		
Czech Republic[1)]	14.8		
Australia	14.5		
Sri Lanka[1)]	14.2		
South Africa[1)]	13.6		
Denmark	12.5		
Egypt[1)]	11.0		
Kuwait[1)]	10.8		
Morocco[1)]	10.1		
Others	182.0	Others	124.0
Total	1744.7		1270.9

Source: ITC UNCTAD/WTO – Internet, 1997.
[1)] Data averaged over less than 5 years

Herbs contributing 10% or more include mint, oregano, sage and thyme. Except for the Netherlands, where local production figures were not available, the supply into the market was predominantly through import (65%–75%) and the rest from domestic production. The origin of imported dried herbs is not very diver-

Table 3. Market size for dried culinary herbs in selected European markets (France, Germany, the Netherlands, United Kingdom) in 1989–1990.

Species	**Amount** (t)
Petroselinum crispum (parsley)	3 550
Mentha spp. (mint)	2 350
Salvia officinalis (sage)	1 950
Thymus vulgaris (thyme)	1 900
Origanum vulgare (oregano)	1 700
Origanum majorana (marjoram)	1 650
Rosmarinus officinalis (rosemary)	1 000
Ocimum basilicum (basil)	850
Laurus nobilis (laurel)	800
Artemisia dracunculus (tarragon)	750
Satureja hortensis (summer savory)	300
Anethum graveolens (dill)	250
Allium schoenoprasum (chives)	30
Anthriscus cerefolium (chervil)	20
Total	17 100

Source: ITC UNCTAD/GATT, 1991.

sified, being mainly countries in the Mediterranean region (e.g. Morocco, Greece, Egypt, Turkey) and eastern Europe (in particular Hungary and Poland).

Essential oils

World production of essential oils (excluding *Citrus* oils) in the mid-eighties was estimated at about 45 000 t with a value of US$ 700 million. The most recent comprehensive review of essential-oil production and marketing (Lawrence, 1993) estimated the production and value of the 20 most important essential oils at 56 000 t with a value of US$ 350 million. Only two 'spice' oils figure among these 20 most important essential oils, i.e. clove leaf oil (1915 t, US$ 7.7 million) and coriander oil (710 t, US$ 49.7 million), the latter being by far the most expensive one.

About 65% of the world production of essential oils is derived from perennial woody plants (some cultivated, some wild); this adversely affects the elasticity of the supply. The remaining 35% is derived from herbs, mostly cultivated.

In terms of value, developing countries account for about 55% of the annual world production, with the main producers (together accounting for 35–40%) being China, Brazil, Indonesia and India. All four countries have large populations and thus large domestic markets. This has led to reliable production and marketing infrastructure, policies favouring local production, scientific and technical training, and a strong economic position for some products (large share of the world market).

Oleoresins

Spice oleoresin consumption in the world was estimated to be about 1000 t in 1977 (Lewis et al., 1982), and is now several thousand t. About 50% of the world's oleoresin production is pepper oleoresin (Richard, 1991). Major producers are India, Indonesia and Malaysia. Another important oleoresin (several hundred t) is derived from capsicum pepper.

1.2.4 Characteristics of the spice sector per country

Based on market visits and interviews with sector specialists, an attempt has been made to indicate the importance of all major 'primary use' spices described in this volume (Table 4). The situation of the sector in some South-East Asian countries is sketched below.

Table 4. Importance of spices in five South-East Asian countries.

	Ind	**Mal**	**Phi**	**Tha**	**Vie**
Aleurites moluccana (candlenut tree)	4	2(I)	1(I)	0	1
Alpinia galanga (galanga)	4	3	1(I)	5	3
Amomum compactum (round cardamom)	3	1	1	0	0
Anethum graveolens (dill)	2	1	2	0	3
Anthriscus cerefolium (chervil)	1	0	2	0	0
Armoracia rusticana (horseradish)	1(I)	0	1	0	0
Artemisia dracunculus (tarragon)	1	1	2	0	2
Boesenbergia rotunda (Chinese keys)	3	2	0	5	1
Brassica nigra (black mustard)	1(I)	1(I)	2(I)	1(I)	0
Capparis spinosa var. *mariana* (Mariana caper-bush)	1	0	1	0	0
Carum carvi (caraway)	1(I)	1(I)	1(I)	1	0
Cinnamomum burmanni (Indonesian cassia)	4	2	2	1	1
Cinnamomum cassia (Chinese cassia)	2	1	0	1	3
Cinnamomum loureirii (Vietnamese cassia)	0	0	0	1	4
Cinnamomum verum (Ceylon cinnamon)	2	5(I)	3(I)	1	3
Coriandrum sativum (coriander)	4	5(I)	3(I)	5	4
Cuminum cyminum (cumin)	3	5(I)	2(I)	3	1
Curcuma longa (turmeric)	3	5(I)	3	5	4
Elettaria cardamomum (cardamom)	2	5(I)	1	2	1
Eryngium foetidum (sawtooth coriander)	2	1	1	2	3
Etlingera elatior (torch ginger)	2	1	0	0	0
Etlingera hemisphaerica (etlingera)	1	1	0	0	0
Foeniculum vulgare (fennel)	2	2(I)	2(I)	2	3
Illicium verum (Chinese star anise)	2(I)	2(I)	3	2	4
Laurus nobilis (laurel)	1(I)	1(I)	4(I)	0	3(I)
Lippia graveolens (Mexican oregano)	0	0	2	1(I)	0
Myristica argentea (Papua nutmeg)	1	0	0	0	0
Myristica fragrans (nutmeg)	4	4(I)	2(I)	2	2
Myristica succedanea (Halmahera nutmeg)	1	0	0	0	0
Nigella sativa (black cumin)	1(I)	1(I)	0	0	0
Ocimum basilicum (sweet basil)	3	2	3	5	4
Origanum majorana (marjoram)	1	1	2	0	0

Table 4. Continued.

	Ind	Mal	Phi	Tha	Vie
Origanum vulgare (oregano)	1	1	3	1(I)	0
Oxalis barrelieri (oxalis)	1	0	0	0	0
Oxalis corymbosa (pink wood-sorrel)	1	0	0	0	0
Oxalis latifolia (purple garden oxalis)	1	0	0	0	0
Pandanus amaryllifolius (fragrant pandan)	4	3	3	3	1
Perilla frutescens (perilla)	1	1	1	0	4
Persicaria odorata (rau ram)	0	0	1	0	4
Petroselinum crispum (parsley)	2	1	2	1	4
Pimenta dioica (pimento)	1(I)	2(I)	4(I)	4(I)	0
Pimpinella anisum (anise)	1(I)	4(I)	3(I)	3(I)	1(I)
Piper cubeba (cubeb)	3	1	0	0	1
Piper longum (Indian long pepper)	2	1	0	3	2
Piper nigrum (pepper)	5	5	5	5	5
Piper retrofractum (Javanese long pepper)	2	1	0	0	2
Rosmarinus officinalis (rosemary)	1	3(I)	2	0	0
Salvia officinalis (sage)	1	1	2	0	0
Satureja hortensis (summer savory)	0	0	1	0	0
Sinapis alba (white mustard)	2(I)	1(I)	2	2(I)	1
Stevia rebaudiana (stevia)	2	0	0	2	1
Syzygium aromaticum (clove)	5	5(I)	4(I)	4	2(I)
Syzygium polyanthum (salam)	2	1	1	0	0
Thymus vulgaris (thyme)	2	1	2(I)	1(I)	2
Trachyspermum roxburghianum (surage)	1	0	0	1	0
Trigonella foenum-graecum (fenugreek)	0	2(I)	2(I)	0	0
Vanilla planifolia (vanilla)	4	3(I)	4(I)	2	2(I)
Zingiber montanum (Cassumunar ginger)	1	1	0	0	1
Zingiber officinale (ginger)	5	5	5	5	5
Zingiber spectabile (black gingerwort)	3	0	0	0	0
Zingiber zerumbet (wild ginger)	4	1	2	1	1

Notes:
- Ind = Indonesia; Mal = Malaysia; Phi = Philippines; Tha = Thailand; Vie = Vietnam.
- Importance on a scale of 0–5 with '0' indicating spice of no importance, and '5' indicating spice of great importance. '(I)' behind the score indicates that the spice is mainly imported.

Indonesia

Spices are very important in the economy of Indonesia, although less now than before the Second World War. The main spices commercially cultivated are candlenut tree, galanga, round cardamom, Indonesian cassia, turmeric, nutmeg, pepper, clove, vanilla and ginger, large amounts of which are used in the traditional medicine ('jamu') industries. They also account for most of the spice exports, although in some cases, such as clove, local production does not always meet domestic demand, leading to imports. National statistics on the spices are not readily available and are often conflicting and confusing. The data available are presented in the individual species entries in this volume.
A number of Indonesia's spices originate from India and China and have been

brought in over the past 1000 years by migrating people. In the last 400 years about 20 species have been introduced from tropical America, the Mediterranean area and other parts of Europe and Africa. The Mediterranean species introduced by the Europeans when they colonized South-East Asia include anise, dill, fennel, parsley, rosemary and thyme; these are grown on a small scale only. Some herbs such as parsley and rosemary were initially introduced without much success, but renewed interest is being shown in them because of the increasing popularity of European dishes. Indonesia imports small amounts of processed spices, mainly from European countries.

In recent decades Indonesia has begun to develop the technology for widening the prospects for the use of spices in the country, particularly by more local industries. The establishment of the Research Institute for Spice and Medicinal Crops (RISMC) testifies to the importance accorded to the commodity.

The Philippines

From 1991–1996 the Philippines imported an annual average of 1400 t of spices, reaching almost 2000 t in 1996. The value of the imports increased from US$ 1 million in 1991 to US$ 3.4 million in 1996, with an annual average of US$ 2 million. On the other hand, over the same six-year period, export of spices amounted to an annual average of only 150 t valued at US$ 0.2 million. Clearly, the Philippines is a net importer of spices.

Pepper constitutes 50% of the total quantity and total value of spices imported in 1996 (Table 5). Individual spices imported in amounts of 30 t or more and valued at over US$ 50 000 include pimento, anise, laurel, vanilla, saffron, nutmeg and ginger. The bulk of the imports of coriander, fennel, pepper, nutmeg and mace comes from Singapore; pimento from Spain; caraway, ginger, thyme, turmeric and vanilla from the United States; clove and saffron from Hong Kong and laurel from Turkey.

In 1996, the small export of spices from the Philippines included ginger, pepper, saffron and vanilla (Table 5). Except for pepper, the values given represent re-exports. Pepper, saffron and vanilla are mainly exported or re-exported to the United States, ginger to the United Kingdom.

Compared with neighbouring countries in South-East Asia, Filipino cuisine is basically bland. Only the Bicol Region, in the far south of the island of Luzon, is known for its spicy hot dishes. Two of the most popular spices used in almost all Filipino households are pepper and ginger; recently, lemongrass has become a popular stuffing for roasted chicken and pork with a proliferation, particularly in Metro Manila, of small food outlets supplying this type of delicacy. Fresh herbs such as coriander, dill, mint, sweet basil and tarragon are produced in small quantities in the province of Cavite, but their market is limited to first-class hotels and speciality-food establishments.

Spice production in the Philippines is dominated by pepper, the current area of production being about 2000 ha located in the provinces of Batangas, Negros Occidental and Basilan. Production of vanilla has been recently initiated in Negros Oriental. Ginger used to be a major spice crop, but areas of production have dwindled because of problems with diseases and product quality. There is renewed interest in the production of ginger but sourcing large quantities of appropriate planting material is a major stumbling block. The feasibility of

Table 5. Philippine spice imports and exports in 1996.

Species	Imports		Exports	
	t	US$	t	US$
Piper nigrum (pepper)	926	1 756 659	51	87 107
Pimenta dioica (pimento)	67	165 652		
Pimpinella anisum (anise)	43	104 194		
Laurus nobilis (laurel)	98	86 916		
Vanilla planifolia (vanilla)	30	79 512	3	19 490
Crocus sativus (saffron)	49	65 004	2	16 897
Myristica fragrans (nutmeg)	40	61 864		
Zingiber officinale (ginger)	31	52 690	16	3 177
Curcuma longa (turmeric)	21	43 990		
Coriandrum sativum (coriander)	29	37 909		
Cinnamomum spp. (cinnamon)	13	32 958		
Foeniculum vulgare (fennel)	28	25 734		
Thymus vulgaris (thyme)	11	16 453		
Cuminum cyminum (cumin)	8	16 377		
Syzygium aromaticum (clove)	9	14 152		
Myristica fragrans (mace)	3	9 791		
Carum carvi (caraway)	<1	415		
Other (including mixtures)	576	864 479	11	19 142
Total	1982	3 434 749	83	145 813

Source: Department of Trade and Industry, Manila, Philippines.

producing locally some of the imported spices, e.g. turmeric and the spice seeds, at least to satisfy the import demand, should be looked into.

Thailand

Table 6 presents a summary of the Thai spice imports and exports in 1997.

1.3 Properties

The detail in which the properties of spices have been studied varies, and there are therefore varying gaps in knowledge. There is still much to be learned about the relationship between chemical composition and organoleptic properties, changes in composition during the development of the spicy parts of the plant and during storage, and the differences in composition within a species produced by environment and geographical location (Purseglove et al., 1981).
Because most spices are consumed in minute quantities, their nutritional contribution is usually minor, but their physiological effects may be pronounced. Monographs on the physiological properties of many fragrance raw materials have been published by the Research Institute for Fragrance Materials (RIFM), United States, many of them in the journal Food and Chemical Toxi-

Table 6. Thai spice imports and exports in 1997.

Species	Imports		Exports	
	t	US$	t	US$
Zingiber officinale (ginger)	–	–	13 977	13 498 000
Pimenta dioica (pimento)	5 080	3 215 066	1 035	2 075 116
Piper nigrum (pepper)	294	383 585	509	2 330 813
Elettaria cardamomum (cardamom)	50	243 840	235	1 446 828
Curcuma longa (turmeric)	–	–	39	125 348
Pimpinella anisum (anise)	163	147 257	9	30 344
Syzygium aromaticum (clove)	45	58 717	7	13 627
Coriandrum sativum (coriander)	953	982 539	5	22 971
Thymus vulgaris (thyme)	10	70 583	–	–
Myristica fragrans (nutmeg)	95	158 109	–	–
Total	6 690	5 259 696	15 816	19 543 047

Source: Thai Customs Department, Finance Ministry, Bangkok, Thailand.
Note: 1 US$ = 25 Baht.

cology. They give numerous biological data, such as metabolism in mammals, toxicity, carcinogenicity, sensitization and pharmacology. The existence of such monographs for the spices dealt with in this volume is indicated in the individual papers.

1.3.1 Description of flavours and fragrances

The ability of spices to impart a distinct flavour to otherwise bland and less exciting meals distinguishes them from food crops. Taste and smell are the two discriminatory chemical or organoleptic senses through which humans obtain information about the chemical composition of the environment. Whereas the sense 'taste' recognizes only 5 conditions (bitter, salty, sour, sweet, umami), the sense of smell recognizes an immense number of odours and odour compounds. The sense of smell is crucial in the study of flavours and fragrances. It is unique among the senses because it is 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 personal and an odour that is repulsive to some may be attractive to others.

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. A standardized vocabulary to describe odours is used, in which each term is precisely defined. Several systems have been developed (Harper et al., 1968; Müller & Lamparsky, 1994; Ohloff, 1990).

The terms 'flavour' or 'sensory properties' pertain to 'an overall integrated perception of all contributing senses (smell, taste, sight, feeling and sound) at the time of food consumption' (Lindsay, 1985). Perception of flavour is a combined effort of the specialized cells of the olfactory epithelium of the nasal cavity, the taste buds on the tongue and back of the oral cavity, and the non-specific or trigeminal neural receptors detecting sensations such as cooling, burning, pungent or biting effects, in contrast to a true or basic taste, i.e. bitter, salty, sour, sweet and umami (Kulka, 1967).

The objective evaluation of flavour in spices has long been a matter of keen interest among food chemists. Correlation of the more or less subjective sensory data with objective flavour chemical profile is more the current practice. Subjective sensory analysis by human beings is being replaced by less subjective instrumental methods (the so-called 'iron nose') (Maarse & van der Heij, 1994; Taylor & Mottram, 1996). Recent developments in more objective sensory analysis are the gas chromatography–olfactometry techniques, which involve sniffing at gas chromatography columns.

1.3.2 Biological and ecological aspects

Many organic products are formed during plant growth. Some (primary metabolites) are necessary for plant development, energy and food reserves, others (secondary metabolites) are not fully understood by-products of the complex physiological processes (Deans & Waterman, 1993). Among the latter are the essential oils.

Essential oils are formed, stored and released by a variety of epidermal or mesophyl structures: oil cells, secretory glands, secretory ducts or canals, glandular hairs or trichomes.

Oil production is usually separate or a side-path from basic metabolic processes, but it must be presumed that it results in the plant having some selective advantage over a non-producing plant.

Essential oils somehow seem to be involved in 'fitness for life':
- attracting insects for pollination (if odour is pleasant);
- attracting animals for seed dispersal (if odour is pleasant);
- protecting against herbivores (if odour is offensive or irritating);
- protecting against pathogens by antibiotic activity;
- reducing competition by allelopathic action;
- influencing nutrient recycling by regulating decomposition of litter;
- acting as solvent for other bioactive lipophilic compounds.

There is certainly increased interest in the commercial exploitation of aromatic plants in food preservation (antimicrobial and antioxidant properties) and crop protection (broad-spectrum activity, no accumulation in the environment, low toxicity to mammals). Antioxidants are added to processed foods to restrict oxidation, particularly of unsaturated lipids, which causes deterioration. The consumer push to replace synthetic antioxidants by naturals has led the search for essential oils that contain phenolic compounds as major constituents (e.g. rosemary, sage, thyme), because the flavour of phenolic oils is acceptable and their antimicrobial activity strong.

In view of heavy losses of food to insect pests, especially in the tropics, effective insecticides or anti-feedants based on cheap essential oils or plant parts containing essential oil would contribute significantly to the alleviation of food shortages.

To date, there is little in vivo evidence of major pharmaceutical activity of essential oils or their components. Medical use is therefore mainly restricted to health care products (non-specific bactericides, decongestants, carminatives).

1.3.3 Physical aspects

Spices and derivatives offered for trade must meet certain quality standards. Spices proper are usually described physically (physico-chemically) in terms of purity (extraneous matter content), moisture content, total ash, acid-insoluble ash, and volatile-oil content. An overview of standard values established for the spices covered in this volume is given in the Table on standard physical properties of some dried spices (see p. 311).
The physical parameters most commonly used to characterize essential oils are relative density, refractive index, optical rotation, and miscibility with ethanol and water.
Relative density is the ratio of a substance's mass to its volume. 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. Optical rotation refers to the fact that 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 asymmetrical 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. Miscibility of essential oils refers to the solubility of an essential oil in a solvent. It is usually measured with aqueous ethanol 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 ethanol, but only slightly soluble in a mixture of ethanol and water. An overview of standard values established for the spice oils covered in this volume is given in the Table on standard physical properties of some spice oils (see p. 317).

1.3.4 Chemical aspects

In most spices it is the essential oils that are responsible for the flavouring properties. Essential oils are complex mixtures of hundreds of chemical compounds, most of which are still unknown. The organoleptic quality of the oil can be due to one or a few so-called character-impact components, e.g. anethole in anise, eugenol in clove, cinnamaldehyde (cinnamic aldehyde) in cinnamon, cuminaldehyde (cumic aldehyde) in cumin and d-carvone in caraway. For an indication of the complexity of the oils, see Composition of spice-oil samples (p. 281).
Although most spices are odoriferous, it is not only the lower molecular volatile compounds that are important for the organoleptic quality, but also the less volatile or non-volatile higher molecular compounds. The latter constituents

comprise principles that give a bitter, hot or pungent taste to the spices, or they consist of pigments psychologically influencing the perception of flavour through appearance.

Most of the chemical compounds can be grouped into a few major classes, but some components are difficult to classify. In the overview of important and characteristic constituents given below the compounds are classified into 4 major groups: aliphatic compounds, terpenoids (or isoprenoids), benzenoids, and miscellaneous compounds (Bauer et al., 1997; Lewis et al., 1982; Oyen & Nguyen Xuan Dung, 1999; Waterman, 1993; Zutshi, 1982).

Aliphatic compounds

Aliphatic compounds are acyclic organic compounds with a straight or branched carbon chain. These compounds can be saturated or unsaturated, the latter meaning that they possess one or more double or triple bonds between two carbon atoms. Aliphatic compounds can, for instance, be derived from fats or amino acids.

The leaves of plants can produce a series of volatile aliphatic compounds, as for instance (Z)-3-hexenol (leaf alcohol) and (E)-2-hexenal (leaf aldehyde), by enzymatic lipoxidation of linoleic acid. The alcohol has the characteristic odour of freshly cut grass, whereas the aldehyde has a sharp herbal-green odour somewhat reminiscent of bitter almond. Aliphatic aldehydes such as octanal and decanal are organoleptically important constituents of sweet-orange oil. The oil isolated from coriander leaves contains a series of higher saturated and unsaturated aliphatic aldehydes, which give the oil its characteristic odour. Many essential oils contain 3-methylbutyl derivatives, such as the alcohol, aldehyde and acetate derived from the amino acid leucine by reaction with a sugar. Aliphatic esters are important flavour and fragrance compounds occurring widely in nature.

Terpenoids (terpenes and terpene derivatives)

Isoprene is one of the basic compounds in animal and plant biochemistry from which terpenoids, carotenoids, steroids and also rubber are formed. Isoprene is formed from acetyl-CoA via mevalonic acid and dimethylallyl pyrophosphate. The terpenoids in spices are built up of 2 isoprene units (monoterpenoids), 3 isoprene units (sesquiterpenoids), or occasionally 4 (diterpenoids).

The terpene hydrocarbons contribute little to the organoleptic quality of essential oils. Monoterpene hydrocarbons conform to the molecular formula $C_{10}H_{16}$ and may be acyclic (e.g. myrcene and ocimene), monocyclic (e.g. limonene and p-menthatriene), bicyclic (e.g. α-pinene and β-pinene), and even tricyclic (e.g. cyclofenchene and tricyclene). The quantitatively most important monoterpene hydrocarbons are limonene and the pinenes. The dominant monoterpene hydrocarbon in all citrus oils is d- or (+)-(R)-limonene; for instance, it is present in amounts of over 95% in cold-pressed sweet-orange oil. Limonene most probably forms during growth and ripening of the fruit via mevalonate, geranyl- and (–)-(R)-linalyl pyrophosphate. Limonene is also an important constituent of caraway oil.

1,3,8-p-Menthatriene makes up to 65% of the oil from parsley leaves. The pmenthane skeleton in monoterpene hydrocarbons can be converted to p-cymene by oxidation. p-Cymene is an important benzenoid in essential oils and can be converted into thymol and carvacrol. Monoterpene hydrocarbons in general have harsh, turpentine-like odours.

The quantitatively most important sesquiterpene hydrocarbon ($C_{15}H_{24}$) occurring in spice oils is caryophyllene; for instance, it is present in clove leaf oil in amounts of up to 20%. Caryophyllene can easily be oxidized to caryophyllene oxide.

Oxygen-containing monoterpene derivatives are important for the organoleptic quality of spice oils. The aliphatic monoterpene alcohol d- or (S)-(+)-linalool (coriandrol) occurs in coriander fruit oil and gives this oil its fresh floral odour. Its enantiomer (optical antipod) l- or (R)-(−)-linalool (licareol) is responsible for the characteristic odour of lavender oil. The monocyclic terpene alcohols α-terpineol and terpinen-4-ol are essential for the odour properties of several herb oils. The monocyclic terpene ketone d- or (S)-(+)-carvone is responsible for the organoleptic quality of caraway oil, which finds application in liqueurs because of its fresh taste. l- or (R)-(−)-Carvone has a different odour and is a character-impact compound of spearmint oil, which is used in toothpaste for its minty note. The bicyclic ketone fenchone is responsible for the camphoraceous odour aspect of bitter-fennel oil. Although present in rather low concentration in rosemary oil, the bicyclic ketone verbenone gives this oil a characteristic odour. α-Thujone and β-thujone are important for the organoleptic quality of oil of *Salvia officinalis* L. Dill ether (3,6-dimethyl-2,3,3a,4,5,7a-hexahydrobenzofuran) is responsible for the characteristic odour of dill oil.

Benzenoids (benzene derivatives)

Many compounds with tasty and spicy odours are found amongst the benzenoids, which is why the chemistry of the benzene derivatives is called aromatic chemistry. All compounds contain the characteristic benzene nucleus to which one or more functional groups are connected, such as allyl, propenyl, hydroxy, methoxy, methylenedioxy and aldehyde. The benzenoid spice constituents can be divided into two groups, i.e. the para-menthanoids such as cuminaldehyde (cumic aldehyde), carvacrol and thymol, and the phenylpropanoids such as cinnamaldehyde (cinnamic aldehyde), methylchavicol, anethole, eugenol, myristicin and apiol.

Cuminaldehyde is the character-impact odour compound in cumin. Carvacrol and thymol are responsible for the organoleptic quality of thyme oils and oil of oregano. Cinnamic aldehyde is olfactively characteristic of cinnamon, whereas its 2-methoxy derivative gives cassia oil its characteristic aromatic odour. Methylchavicol is organoleptically important in chervil. Anethole gives the sweet anisic note to anise oil and other umbelliferous oils, e.g. dill and sweet fennel. Eugenol is indispensable for the flavouring properties of clove oils and of some other spice oils. Myristicin is a character-impact compound in oil of nutmeg. Apiol is an organoleptically important constituent of parsley.

Benzenoid aldehydes are important constituents of spice oils, e.g. benzaldehyde in bitter-almond oil, vanillin in vanilla spice, heliotropin in some exotic flowers. These aromatic aldehydes have tasty, sweet aromatic flavours.

Miscellaneous compounds

Nitrogen and sulphur compounds play an important role in the organoleptic quality of spices. Several nitrogen compounds impart characteristic sensory properties, even when they are present in concentrations of less than 0.1%, e.g. alkylmethoxypyrazines which occur in green capsicum pepper and in green leaves.

Examples of bitter, hot or pungent compounds are: gingerol, shogaol, paradol, piperine, chavicine, isopiperine, isochavicine, capsaicin, dihydrocapsaicin, nordihydrocapsaicin, homocapsaicin, homodihydrocapsaicin, piperyline, piperettine, piperanine, piperoleine A, piperoleine B, zingerone.

Several natural chemical compounds from spices providing a pungent taste sensation are nitrogen derivatives of 2-methoxyphenols. Capsicum pepper, for example, contains a group of substances called capsaicinoids, which are vanillyl-amides of saturated or unsaturated, monocarboxylic acids with straight chains of varying length (C_8–C_{11}). The group includes capsaicin and dihydrocapsaicin. In pepper the pungent principle is mainly piperine, an amide derived from piperic acid and piperidine (hexahydropyridin). The 'trans' or 'entgegen' (E) geometry of the unsaturated part is responsible for the strong, biting effect; isomerization of these double bonds upon exposure to light and storage leads to loss of pungency. The pungency in fresh ginger has been atributed to the phenylketones called gingerols, with 6-gingerol as the most active compound. Gingerols vary in the length of the terminal part of the aliphatic chain (Govindarajan, 1977; Lindsay, 1985). Other examples of methoxyphenol derivatives are eugenol (found in clove) and isoeugenol (found in nutmeg and various other essential oils) (Kulka, 1967). These two not only contribute to the taste sensation but also impart characteristic aroma because of their volatile nature. Sweet aromatic odoriferous substances, like vanillin, for instance, can have a bitter taste.

Sulphur compounds can be very characteristic, such as di-alkyl disulphides and alkenyl isothiocyanates, which are character-impact constituents of garlic, onion, horseradish and mustard. The character-impact compound in black mustard and horseradish is allyl isothiocyanate, in white mustard it is 4-hydroxybenzyl isothiocyanate (Parry, 1969; Pruthi, 1980).

Bitterness as a basic taste in flavour is sometimes disagreeable, but in subtle blend with sweet or sweet and sour condiments it can enhance the basic appeal of a given food. A bitter tonality is appreciated in drinks such as coffee, beer, campari or bitter lemon.

Alkaloids and glycosides are chemical families associated with bitterness and so are other compounds, e.g. coumarins (Kulka, 1967). Coumarins provide a substantial contribution to the organoleptic properties of cinnamon (Purseglove et al., 1981).

Many spices contain pigments, which are mostly carotenoids, often derived from β-carotene. Examples of pigments are: α-crocin, α-crocetin, β-crocetin, γ-crocetin, curcumin, demethoxycurcumin, bis-demethoxycurcumin (Richard, 1991). Turmeric and paprika are appreciated not only for their characteristic organoleptic quality but also for their ability to give colour to food preparations. The colour of turmeric is attributed to the major pigment curcumin, which is used to colour a variety of savoury products, particularly curry powders and mustard pickles. It exhibits an unusually intense yellow colour in acidic products. Paprika powder, on the other hand, is a red-orange colouring material extracted from sweet capsicum pepper (*Capsicum annuum* L.), with capsanthin and capsorubin (red pigments) and β-carotene (yellow-orange pigment) as the major chromaphores (Henry, 1979; Lauro, 1991). Capsicum pepper oleoresin is an economically important natural colourant in foods and drinks, especially for cooked meat products. The green pigment (chlorophyll) from fragrant pandan is traditionally extracted in the Philippines to colour sweet cakes and other food preparations. Perilla leaves, which contain high concentrations of anthocyanins, are extensively used to give an appetizing red colour to various Japanese and Korean dishes.

1.4 Botany

1.4.1 Taxonomy

The heterogeneity of the commodity group spices is well illustrated by the fact that the 126 species described belong to approximately 35 families: spices occur throughout the plant kingdom. Nevertheless, some families figure prominently with respect to number of spice species as well as economic importance:

- *Labiatae:* basil, marjoram, oregano, perilla, rosemary, sage, summer savory, thyme
- *Lauraceae:* cassia, cinnamon, laurel
- *Myrtaceae:* clove, pimento, salam
- *Piperaceae:* pepper, cubeb, Indian long pepper, Javanese long pepper
- *Umbelliferae:* anise, caraway, chervil, coriander, cumin, dill, fennel, parsley, sawtooth coriander, surage
- *Zingiberaceae:* cardamom, Chinese keys, etlingera, galanga, ginger, turmeric

The proper naming of plants is important, because it enables repeatability and use of scientific methods. Taxonomy provides such a naming service and is therefore an important biological science. Many taxonomical problems are still unsolved. Few major genera of economically important spice families have been revised in their entity within the last 50 years. The taxonomy of genera such as *Cinnamomum* Schaeffer, *Piper* L. and *Thymus* L. is still poorly known, and the lack of linkage of data to well-defined taxa makes part of the information useless.

Classic taxonomy is primarily intended for wild taxa, and closely related wild types are often classified as subspecies or varieties (formal classification under the International Code of Botanical Nomenclature). For cultivated plants, the most recent approach is to distinguish cultivars and to group these in cultivar groups (the informal 'open' classification guided by the International Code of Cultivated Plants). The taxonomy of cultivated plants is developing: as yet there is no worldwide accepted system for naming and classification, but proposals are being discussed. Where workable cultivar group classifications seem possible, as for instance in dill, parsley and tarragon, these are being promoted in this volume.

In spices, the number of chemotypes can be considerable because composition is influenced by environment as well as genetic factors and development stage.

In a number of cases, however, strong and simple genetic control has been evidenced, as in sweet basil and perilla. Plant morphology does not necessarily correlate with a plant's essential-oil composition.

1.4.2 Morphology

Plant parts used as spice comprise anything from roots (horseradish) to rhizomes (ginger, turmeric), bark (cassia, cinnamon), leaves (chervil, coriander, laurel, oregano, parsley, rosemary, sage, sweet basil, tarragon, thyme), flower buds (clove), fruits (anise, caraway, cassia, coriander, cumin, dill, fennel, pepper, pimento, star anise, vanilla), seeds (black mustard, fenugreek, nutmeg, white mustard), and aril (mace).

In a number of spice crops more than one plant part is used as a flavouring agent. Aside from the bark, Chinese cassia yields cassia buds (dried unripe fruits). In coriander, the fruit is internationally traded, while fresh leaves are popular for flavouring a number of South-East Asian dishes. Commercial marjoram and oregano are a mixture of both dried leaves and floral parts. Apart from the rhizomes the young shoots of turmeric and galanga are used domestically as a spicy vegetable, while in perilla the leaves, spikes, seeds and sprouts are used as flavouring in Japanese, Korean and Vietnamese dishes.

Considerable anatomical modification can be observed in cells or tissues yielding the specific flavour characteristic of a given spice. Aromatic compounds are formed or stored in special organs in plants. The variability of these organs reflects the varied taxonomy of spice plants; only a few examples of the many structures found can be given here (Hardman, 1973; Parry, 1969).

Oil glands may be simple or compound hairs on the leaves, as in 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 cuticle.

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. Examples are the floral buds of clove as well as the outer mesocarp of the fruit of pimento.

Another form encountered is a secretion-containing cell whose contents differentiate it from the adjacent cells. It is easily recognized by its larger size or cuticularized lining. Examples of this type include the essential-oil cells in the seed-coat of cardamom, in the bark of cassia and cinnamon, and in the mesophyll tissue of laurel leaf, but also the oleoresin cells in the mesocarp of the pepper fruit, in the mesocarp of the carpel and cortex of the peduncle of star anise, and the aril mesophyll, perisperm, embryo and radicle of nutmeg seed.

Umbelliferous spices such as coriander, dill and fennel form long secretory ducts in the fruit wall, called vittae. These vittae, which arise schizogenously and contain oleoresins, serve as a discriminating character for *Umbelliferae*.

The variation in the plant organ utilized and in the position of cellular structures responsible for the flavouring properties of the spice in the specific plant organ, necessitates a diversity of management practices in crop establishment, cultivation, harvesting and primary processing. A different approach is needed, for example, when the product is to be the fresh leaves rather than the fruits, e.g. in coriander. In chervil, where the leaves are important as a culinary herb, inflorescences need to be removed to encourage denser foliage. The lesser pungency of white pepper compared with black pepper has been attributed to the mesocarp of the fruit (where oleoresins are embedded) being removed during processing. The degree of peeling the ginger rhizome before drying affects its quality: removal of the cork layer can desirably lower the fibre level and pungency. If peeling is done without proper care, however, the volatile-oil content can also be reduced due to the removal of oleoresin cells in the cortex (Purseglove et al., 1981).

1.4.3 Growth and development

Knowledge of crop growth and development and insight into the eco-physiology should help the grower to manipulate the crop and its environment to achieve the optimum yield of the desired plant part. Many spices do not pass through their complete life-cycle in cultivation because they are grown for their vegetative parts, or young, immature generative parts. Information on the growth and development of spice crops is rather limited except for some of the economically most important ones. The sequence of germination, vegetative growth, and generative development (flower initiation, flowering, pollination, fruiting) has been highlighted in the species treatments as far as known.

Three major classes of growth habit can be distinguished: annuals, biennials and perennials. In areas with cold winters, annual or biennial crops dominate the agricultural scene, but as one moves from higher latitudes towards the equator, woody perennials become more important, and this also applies to spices.

The annual spices are herbaceous in character and include for the most part the so-called 'spice seeds' (botanically fruits) of commerce, e.g. anise, coriander, cumin and dill. Biennial spices are exemplified by caraway (although annual types exist) and parsley, which remain vegetative during the first year of growth and initiate flowering in the second year.

The vast majority of spices are perennials. Among these are the small, evergreen understorey trees (e.g. clove, pimento, star anise) that take several years to come into bearing. The first flowering of the tree spices often occurs 5–8 years after the planting of seedling material, but usually much earlier for material propagated vegetatively. Full bearing, however, is attained at the advanced age of 15–20 years; productive life can range from a low of 30–40 years to a high of 70–80 years and even up to 100 years.

Much shorter is the productive life for the perennial herbs, e.g. fennel, horseradish, oregano, sage, tarragon and thyme, and the shrub rosemary. They need to be re-established after 3–5 years. Pepper and vanilla are climbing spices which commence flowering 3 years from planting and attain full bearing at the age of 7–8 years. Some biennial and perennial herbs like parsley and the rhizomatous ginger and turmeric are cultivated as annuals.

There is considerable variation in the flowering and fruiting behaviour of spices. Only a few studies have been conducted on the induction or promotion of flowering through exogenous application of plant growth regulators (gibberellic acid on chervil, coriander, fennel and parsley). The same is true for modification of sex expression using plant growth regulators. Indolebutyric acid (IBA), malic acid and 3-chloro-2,2-dimethylpropionic acid reduce the ratio of male to female flowers in andromonoecious coriander. Surprisingly, no such studies have been reported for nutmeg and pimento, which both exhibit dioecy and the problem of sex identification at an early stage. In terms of fruit development, parthenocarpic pods have been successfully induced in vanilla using either 2,4-dichlorophenoxyacetic acid (2,4-D), 2-methoxy-3,6-dichlorobenzoic acid (dicamba) or a mixture of indoleacetic acid (IAA) and indolebutyric acid (IBA) (Gregory et al., 1967). For one reason or another, this treatment, however, has not been adopted to replace the laborious hand pollination still being done in commercial plantations. Nevertheless, these studies reveal the possible application of chemical substances in the control of flowering and fruiting (Halevy, 1989).

1.5 Ecology

The core area covered by Prosea lies between 20°N and 10°S. It consists mainly of tropical lowlands, but also has large areas at medium to high altitude. The choice of crops and cropping systems is mainly determined by interactions of ecological factors (climate, soil) and management variables. However, many spice crops, the herbs in particular, are part of horticulture, an intensive form of agriculture, usually on small acreages, in which restrictions imposed by adverse climatic factors and poor soils can often be overcome by intensive management practices.

On the other hand, a particular area's climate and soil can greatly influence the taste of spices. This has been experimentally proven in many cases, e.g. irradiance in thyme, photoperiod in sweet basil.

1.5.1 Climatic factors

The climates of South-East Asia are of the monsoon type. Monsoons are seasonal winds blowing moist air from the sea to the heated land mass bringing heavy rains during the hot season, and blowing air from the land to the sea during the cool season. In Indonesia and Malaysia, situated close to the equator, the dry south-east trade wind from Australia causes a dry spell from May to October. This wind turns to the north above the equatorial zone and takes up much moisture above the ocean. It is known as the south-west monsoon in Thailand and neighbouring countries and causes the rainy season from May to October ('summer'). The inverse happens from December to February when the north-east monsoon causes the dry season ('winter') in Thailand but brings rain as the west monsoon in Indonesia.

In the lowlands near the equator the average daily temperatures are generally about 27°C the year round, the differences between a hot and a cool season becoming more pronounced northwards. In northern Vietnam the average temperature from November to April is only 16°C. In these areas the summers, from May to October, are very hot and subject to typhoons.

In mountainous areas the temperature drops by about 1°C per 160 m increase of elevation, and the difference between day and night temperature broadens.

The occurrence of micro-climates is quite common. The distinction between highland and lowland cultivars, or, at the higher latitudes of northern Thailand, Philippines and Vietnam, between 'summer' (hot season) and 'winter' (cool season) cultivars is well known, e.g. in coriander.
There are spices which require a period of low temperature exposure (vernalization) for flower initiation, e.g. parsley.
The variation in daylength is a less important climatic factor in the area close to the equator, but is of increasing importance further north. At 10°N (southern part of the Philippines, Thailand and Vietnam) the daylength varies from about 11.30 h to 12.40 h, and at 20°N (northern part of the Philippines, Thailand and Vietnam) from about 10.50 h to 13.20 h. The distinction between a 'summer' and a 'winter' becomes tangible above 10°N, by variations in the photoperiod and in the total daily radiation. Some crops are very sensitive to daylength, examples being the long-day plants fennel and oregano, or the short-day plant perilla. These daylength effects will be dealt with in the species treatments.

1.5.2 Soil factors

The predominant soil types in South-East Asia are andosol and latosol (both of the sandy loam type) and alluvial clays. Light soils have the advantage of easy tillage, adequate drainage and aeration, provided that the organic matter content is sufficiently high. Clay soils have the advantage of a better water-holding capacity and higher natural fertility. Some spices such as horseradish prefer a heavy soil, whereas others such as Ceylon cinnamon, Mariana caper-bush and perilla prefer a light soil.
The lack of chemical fertility is not perceived as the most serious limiting factor, because amendments with manure and/or inorganic fertilizer are relatively easy. However, in most cases appropriate fertilizer recommendations are not available, and farmers must rely on their own experience.
The pH of the soil influences the availability of nutrients and also the soil structure. If the soil is very acid the choice of the crop will be limited to fewer species. Crops on acid soils often suffer from Mg, Ca or P deficiencies, or from Mn and Al toxicity. Liming with basic slag (or preferably with dolomite) is useful at a rate of about 2 t/ha per crop until a level of pH 6–6.5 has been reached. On acid soils, it is recommended not to use too much of acidifying fertilizers such as ammonium sulphate or urea.
The pH tolerance of many spices is well-documented (Barker, 1989; Duke & Hurst, 1975). Four major groupings can be observed in terms of sensitivity to acid soil conditions: very sensitive (where growth is already hampered at pH lower than 6.3, e.g. cumin); sensitive (where growth is hampered at pH lower than 5.3, e.g. perilla); moderately sensitive (where growth is hampered at pH lower than 4.5, e.g. laurel), and less sensitive (where growth is only hampered at pH lower than 4.3, e.g. sweet basil).
Crops such as laurel and rosemary exhibit a wide range of pH tolerance (almost 4 pH units), but most spices have a much smaller range.
A high soil salinity (electrical conductivity > 3.0 mmho/cm) is a serious restriction for crop growth; however, a crop like Mariana caper-bush is reasonably salt-tolerant, whereas Ceylon cinnamon and fennel are very sensitive.

Crops with shallow root systems, such as clove and nutmeg, are much more susceptible to drought than deep-rooting species such as rosemary. Most spices are sensitive to waterlogging.

The type of soil has been shown to have a pronounced effect on the quality of the spice product. In Ceylon cinnamon, for example, the best bark is obtained from trees cultivated around Negombo (Sri Lanka) where the soil is fine white quartz sand. In areas where the soil is lateritic and gravelly, the bark produced is thicker and coarser (Purseglove et al., 1981).

1.6 Agronomy

The expected increase in demand for spices can be satisfied by larger acreages or by intensifying the existing production of spices in short supply. Cultivation offers a number of advantages over collection from the wild: crops give higher yields, with more consistent properties. Cultivation facilitates selection and improvement of planting stock, weeding, crop protection, mechanization, harvesting, transportation and correct processing, all of which help to maintain and improve the aroma. These advantages become more important when quality specifications become more stringent.

1.6.1 Production systems

Collection from the wild

A number of spices are still harvested from the wild. Spices obtained from the wild are intended mainly for local use, e.g. wild cinnamon in Sri Lanka and wild 'Papua' nutmeg (from *Myristica argentea* Warb.) in Indonesia (Purseglove et al., 1981; Rugayah et al., 1989). In the Mediterranean countries the culinary herbs rosemary, sage and thyme are handpicked from the wild and subsequently traded in the international market. It is generally believed that herbs collected from their natural habitat have more flavour than those cultivated commercially. This point, however, is still a matter of controversy. Although some culinary herbs are still collected from the wild since their cultivation has proved uneconomic, e.g. rosemary, harvesting from wild-growing plants may be insufficient to meet the growing demand for the raw material. In the major markets of Western Europe, wild thyme actually accounts for less than 10% of the total import of thyme (International Trade Centre UNCTAD/GATT, 1991).

Harvesting from the wild seems conceptually attractive for a commodity with a relatively small trade volume, particularly if it involves non-destructive harvesting of aerial parts that quickly regrow. However, the problems include the difficulty of collecting material scattered over large areas, unpredictable supply of raw material for processing, and variability in quality related to the origin. Persistent and unregulated collection may also soon lead to the rapid erosion of important genetic resources. In the long run, spices are better cultivated than gathered from the wild.

Production on smallholdings

Smallholdings are generally single-family enterprises (e.g. for clove in Zanzibar), established by cooperatives (e.g. pepper in Indonesia) or formed on a communal basis (e.g. ginger in China) (Purseglove et al., 1981). In India, Indonesia, Malaysia (Sarawak), the Philippines, Madagascar and Brazil, smallholdings devoted to pepper have a mean size of about 1 ha (de Waard, 1980). Smallholdings are often characterized by insufficient cultural and manurial care, resulting inevitably in low yields, e.g. 250 kg/ha of dry pepper for small farms as opposed to 900–1000 kg/ha in large-scale production in India (Paulose, 1973).

Production in plantations

Most tree spices and herbaceous perennial spices are managed as plantation crops. Over 70% of nutmeg production in Grenada, for example, comes from large farms and only 30% is derived from peasant holdings (Cruickshank, 1973). A substantial part of cardamom in Sri Lanka is produced on holdings of 20 ha or more (Wijesekera & Jayawardena, 1973). Large holdings are almost always established by private enterprises that are able to invest more capital to undertake intensive cropping for high yields. In most cases, processing is carried out in the company's own integrated processing unit, thus with better quality control and more added value. In the Philippines, pepper from smallholders' farms is simply sun-dried, usually on concrete floors. In contrast, a private company in the southern region of the country, producing pepper from 20 ha, is fully equipped with artificial driers, blanching apparatus, conveyor belts and mechanized sorters and graders.

Production in market gardens

Herbaceous spices grown as annuals such as coriander, dill, parsley and sweet basil, are often grown in market gardens. They generally follow the techniques and trading and selling schemes appropriate for vegetables. Cultivation is labour-intensive and the product is intended mainly for the local fresh market. Mulching with e.g. rice straw, sawdust, rice hulls is often practised and net enclosures are constructed over raised plots to protect the crop from insect attack. Spices in market gardens have a high rate of production turnover and provide farmers with an opportunity of getting quick cash returns.

A high premium is paid for culinary herbs which are produced organically, making use of farm manure and compost and avoiding pesticides. Such farms are presently very trendy in the Philippines.

Protected cultivation in soilless media

The use of soilless media for spice production under protective cover is fairly recent and has mainly been applied on annual culinary herbs. Successful hydroponic culture of dill, perilla, sweet basil and thyme has been reported (Barker, 1995; Kim, 1995; Udagawa, 1995) while the use of commercial growing media such as peat-like mix have also been tried for rosemary and sweet basil (Adler et al., 1989; Boyle et al., 1991). Nutrient solutions used in these investigations were based on the one developed by Hoagland and Arnon (Hoagland & Arnon, 1950). This nutrient solution is seldom used commercially, however, because of the difficulty of preparing it. Instead, water-soluble, concentrated fertilizers, e.g. 20-10-20 or 20-20-20, supplemented with Ca, Mg and micronutrients are commonly used (Barker, 1995).

Spice production in soilless media under protective cover, particularly the hydroponic system, offers possibilities of overcoming constraints associated with field production: balanced application of nutrients and better control of light and temperature conditions. The system, however, demands a higher level of technical skill, requires a bigger initial capital input, and has considerable operational expenses for maintenance compared with traditional field culture. Such requirements have limited the use of hydroponics to developed, industrialized countries. Despite these constraints, this type of production has great potential for maximizing not only yield but also the level of secondary metabolites associated with the flavour of a particular spice because of the highly controlled growing conditions.

In vitro production

The production of natural flavours through in vitro culture has been explored in recent years. Its application may pave the way for eliminating some constraints associated with spice production from whole plants: wide fluctuation in supply and availability of raw material, difficulties of transport from remote areas, and problems of political nature in the countries of origin (Whitaker & Hashimoto, 1986). Batch culture of natural flavours is also viewed as a possible means towards overcoming toxicological objections to synthetic flavour and colour additives (Collins & Watts, 1983).

However, the exciting promise of large-scale production of spice flavours and other related secondary metabolites using cell cultures remains unfulfilled. The limited body of tissue culture work on the production of food flavours indicates that production has been hampered by the absence of specialized and highly differentiated cells in the cultures. For example, the essential-oil components carvone and limonene in dill cell culture are lost beyond the seventh generation, despite various modifications in chemical and environmental factors (Everitt & Lockwood, 1995). Neither could these components be detected even in the embryoids and embryogenic callus of caraway (Furmanowa et al., 1991).

There are, however, instances where some of the flavour principles have been detected even in undifferentiated cells. In coriander, geraniol has been detected in root callus culture, but not the other flavour components such as linalool, borneol, α- and β-pinene and p-cymene (Sardesai & Tipnis, 1969). In callus culture of oregano, minute amounts of essential oil were found using microsteam distillation apparatus with microcapillary collector (Svoboda et al., 1995). Gas chromatography (GC) analysis revealed the presence of carvacrol in the volatile oil. Small amounts of thymol and β-elemene, but not γ-terpinene and p-cymene, were detected in the volatile oil from thyme callus tissue. Other metabolites, e.g. geranylacetone, chamigrene and nerolidol, were found to exist in the callus culture but not in the intact plant (Tamura et al., 1993).

It is worth noting that the enzyme systems involved in the biosynthesis of important secondary metabolites have been detected even in cultures of undifferentiated cells. These reports point not only to the potential of biotransformation in the production of flavours or other chemicals for industrial purposes, but also to the utility of cell culture in the elucidation of basic metabolic schemes involved in the biosynthesis of secondary metabolites.

The accumulation and isolation of chemical products via cell culture from spices other than those distinctly associated with flavour have also been reported: condensed tannins from *Cinnamomum cassia* (Yasaki & Okuda, 1993); caffeic acid and rosmarinic acid from rosemary and sage (Whitaker & Hashimoto, 1986).

1.6.2 Planting material

Spices are generally propagated by seeds, which normally germinate in a span of 2–3 weeks, but sometimes up to 6 weeks from sowing, e.g. cardamom and nutmeg (Ilyas, 1978; Rosengarten, 1973; Samarawira, 1972). Some spice seeds require pre-sowing treatment to enhance germination. Seed viability may pose a problem in some of these spices. Seeds of the tree spices cassia, cinnamon, clove, pimento and nutmeg are recalcitrant in nature, losing their viability upon drying to a low moisture content and subsequent storage at low temperatures. Thus, freshly harvested seeds are used for sowing. On the other hand, when dried to a certain moisture content and kept under proper conditions, some seeds can maintain their viability for several years: sage and thyme seeds can be stored in airtight, polythene bags for 6 years or more. Seed of anise, chervil, coriander and sweet basil is also viable for long periods (Halva & Craker, 1996).

The flavouring herbs within the *Umbelliferae*, e.g. anise, caraway, coriander, dill and parsley are commercially propagated only by seed. These plants do not transplant well and are thus sown directly into the field. Seeds used for sowing must be obtained from fully ripe fruits collected from vigorous, high-yielding and disease-free mother plants of the desired type.

Some spices are difficult to propagate from seed. French tarragon (tetraploid) and turmeric are sexually sterile and therefore do not produce viable seeds (Nambiar et al., 1982; Rousi, 1969). Fertile seeds are rarely obtained in ginger, while horseradish fruit pods frequently fail to mature or to contain viable seeds (Rosengarten, 1973). In some cases, the seeds are small, e.g. oregano, and thus are difficult to handle. The use of seeds may also result in considerable delay in production. From seed or tissue culture it may require 4–5 years to harvest the first crop for vanilla, as opposed to only 2–3 years when cuttings 1 m long are used (Davis, 1987).

Vegetative means of propagation have been successfully employed for various spices. Since the new plant is genetically identical to the original stock plant, asexual propagation can ensure the continuation of unique genotypes that may have a special type of oil, disease resistance and other useful traits. These are accomplished through the use of cuttings, air layering and grafting. Cuttings are excised from vegetative portions of the plant, such as stems and their modified structures (rhizomes, corms and bulbs), leaves or roots. The most significant type is the stem cutting. The basic protocol is to excise stem portions bearing 2 or more nodes from a healthy, well-established plant, and to treat the basal cut end with plant growth regulators, e.g. indolebutyric acid (IBA), naphthaleneacetic acid (NAA) or a combination of both, to enhance the rooting response and shorten the period to root initiation. Vanilla, pepper and most members of the *Labiatae* such as marjoram, sage, sweet basil and thyme are easily propagated by stem cuttings. Root cuttings are employed for a few spices like horseradish, marjoram and oregano. Sets obtained by dividing old rootstocks are also employed in cinnamon and cassia. Unlike stem cuttings, it can be very laborious to get root cuttings in sufficient quantities, unless they can be obtained by trimming roots from nursery plants as they are dug out. Planting material for cardamom, ginger and turmeric is obtained using their specialized stem structure, the rhizome. Propagation is carried out by cutting the rhizomes into sections, ensuring that each piece has at least one lateral bud or 'eye'. Cardamom can also be propagated from seed.

Vegetative propagation has advantages for nutmeg and pimento, which are normally both propagated by seed. Both crops exhibit dioecy and it is rather difficult to distinguish between male and female trees until they come into bearing at 5–6 years or even later. Although other techniques have been tried, marcotting or air layering appears to be the most effective means of producing new nutmeg plants. The method gives 60–70% success. In pimento, approach grafting has been reported to produce as much as 95% success. Layering is a common technique employed for spice crops such as cassia, cinnamon and pepper.

Division of the crown is an important method of propagation for some herbaceous perennials because of its simplicity and reliability. Many of these spices must be divided every 2 or 3 years to prevent plants from becoming overcrowded. Plants are essentially dug out and cut into sections. Crops that can be propagated by division are oregano and tarragon.

Tissue culture techniques have also been used in the production of planting material. This technique offers a method of mass propagating disease-free plants in a short period of time. It also provides the opportunity to select plants with desirable features through somaclonal variation which is otherwise difficult to obtain by traditional plant breeding. The explants used for tissue culture of spices include rhizome buds, hypocotyls, nodal stem segments, petioles, leaf segments, shoot tips, seeds and young ovaries, generally cultured in Murashige and Skoog's basal medium with various concentrations of auxins and cytokinins. Some of the spices that have been successfully micropropagated are caraway (Furmanowa et al., 1991), clove (Mathew & Hariharan, 1990), horseradish (Meyer & Milbrath, 1977), ginger (Hosoki & Sagawa, 1977), vanilla (Kononowicz & Janick, 1984), turmeric (Nadgauda et al., 1978), parsley (Vasil & Hildebrandt, 1966), fennel (Maheshwari & Gupta, 1965), dill (Sehgal, 1968), cinnamon (Yasaki & Okuda, 1993), cardamom (Bajaj et al., 1993), oregano (Kumari & Saradhi, 1992) and tarragon (Mackay & Kitto, 1988).

As with seeds, planting material produced through whatever type of asexual technique should be derived from well-established, vigorous and disease-free mother plants.

1.6.3 Husbandry

Crop husbandry measures in spices differ little from those of other annual and perennial crops. For most species, the aim is to maximize or optimize yield and to harvest before deterioration in quality and quantity. Best quality and greatest quantity do not always occur at the same moment.

In experiments on temperate culinary herbs, it has been shown that nitrogen application influences crop oil yield predominantly through its influence on biomass production. The effects on oil content and oil quality are much smaller or negligible. It is therefore especially important to monitor the nitrate content in crops produced for direct human consumption. In the case of limitation of biomass production through water stress, there are complex relationships between N application, quantity and timing of irrigation, crop yield and crop quality (Hay, 1993).

Weeds can become a problem in spice production, and their detrimental effects are keenly prominent during the establishment phase. Weeds not only compete with the major crop for nutrients, water and light but can also serve as hosts for a variety of diseases and insects attacking spices. The inadvertent inclusion of weeds in the raw material during harvesting can decrease the quality and market value of the herb product, especially in the case of savoury herbs. In the spice-producing countries in the tropics, weed control is generally and simply accomplished by hand; mechanized weeding is more favoured in the industrialized economies, where it is normally employed on large farms specializing in the production of culinary herbs. Few herbicides have been registered for use in spices. Herbicide use is avoided in organic systems of cultivation. Currently, mulching appears to be the least expensive and environment-friendly technique for reducing if not totally eliminating weeds.

1.6.4 Crop protection

Some spices such as Chinese keys, fragrant pandan, oregano, star anise and tarragon are not seriously affected by diseases and pests. Most spices, however, are damaged to such an extent that considerable production losses may result. For the majority of spices, damage caused by disease is far more significant than that attributed to pests. Fungal infection accounts for most of the diseases that have brought severe havoc to plantations and home gardens: foot rot in pepper, root or stem rot in vanilla and the witches' broom in Chinese cassia. The most common diseases of culinary herbs are leaf-spots or blights, grey moulds, downy and powdery mildews, rusts, vascular wilts and root rots (Schumann, 1989). Other diseases of importance for spices include those caused by viruses (in cardamom, horseradish and chervil), bacteria (in clove and ginger) and nematodes (in cinnamon, oxalis and pepper).

If unchecked, insect pest infestation can also reach serious proportions; nutmeg production was wiped out in Singapore and Pinang in the 1860s due to scolytid beetle (Purseglove et al., 1981). The more common insects attacking spices are chalcid fly, aphids, weevils, leaf-eating caterpillars, borers, thrips and scale insects. Rats, bats and birds can also afflict occasional damage, particularly on fruits and rhizomes. Spice products in storage are also not immune from attack by insect pests, e.g. biscuit beetle in coriander, coffee bean weevil in nutmeg.

By comparison with the major food crops there are only a few chemical pest control techniques available for spices. This has led to severe economic losses in the production of these crops. With regard to the collection of data for pesticide registration, the spices are generally considered as minor crops. The prohibitive cost of generating information to establish legal tolerance levels (pesticide level considered safe in food) and other pertinent data, coupled with the risk of limited sales, have discouraged pesticide manufacturers from registering many chemicals for specialty crops such as spices. Among the herbaceous spice crops where tolerance data (either as insecticide, fungicide or herbicide) have been established are anise, basil, chervil, dill, fennel, marjoram, parsley and rosemary (Frank et al., 1987). The use of herbicides and chemicals for disease and pest control in spices needs special care, as pesticide residues may affect the quality.

Chemical pesticides are generally expensive and often beyond the means of local farmers. This, together with the increasing interest in and demand for organically grown food, has prompted growers to focus on other means of control, particularly those involving appropriate cultural management techniques. Among those being employed include heat treatment of fruits (to eliminate seed-borne diseases), roguing or eradication of infected plants, crop rotation, pruning of infected branches, application of complete and balanced mineral nutrients (e.g. to control yellow disease in pepper), use of raised beds, choosing well-drained sites for cultivation, and grafting of susceptible cultivars onto resistant rootstocks. It is important to emphasize that planting material should be healthy and disease and pest-free to begin with and that proper sanitation should always be maintained in the farm.

For culinary herbs where production is relatively small scale, protected cultivation can be resorted to, as is done in the Philippines, where garden plots are enclosed in cages screened on all sides with very fine nylon nets to exclude insects; in some cases the cages are roofed with polythene film to protect from too much rain during the wet season when most fungal diseases are prevalent. Pesticides of plant origin are also being tested, but their effectivity and non-toxicity still warrant scientific validation. The technique of biological control, e.g. application of *Bacillus thuringiensis*, a bacterium used as insecticide, also deserves some investigation for spices (Halva & Craker, 1996).

1.7 Harvesting and post-harvest handling

1.7.1 Harvesting

Proper harvesting and handling are extremely important for highest organoleptic quality.

The first harvest depends on the plant's growth habit and the nature of the product: fruits and barks from perennial tree spices are first harvested several years from planting; in contrast, leaves, shoots or seeds from culinary herbs may be ready for harvesting a few months after establishment, while sprouted seeds, e.g. white mustard, can be obtained in only a few days after sowing.

To obtain the full flavour of the spice, harvesting should be done at the proper stage of maturity. Earlier or later than this stage could make a difference in quality and yield. Clove buds, for example, should be harvested when the buds become pink and are about 2 cm long; if gathered too early the cloves will be wrinkled, with lower eugenol content, while if picked too late the bud colour will change to deep red and bloom out (Guenther, 1948–1952). For most of the spice 'seeds', e.g. anise, caraway and coriander, late harvesting results in shattering of fruit clusters leading to a lower yield. Some spices are harvested before flowering occurs, e.g. summer savory and chervil, or when the first flowers have just developed, e.g. marjoram, oregano and sweet basil (Halva & Craker, 1996). Ginger and turmeric are harvested when the stalks begin to wither, about 9–10 months after planting.

The time of the day or the season of harvesting is also an important factor to consider. Spice seeds are preferably harvested early in the morning when dew is still fresh and when there is less danger of seed loss. Leaves from laurel and shoots from herbaceous spices are picked by hand early in the day when sunlight is not so intense that it leads to a rapid loss of volatile oil. Cinnamon and cassia bark is best cut during the rainy season, when the bark is easier to separate from the stem because of the increased flow of sap between wood and bark (Rosengarten, 1973).

Techniques of harvesting also vary depending upon the spice. Fruits of pepper and pimento and floral buds of clove are picked by hand, by pickers using ladders to collect those from the upper portion of the tree. For most herbaceous spices in small garden plots, harvesting is simply accomplished by hand or with the use of a knife, pruning shears or a sickle blade; a cereal combine harvester can be used for larger plots. Underground spices, e.g. horseradish and ginger, can be dug out by hand with the aid of tool bars or hoe, or with a mechanical digger when working on larger fields.

1.7.2 Handling after harvest

Damage to oil-filled glands and cells can be avoided, and loss of volatile oils kept to a minimum by careful handling.

Pretreatment

Spices undergo various pretreatment procedures before drying or other processing techniques. The roots and rhizomes of crops used as spices (e.g. horseradish, ginger, turmeric) are initially washed clean of adhering dirt. To enhance the rate of drying some spices are peeled or scraped (ginger, cinnamon bark), sliced (ginger, turmeric) or cut into pieces (quills, quillings, featherings and chips of cinnamon and cassia barks).

Blanching is a common pretreatment done on turmeric; in pepper it is said to hasten drying and provide uniform colour to the peppercorn. Chemical treatments are also employed for various ends: to retain the green colour of cardamom; to stabilize the carotenoids imparting the attractive red colour in capsicum pepper (suitable antioxidants are used for this); to improve the colour of ginger (using bleaching powder, sulphur dioxide or hydrogen peroxide). Vanilla is subjected to a series of curing or fermentation steps for the development of full flavour. In general, fermentation is used to hydrolyze the glucosides of characteristic flavour compounds.

Drying

Drying is considered to be the most important step in the primary processing of spices. The major objective of drying is conservation by reducing the moisture level of the raw material to a safe limit (e.g. 8–10%), to retain the original colour, and to prevent or minimize the action of spoilage organisms without great loss of the flavour characteristic to the spice product. Dried spices can be stored for a considerable period of time. Drying inhibits the activity of intrinsic enzymes and prevents other chemical reactions that can reduce the quality of spice during storage. Cost of storage and shipping is also minimized, since the weight of the dried material is only 10–25% of that of the fresh material.

Traditionally, and mainly for economic reasons, most spices are sun-dried. It is the cheapest method for bulk production and is employed when quality or appearance are not greatly affected by the action of direct sunlight. Sun-drying is done on concrete platforms, floors, grass or straw mats or simply by leaving the raw material to dry in the field. The spice product is often exposed to microbial contamination from the soil. Using raised platforms or racks not only circumvents this problem but also allows for a faster rate of drying because of the draugh of air circulating through the bottom and the sides. Sun-drying may take 2–14 days, depending upon the nature of the raw spice, the pretreatment applied, and the duration and intensity of sunlight.

Shade-drying is resorted to for some spices that tend to discolour or lose a considerable amount of essential oil under direct sunlight, e.g. cardamom, sage and most culinary herbs. Shade-drying permits the crop to be dried more slowly and uniformly.

Drying can also be accomplished by mechanical or artificial means, using natural convection dryers or forced-draugh dryers. It not only eliminates the disadvantages associated with sun-drying (e.g. microbial contamination, discolouration, dependence on the weather), but also provides controlled conditions of temperature, relative humidity and air flow, yielding a high-quality product. Temperature, the most critical factor in artificial drying, should not exceed 75°C, but varies depending upon the type of spice: just under 38°C for leafy and herbaceous spices, cooler for flowers, around 50°C for roots, and over 60°C for barks.

Grinding

Most spices are dried whole or as slices or chips, but not as powder. Grinding is done after drying. Grinding is basically a physical process of comminuting whole or pre-broken spices to a size suitable for a particular purpose. Some products like barks need to pass through a knife cutter or cracking machine before being ground. Various impact/disintegration mills (hammer mills, roller mills, attrition mills, limited mills, pulverizers) have been designed to yield products from coarsely broken uniform pieces to powders with a wide range of particle size. The suitability of these machines varies, depending on the fibre (e.g. high in ginger) or the fixed-oil content (high in nutmeg) of the spice products.

Grinding is generally performed in the consuming countries, to ensure adequate quality control.

Packaging and storage

Packaging aims to conserve the characteristic flavour and appearance of the spice product, protect it from disease and insect infestation, prevent oxidation and rehydration through absorption of moisture from the surroundings and minimize mechanical damage during handling and transport. Crude spices are generally packaged in burlap sacks, boxes, fibreboard drums or polypropylene feed sacks. Packaging is more critical for ground spices than whole spices. Ground spice has a greater surface area and is therefore more likely to lose essential oil; it will also lose or gain more moisture from the atmosphere and more easily oxidize. Three major types of packaging are recognized for ground spices and spice blends and mixtures. For bulk packaging: polythene-lined jute sacks, multi-walled paper sacks and fibreboard drums are preferred; for intermediate, catering or institutional packs: cardboard cartons lined with polythene, multi-walled paper sacks or traditional tinplate containers; for consumer packs: glass jars with plastic lids, acrylic or polythene drums, small tins or fibreboard drums with plastic lids (Hone & Milchard, 1993).

Spices should be stored in clean, dry and cool conditions, away from direct sunlight or heat and air. If stored for prolonged periods, the spice batches should be regularly inspected for insect infestation.

Freeze-drying is the best conservation procedure, but it requires special equipment. An excellent way to conserve spices is in vinegar (herbal vinegar/spice vinegar).

1.8 Processing

Processing of spices is mainly done by the flavour and fragrance industry, which is specialized in bringing together thousands of aromatic materials from all parts of the globe, refining and mixing them, and producing the range of flavours and fragrances that meets the requirements and demands of the user industries.

Grasse (France) was a famous perfumery centre. It developed in the 17th Century, and had its heyday between the two World Wars. The Second World War disturbed commercial activities, led to the loss of control of production through decolonization, breaking the Grasse monopoly.

Newcomers in the sector after the Second World War were huge multinational companies, also intensively involved in synthetic aroma chemistry, such as International Flavors and Fragrances, Quest, Givaudan, Haarmann & Reimer, Firmenich, Polak Frutal Works, Takasago, and Bush Boake Allen. Most companies are involved in food flavours as well as perfumery, because the technology is very similar. For the last 20 years, the natural flavour sector has expanded most, because of stricter legislation on food additives.

The user industries can be divided into 'industries using flavours' (foods and beverages, semi-pharmaceuticals, toothpaste, tobacco), 'industries using perfumes' (soaps, detergents, air fresheners, deodorants, haircare products, cosmetics, perfumes), and the health sector industries (specialized pharmaceuticals in phytotherapy and aromatherapy, animal care).

1.8.1 Techniques

The dried spice can be traded as it is or can undergo some extraction procedures to yield essential oils or oleoresins.

The isolates are further transformed by e.g. purification, decolourization, concentration, separation of single constituents for new formulations or as starting material for the synthesis of new compounds. The next step is the mixing of primary materials for specific requirements of the user industries (Lawrence, 1995).

Essential oils

Three distinct processes are used to produce essential oils: solvent extraction, expression and distillation. Solvent extraction is an industrial process in which highly purified, volatile media are used to extract 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 simple tools, but it has been superseded by large-scale industrial processes.

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 an 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, because in small fields on poorly accessible hilly land, it is more economical to operate small and simple portable stills than to move a bulky crop to a central still. 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 function 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.

The type and duration of distillation depends on the nature and form of the plant material, the capacity of the distilling unit, the nature and volume of steam, and the volatility of the constituents. For clove buds, water distillation has been reported to provide the finest oils; steam distillation yields 'strong oils' with higher levels of eugenol because eugenol acetate hydrolizes during the process. Sweet basil can be distilled in 1–2 hours (batches of up to 1000 kg), while it can take from 6–9 hours for the distillation of clove buds (batches up to 700 kg). In anise and coriander, crushing the seeds immediately prior to distillation has been shown to increase the yield of oil by 5% and 17% respectively, save up to 10–15% steam and reduce distillation time by as much as 25%.

Oleoresins

In some spices, the volatile components in the essential oils are only part of the flavour. For instance, the characteristic bite of pepper and ginger and the characteristic yellow colour of turmeric are absent from the essential oils obtained from these spices. The total organoleptic principle is best approached by oleoresins.

Spice oleoresins are obtained by extraction of the raw material with a volatile, organic solvent. The dried spice is generally crushed into a coarse powder and immediately extracted, using either a single-stage or a double-stage extraction method. In the single-stage technique, the oleoresin is extracted from the spice with the selected solvent, and then the solvent carefully evaporated. In the double-stage extraction, the spice is first steam-distilled to obtain the essential oil, then dried and extracted as in the single-stage process; the oleoresin is eventually mixed with the essential oil to yield a more standardized product. Solvents commonly employed in spice oleoresin extraction include acetone, chlorinated hydrocarbons (e.g. methylene chloride, trichloroethylene), and hexane. The choice of the solvent is determined not only by the nature of the spice but also by the food laws of the country utilizing the oleoresin, e.g. in the United States the use of chlorinated solvents is currently under review. The oleoresin may be used as it is or dissolved in an edible solvent, dispersed in an edible neutral base (fixed oil, salt, dextrose, flour, rusk) or encapsulated in arabic gum or gelatin.

Oleoresins can also be obtained by extraction of spices with supercritical (liquid) CO_2. The process is similar to that used in the production of decaffeinated coffee and hop extracts. It has the advantage that the solvent is non-toxic, very easily removed, non-flammable. The solubility of various compounds can be regulated by manipulating temperature and pressure, making it possible to influence the ratio of volatile compounds to waxes in an oleoresin. CO_2 extraction, however, is a capital-intensive, high-technology operation that is beyond the means of most spice-producing countries.

Oleoresins may be refined (for instance by removing the wax compounds) to adjust their taste or improve their solubility in water. This can be done by distillation or extraction with special solvents, e.g. CO_2.

1.8.2 Quality standards

Quality standards have been defined for many spices, for both the whole and the ground forms, the essential oils and the oleoresins. 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 spices and derivatives 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 establishment of particular parameters. For spices, ISO 927 deals with the determination of extraneous matter, ISO 928 with the determination of total ash, ISO 930 with the determination of acid-insoluble ash, ISO 939 with the determination of moisture content, and ISO 6571 with the determination of volatile-oil content. In the case of essential oils, ISO 279 deals with the determination of relative density, ISO 280 with the determination of the refractive index, ISO 592 with the determination of optical rotation, ISO 875 with the miscibility in ethanol, and ISO 11024 with general guidelines for chromatographic profiles.

The third type of standards defines the limits for several characteristics the dried spice or an essential oil must comply with. Traditionally, these have been physical determinations; for spices proper these are the maximum amount of extraneous matter, moisture content, total ash, acid-insoluble ash, and the minimum percentage of volatile oil; for essential oils these are relative density, refractive index, optical rotation, miscibility with aqueous ethanol, 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. For tabulated overviews of ISO standards for physical characteristics of dried spices and essential oils from plants dealt with in this volume, see pp. 311–320. When no ISO standard was available, the information has been supplemented with data published in the Food Chemicals Codex (Committee on Food Chemicals Codex, 1996).

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 spices and 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. GRAS numbers are given in the individual species entries in this volume.

1.8.3 Adulterations and substitutes

Substitutes for a spice are materials that mimic its character; substitutes for natural essential oils are reconstituted compositions of aroma chemicals that mimic the character of the oil in question.

Spices and their essential oils are complex mixtures of hundreds of chemical compounds, most of which are present in minute amounts (a few parts per million or even less). Many of the minor chemical compounds that occur in nature are not commercially available. Moreover, those natural chemical compounds, which possess an asymmetrical carbon atom, are optically active, and their optical antipods, called enantiomers, may have different organoleptic qualities. No two natural products are chemically identical. Thus, substitutes for spices proper or reconstituted oils are generally approximations and often do not match the richness of their natural model.

Up to the 1930s, the aromatic scene was dominated by natural products. Developments in synthesis were relatively slow; the first step was to isolate natural compounds, e.g. cinnamaldehyde from cinnamon. One of the first nature-identical synthetic flavour compounds was vanillin, which appeared in 1876. It was by the end of the 1950s that synthetic citral, geraniol, nerol and linalool became viable alternatives for the reconstitution of natural essential oils (Verlet, 1993).

Industrialized countries are the most important producers of substitutes for natural aromatic materials. These substitutes can be isolated from other natural sources, e.g. isolation of eugenol from clove leaf oil. They may be produced by chemical modification of natural materials, e.g. methylchavicol and anethole from turpentine. They can be manufactured by chemical reactions with a natural chemical compound, e.g. condensations with citral. Other substitutes may also be produced completely synthetically, such as cinnamic aldehyde from toluene by oxidation via benzaldehyde and condensation with acetaldehyde. Thus the building blocks (chemical compounds) for reconstituted spice oils may be natural, nature-identical, or synthetic, not occurring in nature (for instance ethylvanillin as replacer for natural vanillin).

The identification of aromatic chemical compounds is nowadays facilitated by modern spectroscopic techniques: capillary gas chromatography (GC), mass spectroscopy (MS) and infrared spectroscopy (IS).

Substitution is a legitimate practice as long as it is properly declared. When not properly declared, substitution becomes adulteration.

Spices proper are sometimes adulterated with other dried or ground plant materials and with inorganic materials (sand, salts). Adulteration of natural essential oils takes place in a range of actions: standardization, reinforcement, liquidization, reconstitution, and commercialization.

Standardization involves improving the quality of a product to meet stipulated norms. The content of characteristic substances can be standardized by adding products that have been isolated from another natural source or produced synthetically. Common examples are the addition of eugenol from clove leaf oil to other spicy oils, or of synthetic cinnamaldehyde to cinnamon oil.

Reinforcement is an extension of standardization in which a natural or synthetic organoleptically characteristic compound is used to extend the original oil. When the odour 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'.

Liquidization has the aim not to change the organoleptic quality of a product, but its appearance, in order to improve its applicability. Some oleoresins may be semi-solid or solid. If the liquid form is preferred, solvent or liquidizer can be added to the product. Various solvents are used for this purpose, such as propyleneglycol, triethyl citrate and benzoates.

Reconstitution is the compounding of a natural isolate using natural, nature-identical or synthetic chemical compounds to obtain a product that is similar to the original natural oil. Reconstituted essential oils are especially applied in functional perfumery. When a natural essential oil in a perfume composition is prohibitively expensive it may be replaced by a reconstituted oil.

Commercialization of a natural 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, organoleptic characteristics. However, a buyer has the right to know what he or she is buying.

Because of their food use the adulteration of spice oils for flavouring has more serious implications than adulteration in perfumery. Some examples of adulteration of spice oils are the addition of a chemical compound from a cheaper natural source, e.g. eugenol from clove leaf oil to pimento berry oil, or of 1,8-cineole from *Eucalyptus globulus* Labill. oil to rosemary and cardamom oil, and of camphor from *Cinnamomum camphora* (L.) J.S. Presl to rosemary oil. Other examples of adulteration of spice oils are the addition of (semi-)synthetic components, e.g. methylchavicol and anethole from turpentine, and synthetic cuminaldehyde and cinnamaldehyde.

1.8.4 Quality control

The quality of spices has long been evaluated using microscopic techniques that involve not only examination of cells or structures characteristic of the spice product but also the staining of certain chemical constituents (e.g. starch, lignin) it contains. The method provides initial clues about the identity of the spice; it also aids in the detection of adulteration. Preliminary tests are conducted prior to microscopic examination, such as taking note of the colour, odour and taste of the product. Although several micro-chemical analyses are subsequently performed, much information is yielded by microscopic examination of starch, epidermal trichomes, calcium oxalate, and lignin. For example, calcium oxalate crystals occur as rosettes in the ground form of clove, coriander and fennel, and as prisms in cardamom; they are lacking in ginger and nutmeg. Starch, on the other hand, is present in ground ginger, cardamom and nutmeg, but absent in clove, coriander and fennel (Trease & Evans, 1972). French tarragon (the methylchavicol type) is distinguished from Russian tarragon (the elemicin-sabinene type) by having no hairs or only hairs of the bifid type, whereas the latter has star-type trichomes in dried leaf fragments (ISO 7926). Application of the tools of microscopy to determine the quality of spice products, particularly the ground material, entails a considerable knowledge of plant anatomy. The identity of the spice in question can only be confirmed after all the diagnostic features observed are compared with samples of known authenticity (Parry, 1969).

Until a few decades ago, the chief means of verifying the density, purity and naturalness of essential oils was the human nose, supported by the measurement of a number of physical characteristics and a few chemical analyses. Rapid advances in methods of chromatographic and spectroscopic analysis have revolutionized our 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. One commonly used method of separation is fractional distillation. Recent developments allow 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 (GC), resulting in a chromatogram from which components can be identified qualitatively and quantitatively.

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

Gas-phase infrared spectrometry 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 mass and electric charge of ions derived from the chemical compound are recorded and the identity of the original molecule can be established by comparing the information with reference data stored in a computer.

More detailed information on compounds is obtained by nuclear magnetic resonance spectroscopy (NMR), in which the resonance spectrum of the compound is recorded. All different H bonds are represented by specific peaks. To identify the compound tested, this pattern of peaks can be compared with reference data.

Advances in the chemistry of optical isomers have further enhanced the possibilities of identifying added compounds in essential oils. Most of the asymmetrical, 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 and result in an enantiomeric excess concentration (E.E.C.). As chemically synthesized compounds are only rarely optically active, their presence can be accurately demonstrated. Enantiomers can be separated by gas chromatography on columns with optically active stationary phases.

However, the high prices paid for pure natural essential oils are encouraging the development of increasingly sophisticated reconstitution practices, so 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 pinenes. 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 spectroscopy enables the magnetic resonance of individual bonds between atoms in a molecule to be studied. It appears that the ^2H is unevenly distributed over the various bonds in a molecule. As the internal distribution varies with the origin of the molecule, this method can distinguish whether, for instance, anethole is prepared from star anise, estragole or turpentine.

1.9 Genetic resources and breeding

The spice market is relatively small and comprises a large number of crops. The small size of the market for individual spices hampers the establishment of germplasm collections and breeding programmes.

Both direct selection and breeding work depend on the available genetic diversity. Very little systematic collection and evaluation of germplasm has been performed for tree spices, many of which have recalcitrant seeds, necessitating the establishment of living-tree collections. The genetic diversity of cultivated tree spices is narrowed by clonal propagation. Hence, the wild trees are essential as genetic resources. Breeding work in tree spices has received low priority. Even in 'important' crops such as Ceylon cinnamon no breeding programmes are known to exist. For one thing this requires a long-term research commitment, the benefits of which will be available in the distant future. Fortunately, superior genotypes can in most cases be cloned; in this way, a selection can reach the grower within a reasonable number of years. An intimate knowledge of tree habit and phenology is needed before efficient breeding programmes can be designed. The same applies to breeding for disease and pest resistance: the relation between the life cycle of the pathogen and tree phenology has to be understood (Verhey & Coronel, 1991).

For a number of annual or short-lived perennial spice crops such as coriander, perilla and turmeric, germplasm collection and breeding work has received more attention. However, named, well-defined cultivars have only been developed in a limited number of species treated in this volume, and most of these originate from outside South-East Asia. Similarly, most germplasm collections are maintained outside the area. Institutes in India actively conduct breeding research on many of the aromatic plants highlighted here. Bilateral or regional cooperation between South-East Asian and Indian institutes would be beneficial.

1.10 Sweetening agents and flavour enhancers

Sweetening agents

Sources of sugar were dealt with in Prosea 9: 'Plants yielding non-seed carbohydrates'. Sugar is the ideal sweetener, because it easily dissolves in water, its sweet taste has no unpleasant bitter or salt aftertaste, and it is rather cheap. It has considerable disadvantages, however. For instance, it is a major cause of dental decay and it contributes to obesity. Therefore, there has been a continuing search for sweetening agents that are low in energy value and even sweeter than ordinary sugar. There are some artificial sweeteners, such as saccharin (300–500 times sweeter than sucrose), cyclamate (30 times sweeter than sucrose), and aspartame (100–200 times sweeter than sucrose).

The following sweetening agents of plant origin are found in the following plants (Fox & Cameron, 1977; Rehm & Espig, 1991):

- miraculin, in the fruits of *Synsepalum dulcificum* (Schum. & Thonner) Baillon (syn. *Richardella dulcifica* (Schum. & Thonner) Baehni), which is able to make sour-tasting food taste sweet;
- monellin, in the fruits of *Dioscoreophyllum cumminsii* (Stapf) Diels, which is 3000 times sweeter than sugar;
- thaumatin, in the arillus of fruits of *Thaumatococcus daniellii* (Bennet) Benth., which is about 3 times sweeter than saccharin;
- stevioside, in the dried leaves of *Stevia rebaudiana* (Bertoni) Bertoni, being 200–300 times sweeter than sucrose.

In other cases, such as *Perilla frutescens* (L.) Britton, the plant contains substances that can be easily used for the synthesis of sweeteners (perillartine).
Since these sweetening agents are not carbohydrates, the plants producing them have not been treated in Prosea 9, but are dealt with in this volume.

Flavour enhancers

The most important flavour enhancer, common salt, is not of vegetable origin. Another important flavour enhancer is monosodium glutamate (umami taste) which is a white crystalline powder derived from vegetable protein. In Indonesia it is manufactured from sugar cane molasses (vetsin, ajino moto). Flavour enhancers may have little taste of their own, but they intensify the flavour of other products by making our taste buds temporarily more sensitive. Some 'spices' act in the same way, the kemiri (*Aleurites moluccana* (L.) Willd.) being a nice example.

1.11 Prospects

1.11.1 Uses

Worldwide, the popularity of spices as a basic food-flavouring ingredient has never waned through the years, quite the opposite: in more recent times, much interest has been focused on this special commodity. The interest has been attributed to a growing demand for natural and organic products, both food and non-food in nature, to complement an emerging lifestyle geared towards wholesome living. There is an increasing clamour to dispense with synthetic flavours and essences, artificial food colouring and too much salt in the daily diet, and spices nicely fulfill such a need.
The revived interest in spices has generally painted a more positive future scenario for this crop commodity. Particularly brighter prospects are envisioned for such spices as coriander, parsley, perilla, sage, sawtooth coriander, sweet basil and turmeric. For these and some other spices the greatest potential lies primarily in the development of products other than as flavouring materials per se.
Foremost among such products are the spices processed and manufactured into preparations aiding medicines in the treatment of various ailments through their adjuvant and alleviative qualities.
Essential oils and oleoresins from some spices can make excellent potent an-

tioxidants while a number hold promise as natural biocides. The latter use is particularly significant in view of the ongoing global concern over the hazardous effects of synthetic pesticides on humans and the environment.

In recent years much attention has been devoted to the use of natural pigments as food colourants. The interest is related to the growing restrictions on the use of artificial colouring compounds. A number of spices could fill the need for these, with the extra benefit of imparting aroma, pungency and bitterness to foods and drinks.

Spices are also viable sources of industrial and other types of chemicals, e.g. peroxidase from horseradish, oestrogens from star anise, and diosgenin (a precursor of oral contraceptives and corticosteroids) from fenugreek.

Important as an added source of income to the spice producer is the prospective utilization of the biomass of some spices (e.g. torch ginger and candlenut tree) as a good source of pulp and paper. Others may well be suited for wood and timber production, e.g. cassia and cinnamon. Plant hobbyists and enthusiasts have started exploiting the potential of some spices as a viable component of the ornamental flower industry, e.g. dill, fragrant pandan, laurel, oxalis, rosemary, sweet basil, tarragon and torch ginger.

1.11.2 Marketing

Migration, intercontinental business and pleasure travel, together with the advent of modern satellite communication have all contributed as confluent factors in bringing countries of the world closer to one another, bridging distant cultures, particularly in regard to food habits and cuisines. Exotic oriental dishes are being introduced into the United States and Europe, and so are the vegetables and spices (including their production know-how) peculiar to the preparation of these cuisines. Several spices used in Vietnamese cooking, e.g. fragrant pandan, rau ram and sawtooth coriander have gained popularity in the Western world. In the Philippines savoury herbs such as dill, oregano and tarragon, commonly utilized in Western dishes, have also been introduced and have become established as a lucrative fresh-herb market niche catering to first-class hotels, restaurants and fast-food chains. Production ventures involving this group of spices are profitable; however, the market is rather limited, cultivation is labour-intensive and small-scale plantings can sufficiently satisfy the local requirement.

Production and marketing are generally well-established for some spices, e.g. caraway, cardamom, cinnamon, dill, laurel, mustard, nutmeg, pepper and pimento. In some instances, market growth parallels the increase in population, but current suppliers are expected to fill the need for any additional future increase in demand.

Many fresh culinary herbs in the traditional production areas in temperate and Mediterranean regions are only available for part of the year. This gives tropical countries plenty of opportunities to fill the gap.

1.11.3 Research

The brighter prospect envisioned for a number of spices can only be realized if it is coupled with diligent scientific research, particularly if the development of products other than flavouring agents is pursued. Preliminary indications of the effectivity of spices and spice products for their medicinal, pesticidal and other biological values should be subjected to further rigorous testing. If subsequently confirmed, there will be a need to conduct cost-benefit analyses for formulating such products and to assess realistically their market potential.

The chemical constituents of lesser studied spices, e.g. Chinese keys, galanga, *Zingiber montanum* (Koenig) Dietrich and *Z. zerumbet* (L.) J.E. Smith, need to be characterized and their biological activities examined for various applications, so that their potential can be fully exploited.

For some spices, research should focus on cultivation aspects. The development or improvement of agronomic practices and efficiency of harvesting and processing should be looked into for spices such as coriander, fragrant pandan, galanga, stevia, star anise and turmeric, to maximise production. Appropriate silvicultural techniques for camphor-wood production need to be worked out in detail for cinnamon and cassia, if silvicultural ventures are deemed viable in the long term.

Countries in South-East Asia cannot compete in the production of some spices for global trade, e.g. caraway, chervil, fenugreek, horseradish and summer savory, as these require temperate growing conditions. However, if intended as local import substitute or to satisfy foreign tourists or expatriates, then production trials can be performed and yield responses determined in the cooler, upland areas of South-East Asia.

Hydroponic culture may provide an efficient method for optimizing crop yield. Its use on a few culinary herbs has gained a considerable following in the United States, Japan and industrialized countries of Europe. The initial capital investment cost and the relatively sophisticated technical skills required in the management of such a system has precluded its use not only in South-East Asia but also in other developing regions. Recently a simple non-circulating hydroponic system has been developed for vegetables, showing promise for use in culinary herbs (Midmore, 1994). This method could be looked into, together with other soilless cultivation techniques.

Another interesting research topic for spices is the in vitro culture for secondary metabolite production. Few spices have been investigated in this regard and little success has been attained in laboratory trials so far. The production of bioactive chemicals is still experimental.

Breeding work should also be one of the research priorities on spices, with the primary goal of obtaining high quality and yield of the desired product. Resistance to diseases, pests and environmental stress should also be an important objective of crop improvement. In the case of spices whose flowering and/or seed-setting remain stumbling blocks to conventional breeding work, e.g. ginger, tarragon and turmeric, biotechnological and tissue culture approaches such as selection for somaclonal variants, protoplast fusion, and recombinant DNA technology may be worth resorting to. Not many crop physiological studies have been carried out on spices. This is unfortunate, since a number of interesting physiological phenomena need to be investigated: the mechanism of shade tolerance of pepper and vanilla, the nature of recalcitrant seeds in cinnamon, clove, laurel and pimento, the variation in the growth rhythm in clove, and the influence of daylength and temperature on the vegetative and reproductive stages of spices such as oregano, sage, stevia and tarragon.

Finally, the taxonomy of some spices and their relatives, e.g. *Cinnamomum*, *Piper* and *Thymus*, is poorly known and has often engendered considerable confusion in the literature. Application of modern chemotaxonomy may provide a tool to establish appropriate evolutionary linkages in this regard.

Despite the role played by spices during thousands of years to titivate the palate and olfactory nerves and to fulfill our gustatory desires, research on spices is wanting compared with other economically important crops. A more critical view of this commodity and serious consideration of several suggested avenues of research mentioned above is called for, in view of the growing importance of spices in the modern world.

2 Alphabetical treatment of species

Aleurites moluccana (L.) Willd.

Sp. pl. 4: 590 (1805).
EUPHORBIACEAE
$2n = 22, 24, 44$

Synonyms *Jatropha moluccana* L. (1753), *Aleurites triloba* J.R. & G. Forst. (1776), *Juglans camirium* Lour. (1790).

Vernacular names Candlenut tree, Indian walnut, lumbang tree (En). Noix des Indes, noix de Bancoul, noix des Moluques (Fr). Indonesia: kemiri (general), miri (general), muncang (Sundanese). Malaysia: kemiri, kembiri, buah keras. Papua New Guinea: tutui. Philippines: lumbang, biaw (Cebuano). Laos: kôk namz man. Thailand: phothisat (Bangkok), kue-ra, purat (peninsular), mayao (northern). Vietnam: lai.

Origin and geographic distribution The origin of *A. moluccana* is not accurately known, but it is distributed from India and China, throughout South-East Asia, to Polynesia and New Zealand. It has been introduced for cultivation in many tropical countries all over the world.

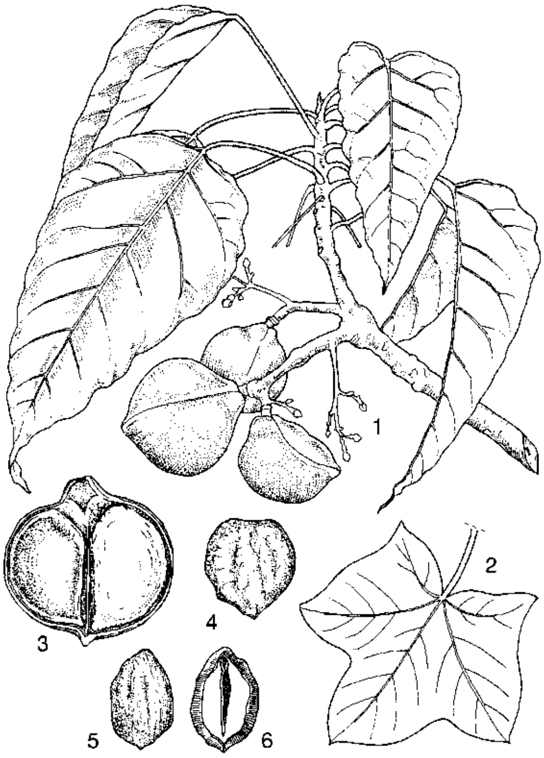
Uses The seed of *A. moluccana* ('kemiri') is an indispensable spice in Indonesian cuisine, possessing little flavour of its own, but mainly acting as an enhancer. Raw, or briefly roasted, it is added to numerous dishes in small quantities, pounded and mixed with other ingredients. Raw seed is slightly poisonous, acting as a laxative.
The fatty seed oil (lumbang oil) is used industrially (in paints, varnishes, linoleum, soap manufacture, wood preservation), for illumination (lamp oil, candles) and medicinally (mild purgative, embrocation for sciatica, against hair loss), but not for cooking. The oil is also used in the batik industry. For illumination, the oily kernels can be burnt as such, or pounded and made into candles.
In Indonesia the residual oil cake is sometimes processed into a snack-food called 'dage kemiri': the oil cake is pounded, soaked for 48 hours in running water, steamed, and stored for 48 hours in a dark place to ferment (covered with a banana leaf with a weight on top of it to press out remaining liquid). The oil cake is an excellent organic fertilizer rich in N and P, but is not recommended as animal feed because of its toxic effects. *A. moluccana* is a commonly planted tree in villages, and is also used for reafforestation. It grows well in fields infested with sedge and can help suppress the weed. The wood is rather light and not very durable. Though not used for construction, it is used to make furniture, small utensils and matches where it is abundant. It is suitable for paper pulp.
In traditional medicine the seed is used as a laxative, pulped kernels are used in poultices to treat headache, fevers, ulcers, swollen joints and constipation, the bark is used to treat dysentery, the bark sap (mixed with coconut milk) to treat sprue, a decoction of young leaves to treat scrophulosis, and boiled leaves are applied externally to treat headache and gonorrhoea.
The hardness of the 'nut' (seed surrounded by the hard endocarp shell) is exploited in a gambling game in which the objective is to break the opponent's 'nut' by hitting it with one's own. In Indonesia a special cultivar supplies oval thick-walled 'nuts' for this ('kemiri pidak', 'muncang kelenteng').

Production and international trade In Indonesia, there is a considerable internal trade in kemiri nuts, mainly with Java as the destination. In the late 1980s, annual exports of kemiri were in the order of 400–600 t with a total value of US$ 200 000–500 000. Kemiri is traded and transported as 'nuts'. At the retail level, small quantities of kemiri are marketed as seed (hard endocarp removed).
Early in the 20th Century, some seed oil (lumbang oil) was exported from the Philippines to the United States for industrial use in paints and soaps.

Properties Per 100 g edible portion, dry seed of *A. moluccana* contains: water 5–8 g, protein 8–22 g, fat 60–62 g, carbohydrates 7–18 g, fibre 2–3 g, ash 3–4 g. The energy value is about 2675 kJ/100 g. Possessing very little flavour of its own, it seems that kemiri mainly acts as a flavour enhancer, making our taste buds temporarily more sensitive.
The fatty component (cold-pressed) is a drying oil, light yellow in colour, with agreeable flavour and smell. When left to stand, it dries in thin films. The main characteristics are a high iodine value (115–170 g/100 g) and a high saponification value (184–227 mg K per g oil). The content of free fatty acids is very low; glycerides of saturated acids form 2%, and glycerides of unsaturated acids 96% (oleic acid 40%, linoleic acid 48%, linolenic acid 8%).
The moderate toxicity of the seed has been ascribed to a toxalbumin similar to the ones in *Abrus* Adans. and *Ricinus* L.
The 'nut' weight is 10–14 g; it is made up of shell (endocarp) for 65–70%, and seed (kernel) for 30–35%.

Adulterations and substitutes Kemiri can be used as a substitute for 'santen' ('milk' pressed from grated coconut in water). Lumbang oil strongly resembles linseed oil (*Linum usitatissimum* L.), and either oil can be used as a substitute for the other.

Description Large, evergreen, monoecious tree, 10–40 m tall, with heavy, irregular, large-leafed crown appearing whitish or frosted from a distance due to a cover of white stellate hairs especially on young parts; stem diameter up to 1.5 m, bark grey, rather rough with lenticels. Leaves alternate, simple; stipules small, early caducous; petiole up to 30 cm long, bearing a pair of small, green-brown glands at the top on the upper side; blade in young trees and suckers subcircular in outline, up to 30 cm in diameter, with a cordate base and 3–5 triangular lobes; blade in adult trees ovate-triangular or ovate-oblong, 12–23 cm × 6–12 cm, margin entire or slightly sinuate, apex pointed, curved and drooping, dark green with a silvery gloss. Inflorescence thyrsoid, terminal or upper-axillary, 10–20 cm long; flowers unisexual, on a small pedicel, white, female flowers terminating the ultimate branchlets of the cymes, male flowers much more numerous, smaller, opening earlier, arranged around the female flowers in bunches; calyx 2–3-lobed at anthesis; petals 5, lanceolate, 6–7 mm long in male flowers, 9–10 mm in female ones; disk glands 5; male flowers with 10–20 stamens, arranged in 3–4 series, the outer ones free, the inner ones connate; female flowers with 2–4-locular, tomentose ovary and 2–4, deeply bipartite styles. Fruit drupaceous, laterally compressed, ovoid-globose and 2-seeded or semiglobose and 1-seeded, 5–6 cm × 4–7 cm, tomentose, indehiscent, olive-green with whitish flesh. Seed compressed-globose, up to 3 cm × 3 cm; endocarp thick, bony, rough; albumen thick, rich in oil.



Aleurites moluccana (L.) Willd. – 1, fruiting branch; 2, leaf of young tree; 3, fruit (longitudinal section); 4, 'nut' (front view); 5, 'nut' (side view); 6, 'nut' (longitudinal section).

Growth and development *A. moluccana* first flowers when it is about 4 years old. Flowering can occur year-round. Fruits need 3–4 months to develop and mature. In the Philippines, trees reached 12.5 m in height and 15 cm in diameter, in 8 years.

Other botanical information *Aleurites* J.R. & G. Forst. is a small genus of only 2 species since *Aleurites* sensu lato has been split up into 3 genera:
- *Aleurites* J.R. & G. Forst., comprising *A. moluccana* and *A. remyi* Sherff, the latter only occurring in Hawaii;
- *Reutealis* Airy Shaw, comprising *R. trisperma* (Blanco) Airy Shaw (syn. *Aleurites trisperma* Blanco), used for oil production in the Philippines;
- *Vernicia* Lour., comprising *V. cordata* (Thunb.) Airy Shaw (syn. *Aleurites cordata* (Thunb.) Muell. Arg.), *V. fordii* (Hemsl.) Airy Shaw (syn. *Aleurites fordii* Hemsl.), and *V. montana* Lour. (syn. *Aleurites montana* (Lour.) Wilson). *V. montana* and *V. fordii* yield the well-known tung oil.

Var. *floccosa* Airy Shaw, occurring in New Guinea, is distinguished on the basis of a much more copious subfloccose stellate indumentum, contrasting with the minute smooth covering of typical *A. moluccana*, and in having 3–4-locular ovaries instead of bilocular ones.

Ecology *A. moluccana* occurs commonly in the drier regions of South-East Asia. In the more humid parts it is found naturally in rather specific locations, such as well-drained sands near the coast and on limestone, but it is also present naturalized in mixed and teak forests, at altitudes up to 1200 m.

Propagation and planting Propagation of *A. moluccana* is usually by seed, but vegetative propagation, e.g. by marcotting, seems possible. The hard-shelled seeds retain their viability for over a

year. The hard shell, however, is also the cause of uneven and often strongly delayed germination. Germination percentage is usually low (30–40%), but can be improved significantly by scarification: mechanical, physical (successive heating and cooling), or chemical (H_2SO_4, HNO_3).
Seeds are sown in a seedbed or in polythene bags at a depth of 3–10 cm. In the field the planting distance is about 10 m × 10 m when grown for seed, whereas closer spacings of 4 m × 4 m are applied if pulp-wood is the main objective.

Husbandry Established seedlings require little tending. The leaves are renewed regularly, and old leaves left on the soil soon rot, enriching the soil with organic matter and nutrients.

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

Harvesting Fruits of *A. moluccana* are allowed to fall and lie on the ground until the outer fruit wall has decayed, after which the 'nuts' (hard-shelled seeds) are collected.

Yield Yield estimates of *A. moluccana* vary from 2500–15 000 'nuts' per tree per year, or 25–150 kg (at a 'nut'-weight of 10 g). This corresponds to 8–50 kg kernels per tree per year, or 5–30 kg oil per tree per year.

Handling after harvest Since it is difficult to crack the 'nuts' of *A. moluccana*, a combination of mechanical (hammering) and physical (successive heating and cooling) methods is usually applied. The best quality 'nuts' for use as a spice are obtained by sun-drying for 5–10 days, followed by mechanical cracking.
'Nuts' may be stored for over a year without appreciable change in the amount and composition of the oil. Seeds (kernels) cannot be stored for long, since they are attacked by small beetles, and the oil acidifies.
The use of an oil mill for crushing and grinding the whole 'nuts' and pressing the oil, gives a low oil yield and the oil cake is of less value as organic fertilizer.

Genetic resources and breeding A living collection of *A. moluccana* is maintained by the Research Institute for Spice and Medicinal Crops (RISMC), Bogor, Indonesia. No breeding programmes are known to exist for *A. moluccana*.

Prospects The value of kemiri as a spice is uncontested. Only if tree stocks considerably increase, e.g. as a result of use in reafforestation and agroforestry, might there be sufficient raw material for significant oil production. The oil produced might find a use in applications that currently use imported linseed oil or petrochemicals. However, it is still doubtful whether this is economically viable. The use of the wood in the paper industry might become a major application in the long term.

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J.S. Siemonsma

Alpinia galanga (L.) Willd.

Sp. pl. (ed. 4): 12 (1797).
ZINGIBERACEAE
$2n = 48$

Synonyms *Maranta galanga* L. (1762), *Languas vulgare* Koenig (1783), *Amomum galanga* (L.) Lour. (1790), *Languas galanga* (L.) Stuntz (1912).

Vernacular names Galanga, greater galangal (En). Galanga (Fr). Indonesia: langkuas (general), laos (Javanese), laja (Sundanese). Malaysia: lengkuas, puar. Philippines: langkawas, palla, langkuas (Bicol). Burma (Myanmar): padagoji. Cambodia: rumdéng. Laos: kha:x ta: dè:ng. Thailand: kha. Vietnam: ri[eef]ng n[ees]p, s[ow]n n[aj]i.

Origin and geographic distribution The exact origin of galanga is unknown; the oldest reports about its use and existence come from southern China and Java. At present it is cultivated in all South-East Asian countries and in India, Bangladesh, China and Surinam.

Uses Galanga is principally used as a spice. It has a strong pungent taste like a mixture of pepper (*Piper nigrum* L.) and ginger (*Zingiber officinale* Roscoe). Its rhizomes are very commonly used and said to be indispensable in everyday cooking throughout South Asia and South-East Asia. The flowers and young shoots are used as a vegetable or as a spice. The rhizomes have a wide range of applications in traditional medicine, e.g. in skin diseases, indigestion, colic, dysentery, enlarged spleen, respiratory diseases, cancers of mouth and stomach, for treatment of systemic infections and cholera, as an expectorant, and after childbirth. The rhizomes have also been used as an aphrodisiac, for other stimulating properties and as a veterinary medicine. The rhizomes, the rhizome oleoresin ('root extract'), and the essential oil isolated from the rhizomes ('root oil') are used to flavour liqueurs, ice-cream, pastry, etc. An essential oil can also be isolated from the leaves, but it is not used. In the United States the regulatory status 'generally recognized as safe' has been accorded to galanga root (GRAS 2498), galanga root oleoresin (GRAS 2499) and galanga root oil (GRAS 2500). The fruits of galanga are used locally as a substitute for true cardamom (*Elettaria cardamomum* (L.) Maton).

Production and international trade Data on the production, consumption and trade of galanga are scarce and unreliable because often no distinction is made between *A. galanga* and *A. officinarum* Hance. Production in South-East Asia must be considerable as it is a common spice used daily by millions of people. It is mostly cultivated in home gardens. The Netherlands imports yearly at least 100 t fresh rhizomes and 25–30 t dried rhizomes. The main suppliers are Thailand, Indonesia and India. Prices fluctuate from 1–2.5 US$/kg dry weight.

Properties The composition of galanga rhizomes per 100 g air-dry matter is: moisture 14 g, total ash 9 g, matter soluble in 80% ethanol 49 g, matter soluble in water 19 g, total sugar 9 g, total nitrogen 3 g, total protein 16 g. Essential-oil content ranges from 0.2–1.5% (of dry weight); fresh rhizomes yield about 0.1% of oil. Camphor, cineole (20–30%) and methyl cinnamate (48%) have been described as oil components in older literature. Studies performed in the 1980s confirmed the presence of 1,8-cineole as main component, but the other two compounds were not detected. Studies, mostly in vitro, of the biological activities of the rhizomes revealed antibacterial, antifungal, antiprotozoal, and expectorant activities. 1'-Acetoxychavicol acetate, a component of fresh and newly dried rhizomes, has been proved to be active against dermatophytes. The same compound and another constituent of the rhizomes, 1'-acetoxyeugenol acetate, were found to have anti-tumour activity in mice (against Sarcoma 180 ascites). The same compounds, isolated from galanga fruits, showed anti-ulcer activity in Shay rats, while the chavicol derivative depressed the gastric secretion of these rats. The oil has also shown interesting potential as an insecticide against house-flies.

Adulterations and substitutes Dried powdered galanga rhizome is sometimes adulterated with rhizome powder of lesser galangal (*A. officinarum*).

Description A robust, tillering, perennial herb, up to 3.5 m tall, with subterranean, creeping, copiously branched, rhizome. Rhizome subterete, 2–4 cm in diameter, hard, fibrous, shiny, light red or

Alpinia galanga (L.) Willd. – 1, rhizome; 2, shoot with inflorescence.

pale yellow, fragrant. Pseudostem erect, formed by the rolled leaf sheaths. Leaves alternate, distichous, lowest and uppermost ones smallest; sheath densely pubescent at apex; ligule truncate, 1 cm long, densely pubescent; petiole 1–1.5 cm long, hairy; blade oblong-lanceolate, (20–)50(–60) cm × (4–)9(–15) cm, base cuneate, apex with short point, subglabrous, glossy green, densely white-dotted. Inflorescence terminal, erect, many flowered, racemose, 10–30 cm × 5–7 cm, pubescent; bracts ovate, up to 2 cm long, each subtending a cincinnus of 2–6 flowers; bracteoles similar to the bracts but smaller; flowers fragrant, 3–4 cm long, yellow-white; calyx tubular, about 1 cm long, white; corolla tube terete, about 1 cm long, lobes 3, recurved, oblong-lanceolate, 1.5 cm × 0.6 cm, margins ciliate, greenish-white; labellum (central staminode) petaloid, spatulate, 1.5–2.5 cm × 0.5–0.75 cm, white veined with lilac, undulate crenate with a stalk-like base and a recurved apex; lateral staminodes represented by 2 subulate lobes at the base of the labellum, 7–8 mm long, reddish; stamen 1, erect with incurved anther, 2–2.5 cm long; style slightly longer than stamen, stigma obtriangular. Fruit a globose to ellipsoidal capsule, 1–1.5 cm in diameter, orange-red to wine red.

Growth and development Shoots from pieces of galanga rhizome emerge about 1 week after planting. About 4 weeks after planting 2–3 leaves have developed. Rhizomes develop quickly and reach their best harvest quality about 3 months after planting. If left longer in the field, they become too fibrous and the large clumps of plants that are formed hamper harvesting. Flowering occurs after exceptionally dry weather. In India, plants start flowering in the latter half of the hot season (April–May) and seeds ripen in November. However, seeds rarely reach maturity.

Other botanical information The name *A. galanga* (L.) Swartz is common in the literature. In 1791, however, Swartz published on this species, using the name *Maranta galanga* L., and he did not transfer the genus name to *Alpinia.* Several cultivars probably exist, but no clear descriptions are available. Cultivars with yellow-white rhizomes and with pink to red rhizomes are known. The pseudostems of white cultivars reach about 3 m in height, with stems 2.5 cm and rhizomes 3–4 cm in diameter; by comparison, red cultivars reach about 1–1.5 m in height with stems up to 1 cm and rhizomes up to 2 cm in diameter, but white-rhizomed cultivars with such characteristics are also reported.

Plants with broad leaves, tomentose beneath, are sometimes distinguished as var. *pyramidata* (Blume) K. Schumann, occurring both wild and cultivated in Java, Borneo and the Philippines.

A. officinarum (lesser galangal) can be distinguished from *A. galanga* as follows: its rhizomes are smaller and dark brown to black, 8–12 mm in diameter with 4–6 mm long, finely ridged internodes; the plant is also smaller, about 1–1.5 m tall.

Ecology Galanga requires sunny or moderately shady locations. Soils should be fertile, moist but not swampy. Sandy clayey soils rich in organic matter and with a good drainage are preferred. Wild or semi-wild types occur in old clearings, thickets and forests. In the tropics, galanga occurs up to 1200 m altitude.

Agronomy Long tips of rhizomes of galanga are used for propagation. The soil should be well tilled before planting. Alternatively holes, 35 cm × 35 cm and 15–20 cm deep, are dug, filled with manure mixed with soil, inorganic fertilizers and lime (for acid soils). One piece of rhizome is planted per hole, and then covered with mulch. Often, trenches are dug to drain the field after rainfall, as rhizomes do not develop under waterlogged conditions. Galanga is usually planted along the borders of gardens, in rows at distances of 0.5–1 m square. Weeding and subsequently earthing up are carried out respectively 1 and 2 months after planting. If produced for the market, rhizomes of galanga are harvested about 3 months after planting. Whole plants are pulled out, the shoots cut off and the rhizomes washed and cleaned. Rhizomes older than 4 months turn woody, fibrous and spongy and lose their value as a spice. For local use plants are left in the field and, as they tiller vigorously, small quantities of good quality rhizome can always be harvested. For the production of essential oil rhizomes are harvested when the plants are more than 7 months old. No reliable data are available on the yield of galanga. The rhizomes are marketed fresh or dried. The dried product is usually ground before use, but ground rhizomes are not traded in bulk, as adulteration can occur, e.g. with *A. officinarum*.

Genetic resources and breeding There are no known germplasm collections of galanga, and no galanga breeding programmes.

Prospects Galanga will remain an important spice for the local market in South-East Asia. Botanical and agronomic research is urgently needed to obtain more information on its requirements, variability and potential. Existing trade proves the interest of international markets in good quality galanga. Further studies on the biological activities of the rhizomes, their usefulness in medicine and their potential as insecticide may give rise to cultivation on a larger scale.

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Amomum compactum Soland. ex Maton

Trans. Linn. Soc. 10: 251 (1811).

ZINGIBERACEAE

$2n = 48$

Synonyms *Amomum cardamomum* auct., non L. (1753), *A. kepulaga* Sprague & Burkill (1929).

Vernacular names Round cardamom, Java cardamom, false cardamom (En). Amome à grappe (Fr). Indonesia: kapulaga (Javanese), kapol (Sundanese), puwar pelaga (Sumatra). Malaysia: kepulaga, puar, pelaga.

Origin and geographic distribution *A. compactum* originates from and is an endemic of the lower hills of western Java. At present it is also cultivated in western Java, in southern Sumatra, in the Moluccas and occasionally elsewhere (e.g. in Singapore, Peninsular Malaysia, southern China).

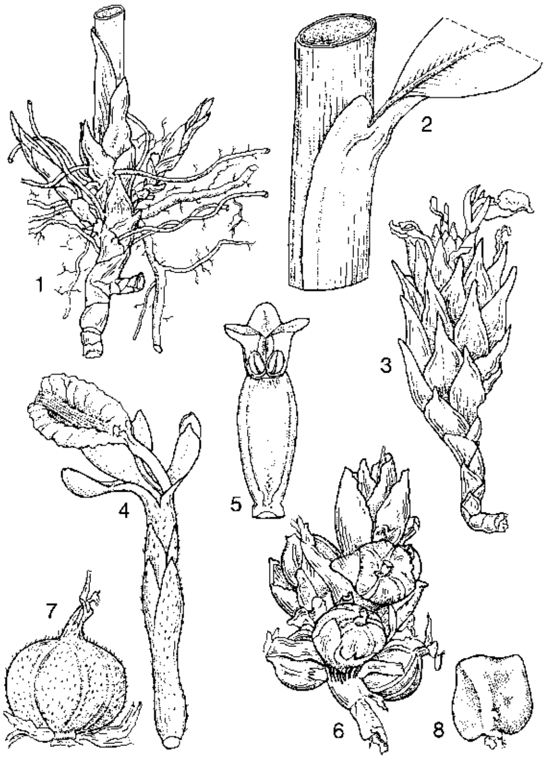
Uses The seeds of round cardamom have a peppery, ginger-like flavour and serve as a warm aromatic spice to sweeten the breath and to appetize food. They are sometimes considered as having a more appreciated taste than the seed of the true cardamom (*Elettaria cardamomum* (L.) Maton) for which they also serve as a substitute. Steam distillation of the seed yields an essential oil that is used in the perfume and flavour industry. Medicinally the seeds are used as a stomachic, as a remedy against colds and coughs and as a tonic, especially after childbirth. Raw, cooked or steamed young shoots are often eaten as a vegetable. A decoction of the whole plant is drunk as a tonic and to alleviate rheumatic pain. Dried crushed rhizomes are taken to reduce fever and to combat intestinal pains.

Production and international trade Data on production, consumption, and trade are unreliable because generally no distinction is made between true cardamom and round cardamom. Round cardamom is only grown commercially in Indonesia, primarily in southern Sumatra and Java. The production of cardamom (both species) in Indonesia is still unstable and variable, with 90–300 t produced annually during 1976–1983. In 1984 there were 1000 ha of cultivated cardamom (both species), which produced 935 t of seeds. The bulk was consumed locally (especially in the traditional medicine industry), with 200 t exported. The dried seeds had a value of US$ 1660/t. North America, Europe, and Japan are the main importers of true cardamom, while round cardamom is mostly traded in Asia. However, there is strong competition for this Asian market from other species of false cardamom grown in other South-East Asian countries. Because production is low and variable there are no reliable trade statistics specifically for round cardamom and its production is still included under true cardamom production or in the general category of 'spices'.

Properties Dried round cardamom seed has an essential-oil content of 2–4%, composed primarily of 1,8-cineole (up to 70%), β-pinene (16%), α-pinene (4%), α-terpineol (5%) and humulene (3%). Fresh rhizomes and roots have an essential-oil content of about 0.1% which also contains 1,8-cineole.

Adulterations and substitutes The primary substitute for round cardamom is true cardamom (*Elettaria cardamomum*), because of the higher essential-oil content of the dried seeds (5–8%). Other species labeled and used as 'false' cardamoms in South-East Asia (see Chapter on 'Minor spices' and 'Spices with other primary use') include *Amomum acre* Valeton, *A. krervanh* Pierre ex Gagnepain, *A. ochreum* Ridley, *A. testaceum* Ridley, *A. uliginosum* Koenig, *A. xanthioides* Wallich ex Baker and *A. xanthophlebium* Baker. Outside South-East Asia, 'false' cardamoms include *Amomum aromaticum* Roxb. and *A. subulatum* Roxb. (Eastern Himalayas), *Alpinia globosa* Horan. (Indo-China and China), *Aframomum corrorima* (Braun) Jansen (Ethiopia), *Aframomum daniellii* K. Schumann (Cameroon) and *Aframomum melegueta* (Roscoe) K. Schumann (West Africa).

Description Robust, perennial, aromatic herb, up to 2 m tall, with subterranean, copiously branched rhizome from which arise erect leafy stems and separate inflorescences. Rhizome hard, subterete, 1–2 cm in diameter, yellow-white, covered with red-brown, glabrous scales. Leafy stem terete, up to 1.5 m tall and up to 2.5 cm in diameter. Leaves alternate, distichous, sessile, sheathed, smelling strongly of turpentine when bruised; ligule semilunar, 5–7 mm tall, deeply emarginate, glabrescent; blade lanceolate, 7.5–50 cm × 3–10 cm, base gradually narrowing, margins finely ciliate, apex acuminate with acumen up to 3 cm long, shiny green with numerous initially white dots that turn blood-red. Inflorescence sprouting laterally from the rhizome, sometimes partly subterranean; peduncle ascending, 2–10 cm × 5–6 mm, clothed with dense, imbricate, persistent scales; flower-bearing part of inflorescence spike-like, ellipsoidal or oblongoid, in fruit more ovoid, 3–9 cm × 2–5 cm, densely covered with numerous bracts; sterile bracts absent; fertile bracts ovate-oblong, 1.5–4 cm × 1.5–2.5 cm, acuminate, densely striate, ciliate, silky on the back, persistent, each one covering a bracteole with a sessile flower; bracteole tubular-spathaceous, 3-dentate, silky hairy, much shorter than the calyx; calyx tubular-spathaceous, 1.3 cm long, hairy; corolla tubular, 3-lobed, lobes oblong-linear and about 8 mm long, white or yellowish; labellum broadly elliptical, 15–18 mm × 10–15 mm, narrowed and stalk-like at base, hairy inside, yellow with dark purple median band or yellow-white with purple-margined yellow median band; staminodes absent; stamen 1.3 cm long, filament hairy at base, anther connective distinct and 3-lobed; pistil surrounded by connate stylodes of 2 mm length, style glabrous, stigma cup-shaped and ciliate. Fruit a depressed globose capsule, 1–1.5 cm in diameter, densely striate and silky hairy, crowned by the remnants of the flower, yellow-white. Seed polygonal, obtuse, about 4 mm long with white aril.



Amomum compactum Soland. ex Maton – 1, stem part with rhizome; 2, stem part with leaf base; 3, inflorescence; 4, flower; 5, stamen; 6, infructescence; 7, fruit; 8, seed.

Growth and development During the first years of growth, flowers produce hardly any fruit. New inflorescences develop continuously from the 3rd or 4th year and produce fruits that mature 1.5–2 months after flowering. Rainfall (or irrigation) promotes flowering, while fruit-set is increased by the presence of pollinating insects.

Other botanical information There has been no thorough taxonomic revision of the genus *Amomum* Roxb.; as a result, confusion prevails in the literature. Species from at least 4 different genera (*Aframomum* K. Schumann, *Alpinia* Roxb., *Amomum* Roxb., *Elettaria* Maton) are indicated with the English vernacular name cardamom. Only *Elettaria cardamomum* is the 'true cardamom', other species are 'false cardamoms'. The round cardamom (*Amomum compactum*) occurs naturally in western Java only; other cited occurrences refer to other species, to cultivated plants or to escapes from cultivation.

Ecology Optimum growing conditions for round cardamom are: average annual temperature 23–28°C (ranging from 10–35°C), a constant high relative humidity, annual rainfall 2500–4000 mm with at least 136 rainy days and partial shade (arid conditions and direct sunlight are not well tolerated). Well-drained soils with pH 5–6.8 and high organic matter content are preferred. Favorite soil types are latosols, andosols, alluvials and red-yellow podsols with a loamy or sandy loam texture. In the tropics round cardamom grows well at altitudes of 200–1000 m, but greatest yields are obtained at 300–500 m altitude. In Java it grows wild in primary and teak forests.

Propagation and planting Round cardamom can be propagated by seed but most commonly rhizome cuttings or offsets of the plant clump are used. The rhizome cutting or offset (with rhizome part and adventitious roots) should bear 1–2 shoot buds or young plantlets 10–15 cm tall bearing 4–8 leaves and may bear a 80–100 cm long stem part. Under dry weather conditions some of the lower leaves are removed to prevent rapid dehydration. Planting holes 50 cm deep and wide are first prepared, the soil is loosened and organic matter is incorporated. Per hole 1–2 cuttings are planted about 10 cm deep. Plant spacing is 1.5 m × 1.5 m. Tree crops such as coconut or sugar palm can provide shade. If rainfall is poor, regular watering is necessary until establishment.

Husbandry Round cardamom should be weeded regularly. Mulching (e.g. using large banana leaves) is recommended. Occasionally the clumps are thinned to 4–5 stems per clump, and the soil around the plants is kept loose to prevent waterlogging. When grown under shade, the shade plants must be pruned and dead or diseased plants removed regularly. One month after planting and every 6 months thereafter, inorganic fertilizer is applied in a circle dug 20 cm deep around the plant. N (45–67 kg), P (34–45 kg), and K (45–100 kg) are applied per ha.

Diseases and pests No serious diseases and pests of round cardamom have been reported. *Pentalonia nigronervosa*, a viral disease, causes wilting and dieback. *Phyllosticta* sp. is a fungal disease attacking the leaves, especially of seedlings. *Cephalosporium* sp., *Pythium aphanidermatum*, and *P. vexans* attack the rhizomes. Control measures are primarily removal of the affected plants, but also avoiding waterlogged soils, and the application of fungicides. Insects, especially maggots, have been reported as attacking all parts of the plant, but no detailed information is available. Rats and bats occasionally cause damage.

Harvesting The fruits are ready for harvest about 1.5–2 months after flowering. When mature, the fruit feels firm, the corolla has been shed, and the skin is wrinkled and reddish-purple. Harvesting is carried out by cutting the entire fruit cluster and then removing the individual fruits. From the 4th year onwards, round cardamom fruit can be harvested every 35–45 days. In Java, 4 small harvests are possible between January and July (rainy season) and 3 larger ones between August and December (dry season). Fresh plant material such as stems and rhizomes, is harvested as needed for local consumption.

Yield During the first year yields of round cardamom are quite low. Dry fruit yield can reach 275 kg/ha during the second year, rising to 475 kg/ha during the following years.

Handling after harvest Round cardamom fruits are washed in a 2% soda solution for 10 minutes, to bleach them. Occasionally they are bleached by steaming with sulphur. They are then dried carefully to prevent fruit splitting, which decreases the quality. A common practice is to sun-dry the fruits for 2–3 hours in the morning and then move them to a shady location for air-drying. This process is repeated for 5–10 days until the fruits are dry and contain 15–20% water. Finally, the fruits are sorted by size and colour.

Genetic resources and breeding No germplasm collections or breeding programmes are known to exist for round cardamom.

Prospects It is questionable whether round cardamom will gain in importance economically, since true cardamom produces higher fruit yield and fruits with a higher essential-oil content. It seems that growing true cardamom is more profitable than producing round cardamom. However, the production of true cardamom requires higher inputs of labour than that of round cardamom, and true cardamom does not thrive as readily in Indonesia as round cardamom does.

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X.Y. Wolff & Hartutiningsih

Anethum graveolens L.

Sp. pl.: 263 (1753).
UMBELLIFERAE
$2n = 20$

Synonyms *Anethum sowa* Roxb. ex Fleming (1810), *Peucedanum graveolens* (L.) Hiern (1877), *P. sowa* (Roxb. ex Fleming) Kurz (1877).

Vernacular names Dill (En). Aneth, aneth odorant, fenouil puant (Fr). Indonesia: adas manis, adas sowa, ender. Malaysia: adas china, adas pudus, ender. Burma (Myanmar): samin. Laos: phak s'i:. Thailand: thian-khaopluak, thian-tatakkataen (central), phakchi lao (eastern). Vietnam: thi[af] l[af].

Origin and geographic distribution The origin of dill is not known; it is thought to be native to the Mediterranean and to South and south-western Asia. Now it is cultivated, usually in home gardens, all over the world, including South-East Asia. Sometimes it escapes from cultivation and naturalizes.

Uses The green parts and the fruits of dill have been used since ancient times both as a culinary and as a medicinal herb. It has a pleasant aromatic odour but a slightly bitter and pungent taste. Finely chopped fresh or dry leaves and young inflorescences are used as a culinary herb in soups, salads and sauces. Inflorescences and ripe fruits are used to flavour pickled cucumbers, onions, vinegar, sauces, pastries and bread; in India the fruits are an ingredient of curry powder. Dill oleoresin is a concentrated aromatic powder, obtained by extracting the fruits with alcohol and then drying the extract; it is especially recommended for low-salt or salt-free diets. Essential oils can be steam-distilled from the green parts (dill herb oil, dill weed oil) and from the fruits (dill seed oil). In the United States the regulatory status 'generally recognized as safe' has been accorded to dill (GRAS 2382), dill herb oil (GRAS 2383) and dill seed oil (GRAS 2384). Dill herb oil is mainly used for flavouring and seasoning in the food industry and has largely replaced the whole herb. Dill seed oil, usually in the form of dill water (distilling one part of fruits with 20 parts of water), is used medicinally to alleviate digestion problems, especially of children. Dill oil is said to be strongly antiseptic; it inhibits the activity of several fungi and in mice it shows anticarcinogenic properties. Dill fruits have been shown to be spasmolytic and bacteriostatic for dyspeptic disorders. Bruised and boiled in water and mixed with dill roots, dill fruits are applied externally against swellings of the joints. In general dill is said to have carminative, stomachic, stimulant, diuretic, resolvent, emmenagogue and galactogogue activity. Extracted dill parts are used as cattle fodder. Fresh and dried inflorescences and infructescences are increasingly being used in the ornamental flower industry.

Production and international trade Worldwide the cultivation of dill for its fruit is most important; the largest producers are India, Pakistan, China, western Russia and surrounding republics, Hungary and Egypt. Major users are the United States (about 600 t annually), Japan (50 t) and Germany (30 t). Worldwide annual production of dill seed oil is estimated at 50 t with a value of US$ 0.3 million. Dill herb production (mostly fresh, sometimes dried or freeze-dried) is predominantly small-scale in gardens all over the world, including South-East Asia, but no statistics are available. Larger scale production in Europe is known from Scandinavia and Germany (200 ha). Worldwide annual production of dill herb oil is estimated at 100–150 t with a value of about US$ 1 million. The largest producers are the United States (1000 ha), China and Australia.

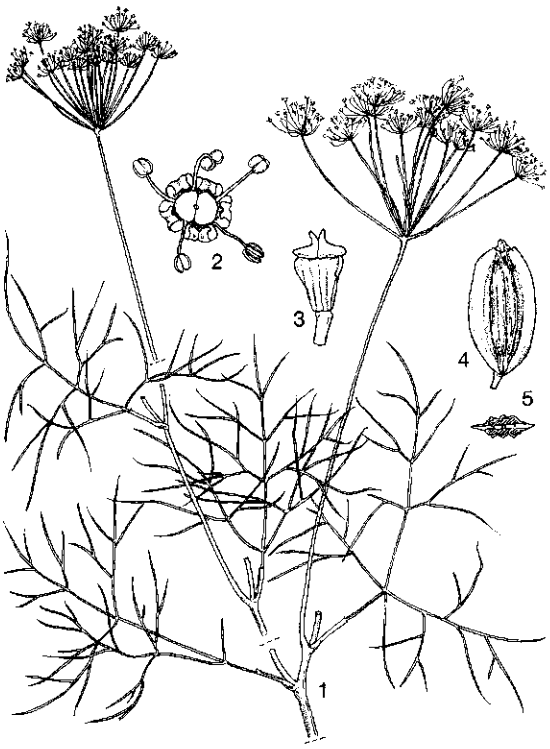
Properties Per 100 g edible portion dry dill herb contains approximately: water 7 g, protein 20 g, fat 4 g, carbohydrates 44 g, fibre 12 g, ash 12 g, ascorbic acid 60 mg. The energy value is approximately 1060 kJ/100 g. The essential-oil content is 0.1–1.5%. The approximate composition of dry dill fruits per 100 g edible portion is: water 8 g, protein 16 g, fat 14 g, carbohydrates 34 g, fibre 21 g, ash 7 g. The energy value is 1275 kJ/100 g. The essential-oil content is 2–6%.

Dill essential oil is colourless or pale yellow when freshly distilled. The chief components of dill herb oil are phellandrene (35%) and 3,9-epoxy-p-menth-1-ene (25%), of dill fruit oil limonene (up to 70%) and carvone (up to 60%) (limonene and carvone are closely related; together they represent about 95% of the oil). Carvone can be applied as germination suppressor, e.g. in potatoes. The essential-oil composition of dill varies strongly with geographical origin, cultivar and maturity of the extracted part, e.g. carvone content in fruit oil ranges from 50–60% in the United States and

35–60% in Europe. Wide differences in data on the composition of the essential oil can also partly be explained by different extraction and distillation methods. After oil extraction, the fruits contain approximately 15% protein and 16% fat, and are used as cattle fodder. Monographs on the physiological properties of the dill oils have been published by the Research Institute for Fragrance Materials (RIFM).
The 1000-seed weight is 4–5 g.

Adulterations and substitutes Dill herb oil is frequently adulterated with d-limonene, which is obtained in the preparation of sweet-orange oil concentrate, and with synthetic carvone.

Description Erect, annual, blue-green, glabrous herb, up to 1.5 m tall, taproot up to 12 mm in diameter, all parts strongly smelling (herbaceous) especially after crushing. Stem subterete, up to 12 mm in diameter, very branched, sulcate, internodes often hollow. Leaves alternate, decompound, sheathed; sheath forming an open cone, embracing the stem at base, 1–3(–5) cm long, sulcate; petiole subterete, equally long or up to 13 cm



Anethum graveolens L. – 1, flowering branch; 2, flower at male flowering stage; 3, flower at female flowering stage; 4, fruit; 5, cross-section of fruit.

longer than the sheath, lower leaves usually rather long petiolate, higher ones almost without petiole; blade triangular to ovate in outline, up to 30 cm × 50 cm, usually much smaller, pinnately divided into 2–6 pairs or whorls of primary pinnae and one top-pinna; each pinna again pinnately divided 2–4 times into linear or filiform, acute lobes of 1–60 mm × 0.1–1 mm. Inflorescence a compound umbel, 4–16 cm in diameter; peduncle up to 30 cm long; bracts and bracteoles usually absent; primary rays 5–35 per umbel, 1–10 cm long, unequal in length, longest ones at the outside of the umbel; secondary rays 3–35 per umbellet, 1–15 mm long; flowers bisexual, actinomorphic, some central ones often remaining rudimentary, protandrous (usually the styles and stigmas becoming fully developed after shedding of the corolla and stamens); calyx vestigial, sometimes 5 small teeth present on top of ovary; petals 5, distinct, subovate in outline, up to 1.5 mm × 1 mm, top strongly inflexed and notched, yellow; stamens 5, filaments about 1.5 mm long, yellow; pistil with inferior, bilocular ovary and a fleshy, conical stylopodium bearing 2 spreading styles about 0.5 mm long. Fruit a lens-shaped schizocarp, 2.5–6 mm × 2–4 mm, light or dark brown with a whitish to pale brown margin, splitting at maturity into 2 one-seeded mericarps which are attached at their top to an erect thin carpophore; mericarp flat, usually with 3 longitudinal prominent ridges and 2 flat, wing-like commissural ridges; on the commissural side, usually 2 dark brown longitudinal vittae, and on the dorsal side, between each 2 ridges, one vitta; the fruits are crowned by the persistent stylopodium and styles. Seed with testa adnate to the mericarp. Seedling with epigeal germination; hypocotyl 5–25 mm long; cotyledons opposite, linear, 15–50 mm × 1–2 mm, entire.

Growth and development Seeds take 2–4 weeks to germinate, flowering starts about 2–3 months after sowing, and ripe seed is harvested 5–6 months after sowing, but wide fluctuations are possible depending on climatic circumstances, cultivar, available nutrients and water. Flowering and fruiting are extended over a long period per plant. Because dill flowers are strongly protandrous cross pollination and fertilization seem normal; the flowers are well visited by bees and flies.
Dill grown under full sun produces significantly more leaves, a larger leaf area and a higher herb yield than plants that receive only 30–70% of natural light. Flower-bud development is also faster and the oil concentration almost 6 times higher than in plants grown under reduced light levels.

The essential-oil content in the fresh herb increases gradually with advancing growth and development, peaking at the young-fruit stage, and then declining until seed maturity.

Other botanical information Dill is a very variable plant species and several botanical subclassifications have been made on the basis of different sizes and forms of the plants, leaves and fruits. The major differences, however, are found in cultivated plants, so a subclassification into cultivar groups would be more appropriate. Unfortunately, no such classification exists. Dill grown in India belongs to a different cultivar group than dill grown in Europe or America (it has often been classified as a separate species, *Anethum sowa*). Its inflorescence has fewer primary rays, its fruits are less flat but longer with more prominent ridges, and the essential oil from the fruits is different (less carvone but containing dillapiole which is absent in European dill). The Indian type of dill predominates in South-East Asia.

Several chemotypes of dill have been distinguished on the basis of the essential oil: chemotype 1 contains limonene, carvone, myristicin and dillapiole; in chemotype 2 myristicin is absent, whereas in chemotype 3 limonene and carvone are the only major components.

Dill much resembles fennel (*Foeniculum vulgare* Miller); it can be distinguished by its smell (dill smells bitter, slightly pungent, fennel smells like liquorice), by its fruits (dill fruits are lens- shaped and narrowly winged, fennel fruits are not as flat and are not winged) and by the average length of the secondary rays in the umbel (longer in dill).

Ecology Dill is primarily a summer crop of temperate climates. It is generally considered a long-day plant in terms of flower initiation, with a critical period of 11–14 hours. Some reports, however, indicate that dill is probably day-neutral, long-day conditions merely enhancing anthesis. In the tropics it can successfully be grown up to altitudes of 2000 m. The annual rainfall or water requirement (irrigation) ranges from 500–1700 mm. It does not tolerate wet conditions or frost and thrives in full light at monthly average temperatures of 16–18°C. Minimum temperature for growth is about 7°C. It prefers a sandy loam soil with pH 5.6–6.5.

Propagation and planting Dill is easily raised from seed. Seeds remain viable for 2–3 years without special storage measures and the germination rate is about 75%. In temperate climates seeds are sown in early spring, or, in areas with very hot summers, towards the end of the summer. Seeds are sown directly in the field (which should have been thoroughly cultivated and be weed-free) at a depth of 3–6 mm. In India, the soil is often enriched with farmyard manure before sowing. The sowing rate is 5–7 kg seed per ha. Germination occurs in about 1–3 weeks (faster at higher temperature). When grown for seed, optimum row and plant spacings are 45 cm and 10 cm respectively; dill grown for the herb is sown at higher densities (e.g. 15 cm and 10 cm respectively). Mostly, however, dill grown as a garden crop is intercropped, e.g. between onions, parsley or carrots.

Husbandry Frequent weeding and regular water supply are essential for good growth. To maximize essential-oil yield, an application of 80 kg N, 30 kg P and 30 kg K per ha is recommended. When grown for seed, windbreaks should be established to prevent lodging. A crop rotation of 4 years is recommended.

Diseases and pests Between the early seedling stage and flowering, dill is often attacked by the fungus *Erysiphe anethi*, which can be controlled by spraying with a copper-containing fungicide at intervals of 7–10 days. Root rot, caused by a *Fusarium* sp. can lead to serious damage. Prolonged wet weather in temperate climates encourages the fungi *Fusarium culmorum*, *Pythium* sp. and *Rhizoctonia* sp., which can destroy the crop; control is not possible; the only possible measure is to grow a crop that can easily be wind-dried (not too dense, sparingly supplied with N). Wet weather at flowering stage can cause fungal attack of *Botrytis* sp. and *Alternaria* sp. which prevent fruit set. Virus infections and insect pests (lice and caterpillars) are possible but are seldom very serious. Larvae of the chalcid fly *Systole albipensis* may infest fruits.

Harvesting The moment of harvesting depends on the required product. For dill herb (foliage), harvesting usually takes place before flowering, about 40–50 days after sowing. For the production of herb oil, dill is cut immediately after flowering, when the seed has just started to ripen but is not yet fully developed. As this period is very short, planting should be staggered to enable the harvesting of larger areas at the proper stage of maturity.

Fruits are harvested at a stage when they are fully developed but still green, i.e. 7–9 days after petal drop (oil content 2.6–3.7%). When the colour changes from green to dark grey, the oil content decreases to about 1.7%, i.e. 22–24 days after petal drop. At this stage profuse shedding takes place resulting in substantial yield losses.

Yield The yield of fresh dill herb varies from 3–20 t/ha, while dill seed yields range from 0.7–1.2 t/ha. Essential-oil yields of dill herb and dill seed are estimated at 56 kg/ha and 30 kg/ha, respectively. The yield of dry dill herb is about 10% of the fresh product.

Handling after harvest Dill herb is marketed fresh for culinary use. To maintain its keeping quality, the fresh herb can be put in sealed, polythene bags in cartons and kept at low temperatures (6–12°C). Fresh dill may be chopped and frozen with water in ice cube trays. When it is to be marketed in dried form, the drying temperature should be 80°C initially, lowered to 40°C halfway through the drying process. The dried product should have a minimum essential-oil content of 0.15% and maximum contents of water and ash should be 8% and 6%, respectively.
For herb-oil production, it is advisable to harvest only as much fresh plant material as can be distilled during one day. Prolonged drying in the field results in considerable loss of oil by evaporation, especially of the more volatile terpenes. Moreover, fruits still attached to the harvested plant material continue to ripen, and the oil thus obtained approaches the composition of dill seed oil, which is undesirable in dill herb oil. Therefore, plant material should be distilled as fresh as possible or dried for a very short period.
For seed production harvested plants are dried under shade and fruits are threshed out in regular threshers. Threshed fruits should be spread out in a thin layer and turned over frequently until thoroughly dry. When dill seed oil is desired, the fruits are crushed between heavy cylinders, mixed with water and then distilled.

Genetic resources and breeding Institutional germplasm collections are rare (82 accessions at the North-Central Regional P.I. Station of the United States Department of Agriculture) and breeding programmes of dill are not known to exist. Even officially released cultivars do not exist. Seed firms in Europe market their own, unofficial selections. Some examples of selections for herb production are Dukat, Superdukat, Mammut and Pikant (Scandinavia), Mammoth (United States), Sari, Herkules, Goldkrone, Prager and Tetra-dill (Germany), Budakalaszi (Hungary). No special selections are known for dill seed production, although some of the herb selections are recommended for that purpose.

Prospects Worldwide, dill production and utilization is increasing very slowly. It is inadvisable to recommend expansion of production, because a small market can easily become glutted, resulting in very low prices. Dill will primarily remain, also in South-East Asia, an easily grown home-garden herb, which anybody harvests from the garden according to one's needs.

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Nguyen Thi Tâm, C.C. de Guzman & P.C.M. Jansen

Anthriscus cerefolium (L.) G.F. Hoffmann

Gen. pl. umbell.: 41 (1814).
UMBELLIFERAE
$2n = 18$

Synonyms *Scandix cerefolium* L. (1753), *Anthriscus longirostris* Bertol. (1837), *Chaerefolium* *cerefolium* (L.) Schinz & Thell. (1909).

Vernacular names Chervil, garden chervil (En). Cerfeuil (Fr).

Origin and geographic distribution Chervil is indigenous to south-eastern Europe, western Asia and central and southern Russia. It has been cultivated in Europe since the 16th Century; at present it is cultivated and subspontaneous in all parts of the world. In South-East Asia it is occasionally cultivated in Java (Indonesia) and the Philippines.

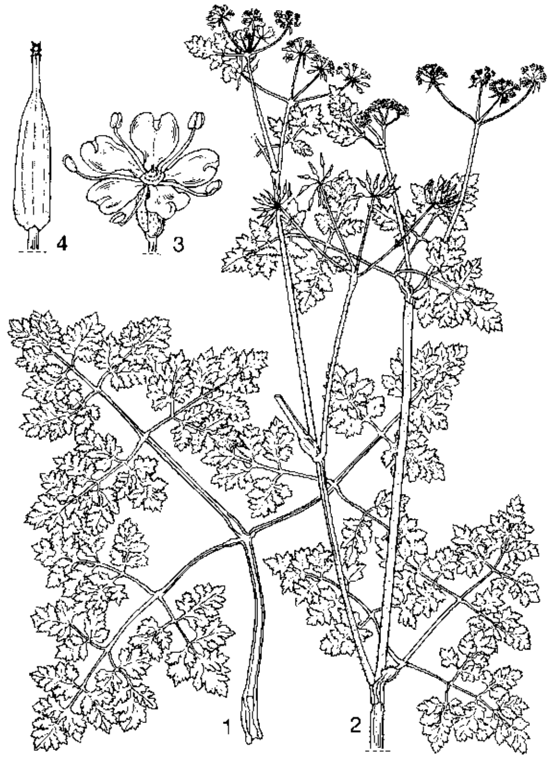
Uses Chervil is widely used as a culinary herb; it is one of the traditional 'fines herbes' in French cuisine, valued for its light parsley-like flavour with a hint of myrrh. Dried chervil may be used to scent potpourris. Fresh leaves and stems are used to flavour soups, casseroles, salads, sauces, eggs (particularly omelettes), carrots, spinach, sorrel, fish, and cheese. Chervil also is used in herbal butters and in cosmetics. Medicinally, an infusion of chervil is used to stimulate the digestion and alleviate circulation disorders.
The regulatory status of chervil in the United States is 'generally recognized as safe' (GRAS 2279). The maximum permitted level is 0.1% of the herb in meat and meat products.

Production and international trade Chervil is of minor importance in trade; no information on production and trade is available.

Properties Chervil was once called 'myrrhis', because of its volatile oil, which has an aroma similar to the resinous substance of myrrh. The essential oil is characterized by 3 constituents: undecane, methyl chavicol (estragole) and methyl eugenol (1-allyl-2,4-dimethoxybenzene). These compounds constitute about 95% of the oil. The composition of the essential oil varies at different stages of growth. Undecane increases to a maximum of about 20% after flowering, methyl chavicol increases to a maximum of about 70% at full flower and methyl eugenol reaches a maximum of about 70% before flowering. Methyl chavicol and methyl eugenol are carcinogenic in rats.

Adulteration and substitutes The closest substitute as an edible herb is parsley. The oil may be adulterated with methyl chavicol.

Description Annual, sweetly aromatic herb, up to 70 cm tall, somewhat hirsute. Roots thin, whitish. Stem branched, terete, finely grooved. Leaves alternate, up to 3-pinnate with pinnatifid lobes; petiole of the lower leaves up to 7 cm long, with sheathed base, upper leaves with shorter petiole or sessile on the sheath; blade of lower leaves triangular in outline, 4–11 cm × 3–15 cm,



Anthriscus cerefolium (L.) G.F. Hoffmann – 1, leaf; 2, flowering and fruiting branch; 3, flower; 4, mericarp.

2–3-pinnate. Inflorescence a di-monochasium of sessile compound umbels; involucre absent; involucel with 3–4 narrow, lanceolate bracteoles, about 2 mm × 0.75 mm; umbels 2–5 cm in diameter; rays of the main umbel 2–6, 0.5–2.5 cm long; pedicels 4–9, 2–5 mm long; flowers bisexual, 5-merous, white, small; calyx absent or greatly reduced; petals 5, obcordate, 1–1.5 mm long with short inflexed tips; stamens 5, free; pistil with inferior, bilocular, 2-carpelled ovary and 2 styles, swollen and spreading at the base. Fruit a schizocarp with 2 glabrous or hairy mericarps; mericarp almost linear, 5–10 mm × 1 mm, slightly 5-ribbed, black and finely granular when ripe, bearing a beak up to 4 mm long.

Growth and development Chervil has a short life span. The period from sowing to harvest can be as short as 6 weeks in a greenhouse, and less than 6 months in the field.

Other botanical information In *A. cerefolium* 2 groups of plants can be distinguished:
- cv. group Chervil (synonym: var. *cerefolium*): fruit glabrous. This is the cultivated form in

which several cultivars can be distinguished (e.g. plants with curled or flat leaves);
- var. *longirostris* (Bertol.) Cannon: fruit with numerous hooked hairs. This is the wild form from which the cultivated form has been derived.

Ecology Chervil is heat-sensitive; it grows poorly in hot, dry conditions and needs protection against direct sunlight. In the tropics cultivation is normally restricted to the cooler, high-altitude regions. Chervil prefers moist soils rich in organic matter with a pH of 6.5. Chervil is susceptible to frost.

Propagation and planting Propagation is by seed. Seeds remain viable for 2–3 years. Seeds should be sown in shallow drills 30 cm apart. When seedlings are 7.5 cm tall, they should be thinned to 7–10 cm apart; they are too fragile to be transplanted.

Husbandry In small-scale cultivation, weed control is by mechanical means, but herbicides can be used. High levels of N (e.g. 400 kg/ha) give a marked increase in nitrate levels in chervil.

Diseases and pests A number of virus diseases (e.g. parsnip yellow fleck, anthriscus yellow) occur, probably transmitted by aphids. The chervil webworm (*Depressaria chaerophylli*) and larvae of *Lixus paraplecticus* may damage the umbels; the leaves are sometimes damaged by aphids.

Harvesting Leaves and stems are picked as needed, but before the flower buds open. For denser foliage, flower stems should be cut before they bloom.

Yield After 42 days in hydroponics in a greenhouse a yield of 2.3 kg/m^2 has been reported. No field information is available.

Handling after harvest The foliage is dried on wire racks in a cool, ventilated, shady place. Dried, brittle leaves (either whole or crumbled) must be stored in an airtight container. Fresh chervil may be chopped and frozen with water in ice cube trays. Post-harvest handling of fresh chervil involves delaying senescence by vacuum pre-cooling, refrigeration during transport, and using unperforated polythene liners to increase the CO_2 levels in the atmosphere and diminish the effect of ethylene.

Genetic resources and breeding There are no germplasm collections and breeding programmes for chervil.

Prospects A recent development in north-eastern Europe has been the production of chervil in a hydroponic system year-round, with supplementary lighting in winter, and cooling in summer. This has the advantage of providing a high-quality leafy product with a lower nitrate level than can be achieved in soil.
Chervil is produced small-scale in the Philippines by specialized farms meeting the demand from international hotels and restaurants.
The production of chervil solely for its essential oil is unlikely to be economic.

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M.A. Nichols

Armoracia rusticana P.G. Gaertner, B. Meyer & J. Scherbius

Oekon.-Techn. Fl. Wetterau 2: 426 (1800).
Cruciferae
$2n = 32$

Synonyms *Cochlearia armoracia* L. (1753), *Armoracia lapathifolia* Gilibert (1782), *Nasturtium armoracia* (L.) Fries (1835).

Vernacular names Horseradish (En). Cran, mérédic, raifort sauvage (Fr). Philippines: kamunggay (Cebuano).

Origin and geographic distribution Horseradish is believed to originate from south-eastern Europe and western Asia where it has been cultivated since antiquity. It can now be found naturalized as an escape from cultivation in many temperate regions of the world. Its cultivation is most important in Europe and North America. In South-East Asia it is occasionally cultivated in mountainous areas, e.g. in Indonesia, Malaysia and the Philippines.

Uses Horseradish roots have a sharp, mustard-like taste and are used as a condiment with fish, beef, sausages, poached chicken, egg salad, potato salad, and beets. The roots can also be dried, ground and mixed with vinegar, milk and seasonings to make horseradish sauce, used commonly as a condiment with beef. Young leaves and seedlings can be eaten as a salad. Horseradish root extract has been approved for food use by the Food and Drug Administration (FDA) of the United States.

Horseradish is said to have some medicinal qualities. Like mustard, it acts as a stimulant to the stomach and it shows antibiotic activity against bacteria.

Peroxidase obtained from horseradish roots has become an important industrial product used in analytical biochemistry, medicine and immunology for antibody and antigen labelling.

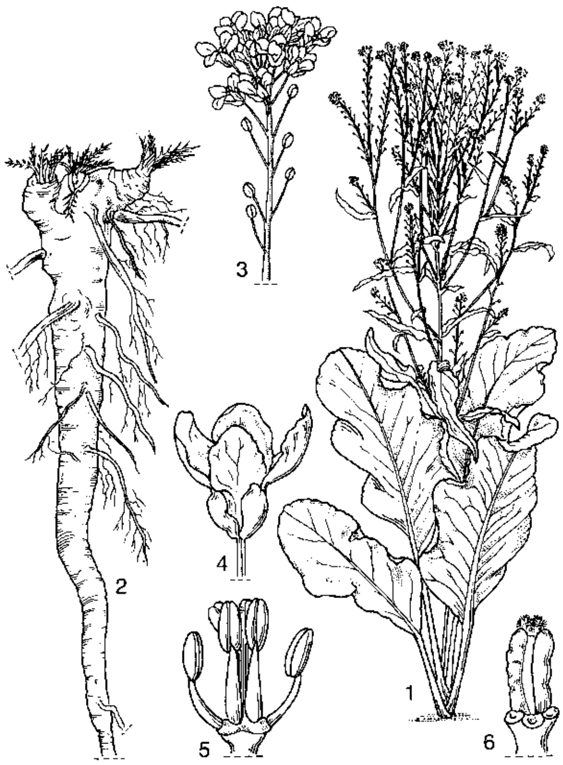
Production and international trade Most horseradish is produced by smallholders, and no production statistics are available. In the United States horseradish is grown commercially on about 800 ha and annual production is about 6000 t. The price for the raw product fluctuates from year to year. When there is a short supply of the domestic product, prices rise and some horseradish is imported.

Properties Per 100 g edible portion the roots contain approximately: water 65 g, protein 3.9 g, fat 0.2 g, carbohydrates 27 g, fibre 2.2 g, Ca 117 mg, Fe 2.7 mg, thiamine 0.20 mg, ascorbic acid 100 mg, riboflavin 0.08 mg and niacin 0.5 mg. The energy value is about 525 kJ/100 g. At least 17 volatile compounds have been identified in horseradish root, including several isothiocyanate and thiocyanate derivatives.

The chief pungent principle of horseradish is allyl isothiocyanate. In a raw root the mustard-like oil is bound with glucose and sulphate as a water-soluble glucoside: sinigrin. When raw root is macerated, the enzyme myrosinase and sinigrin unite to form allyl isothiocyanate.

Adulterations and substitutes In Japan 'wasabi' (*Eutrema wasabi* (Sieb.) Maxim.) is used in a similar way as horseradish. The root bark of the horseradish tree (*Moringa oleifera* Lamk) has the same pungent taste and is used as condiment and garnish.

Description Erect, perennial, glabrous herb, up to 1.5 m tall, often grown as an annual. Primary root (taproot) thick, often several-headed, cylindrical to conical, up to 50 cm long, woody in wild, fleshy in cultivated plants, yellowish-white, developing long secondary roots and subterranean runners. Stem single or multiple, straight, branched in upper part, ribbed, hollow. Leaves smooth or



Armoracia rusticana P.G. Gaertner, B. Meyer & J. Scherbius – 1, flowering plant; 2, primary root; 3, part of inflorescence; 4, flower; 5, stamens; 6, immature fruit.

crinkled; lower leaves initially in rosette, long-petioled, ovate-oblong from an acute or cordate base, 30–100 cm long, irregularly crenate-lanceolate, coarsely serrate; cauline leaves spirally arranged, lower ones petioled, often pinnatilobed-pinnatipartite, higher ones gradually becoming subsessile, lanceolate and crenate-serrate or subentire. Inflorescence a raceme, 20–40 cm long, many-flowered, racemes combined into a terminal panicle; pedicel erecto-patent, in flower 5–10 mm long, in fruit up to 2 cm long; sepals 4, broadly ovate, 3 mm long; petals 4, broadly obovate, 5–7 mm long, white; stamens 6, tetradynamous; disk glands united into a ring; pistil with glabrous ovary, short style and slightly lobed stigma. Fruit a silique, globose to broadly obovoid, 4–6 mm long, abruptly contracted into the style, 2-valved. Seed 1–6 per fruit.

Growth and development Due to the thick and deep taproot, horseradish can survive for many years, once it is established. Old roots, however, tend to become woody. The roots required for

consumption and commerce should be fleshy, which is why the crop is cultivated as an annual. Starting from a part of the primary root, or from a one-year-old secondary root, a harvestable root is produced in one growing season, e.g. in the United States from April to November. Crowns of primary roots, stored during the winter and planted in April, flowered after 3 weeks in the United States and produced viable seed 1 month later. Pollination is mainly by insects. About 95% of the genotypes set viable seed – only cultivars with crinkled leaf-types often do not produce viable seed.
The thick and strong roots make horseradish difficult to eradicate from old fields. Any small pieces of root left in the soil will start growing the next season.
In the United States and in Europe the factors influencing yield (apart from fertilizers, diseases and pests) are size of the original cuttings and growing period. The larger the original cuttings, the higher the yield, although extremely large cuttings tend to produce hollow roots. Early planting and late harvesting also increase yield. In the United States enlargement of the primary root occurs mainly during the cooler months of September and October.

Other botanical information Outside its natural area, horseradish easily runs wild and survives along roads, fields, in hedges and places with a relatively rich soil. The species is quite variable in leaf size and form, in pungency of the root and in disease resistance. Possibly, horseradish originated from an interspecific hybrid, which may explain the occasional sterile plant. Several forms have been given special botanical names, but it seems more reasonable to name only different cultivars. Many cultivars exist, such as 'Big Top Western' (leaves smooth), 'Common' (leaves crinkled), 'Swiss' (leaves smooth) in the United States, and 'Spangsbjerg 12/68' and 'Frieslander' in Europe.

Ecology Horseradish is suited for temperate climates and grows best in full sun to partial shade in a moist, rich, heavy soil with pH 6.8. A well-drained moisture-retentive loam is preferred. Sandy soils are not suitable, and neither are shallow clays with a hard pan. Horseradish can only be cultivated in the tropics at altitudes above 1000 m. It easily survives severe winter conditions.

Propagation and planting Although horseradish can be propagated by seed, the normal propagation method is by root cuttings. Seed is generally only used in plant breeding as a means to obtain new cultivars. One-year-old secondary roots are selected from 2-year-old primary roots for planting the following year. Cuttings (up to 12 mm in diameter and 35 cm long) are placed obliquely in shallow furrows and covered with up to 10 cm of soil, after which the soil is firmed by rolling. Spacing is 45–60 cm within the row and 90–100 cm between the rows. An implement similar to a potato planter can mechanize the operation. Besides a driver it has 2 workers, who sit behind a box containing bundles of roots and plant them in the furrows where they are covered with soil by discs.
Horseradish can also be propagated by in vitro techniques using leaf pieces.

In vitro production of active compounds Peroxidase production by in vitro culture of horseradish is a rapidly developing area. The peroxidase content obtained is equal to or higher than that in field-grown roots.

Husbandry After the cutting has rooted, its crown end is lifted slightly to break off the new secondary roots on the upper portion. This is done because the secondary roots of the basal end nourish the young plant and if secondary crown roots are permitted to develop they tend to prevent the main root from enlarging, resulting in a lower-quality root. High levels of fertilizer are not required, although trials in Europe show that the crop may accumulate up to 200 t/ha of dry matter per season and for this yield 500 kg N, 630 kg P_2O_5, 90 kg K_2O, 260 kg Ca and 100 kg Mg are needed. This can be provided by 60 t/ha of farmyard manure, supplemented by some 200 kg/ha of N as a split dressing.
Weed control can be mechanical, or by post-planting use of chemicals such as xyfluorfen and oryzalin. Fusilade is a useful post-emergence grass killer. Horseradish itself is particularly difficult to eradicate. The most effective treatment is glyphosate at 4.5 kg/ha applied some 6–8 weeks after discing.

Diseases and pests In the United States 3 diseases are of major economic importance: white rust, turnip mosaic virus and brittle root.
White rust, caused by the fungus *Albugo candida*, is the most damaging foliage disease, attacking the leaves and preventing normal root development. The disease spreads from the crown of the primary root into secondary roots. Control is possible by carefully selecting planting material, spraying with fungicides in the growing season and eradicating infected plants.
Turnip mosaic virus causes mosaic mottling and chlorotic rings on the leaf blade. Most plants are

infected to a certain degree with this virus, for which many hosts are known. It is transmitted by aphids and mechanical means, not by the seed. Control is possible by careful selection of the planting material.
The causal agent of brittle root is not known. The leaves of infected plants become chlorotic and the aerial part of the plant collapses; the roots become turgid and snap when bent. This is the most serious disease and is possibly transmitted by insects. Many insects attack horseradish but only a few cause economic damage: onion thrips (*Thrips tabaci*), beet leafhopper (*Circulifer tenellus*), green peach aphid (*Myzus persicae*), mealy plum aphid (*Hyaleptorus arundinis*), diamondback moth (*Plutella maculipennis*), horseradish flea beetle (*Phylletreta armoracies*) and southern cabbage worm (*Pieris protodice*). Spraying with insecticides usually limits the damage.

Harvesting In temperate climates the roots are harvested in late autumn or early spring, by hand or by a harvesting machine operating to a depth of about 50 cm. Care should be taken not to damage the roots. Secondary roots are broken off, and cuttings to be kept for planting the next crop are buried in outdoor pits or kept in cool cellars. In some areas horseradish is grown as a perennial crop with a harvest every 2 years. Horseradish gives best results when grown as an annual crop.

Yield In the United States average yields of primary roots are 7 t/ha ('Common'), 8 t/ha ('Swiss') and 12 t/ha ('Big Top Western'). In Europe average yields are 7.5 t/ha for primary roots and 4.9 t/ha for lateral roots. There are considerable differences in yield between cultivars. In a collection of 10 European cultivars the content of isothiocyanates varied from 12.2 mg per g freeze-dried root in the Danish 'Spangsbjerg 12/68' to 20.4 mg/g in the German 'Frieslander'. Tissue-cultured regenerated leaf pieces show considerable somaclonal variation and appear to be a good source of breeding material; peroxidase content varied in some cell lines.

Handling after harvest Roots are cleaned of excess dirt and either graded and sold immediately or stored under cool moist conditions without washing or chemical treatment (e.g. in polythene bags at 2°C). Storage of up to 6 months at 0–1°C at 93% or 97% relative humidity (RH) had no deleterious effect on the composition of horseradish oil, the vitamin C content, or on the crude fibre, but weight losses after 4 months in storage were 1.6–3.3 times greater at 93% than at 97% RH. The amount of blackening of the root was found to be greater when roots were stored at high temperature. The levels of peroxidase in roots stored for one month at 20°C, 4°C or −18°C showed that at 20°C the peroxidase level did not change compared with the initial value, whereas cold storage increased peroxidase levels. Processors manufacture fresh horseradish sauce continually from supplies of root held in cold storage. High-quality horseradish sauce is white and pungent but in storage the sauce gradually looses its pungency, becomes discoloured and develops an earthy odour and taste. Shelf-life of the sauce can be increased by adding fresh whipped dairy cream, by storing the sauce at −18°C and by adding an acid solution (e.g. vinegar). Researchers continue to look for a more keepable end-product.

Genetic resources and breeding The United States Department of Agriculture maintains a germplasm collection of about 200 accessions of horseradish. The variability is great and offers ample scope for breeding new cultivars. Wild types, for example, contain markedly higher levels of peroxidase compared with domesticated cultivars. A typical cycle for breeding, testing and introduction of a new cultivar takes 8 years. Breeding goals include higher yield, disease resistance and high content of desired compounds, e.g. peroxidase.

Prospects As a condiment, horseradish will remain of limited, regional importance. The consumer market will only grow if a product that does not deteriorate rapidly can be obtained. In South-East Asia horseradish will remain of minor importance. There are prospects of developing intergeneric hybrids of wasabi and horseradish. The industrial use of horseradish (peroxidase) has potential, as does the use of horseradish root material to decontaminate water polluted with phenols, and to control pathogens (bacteria, etc.).

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M.A. Nichols & P.C.M. Jansen

Artemisia dracunculus L.

Sp. pl.: 849 (1753).

COMPOSITAE

$2n = 18, 36, 54, 72, 90$

Synonyms *Artemisia inodora* Willd. (1809), *A. redowskyi* Ledeb. (1815), *Oligosporus condimentarius* Cass. (1826).

Vernacular names Tarragon, estragon, dragon mugwort (En, Am). Estragon, dragon (Fr).

Origin and geographic distribution The origin of tarragon is not known with certainty; it may be Siberia. It has a very wide distribution, from central Europe and western and northern Asia (Asia Minor, Mongolia, northern China, Siberia) to western North America (up to Colorado and Texas). It is also widely cultivated, e.g. in Europe (France, Germany, Italy, the Netherlands), United States, Brazil, Egypt and India. In South-East Asia it is locally cultivated in the mountainous regions of Java (Indonesia) and it has been introduced into the Philippines.

Uses The fresh or dried leaves of tarragon have a sweet anise-like scent and a peculiar bittersweet flavour and are used for seasoning foods like salads, soups, stews and sauces. They are particularly suited to flavour chicken, egg and lobster preparations. The popular tarragon vinegar is prepared by adding the herb to wine vinegar. Due to its low sodium content tarragon can be safely used as a substitute for sodium chloride in sodium-restricted diets. Medicinally, tarragon is believed to have aperient, stomachic, stimulant and febrifuge properties. On steam distillation, the leaves yield an essential oil (known as tarragon or estragon oil) which is used in perfumery, in canning pickles and in flavouring vinegar and liqueurs. Tarragon oil also possesses bactericidal and nematicidal activity. In the United States the regulatory status 'generally recognized as safe' has been accorded to tarragon (GRAS 3043) and tarragon oil (GRAS 2412). The maximum permitted level of tarragon leaves in food products is 0.3%, and the highest level of the oil is 0.04% in baked goods.

Production and international trade The major markets and their annual tarragon consumption are: France (80–100 t), the United States (40–50 t), Germany (10–80 t), the Netherlands (25 t), Belgium (10–15 t), the United Kingdom (10 t), Switzerland (2 t), Japan (2 t). Annual world production of tarragon oil is about 10 t, with a value of US$ 0.8 million.

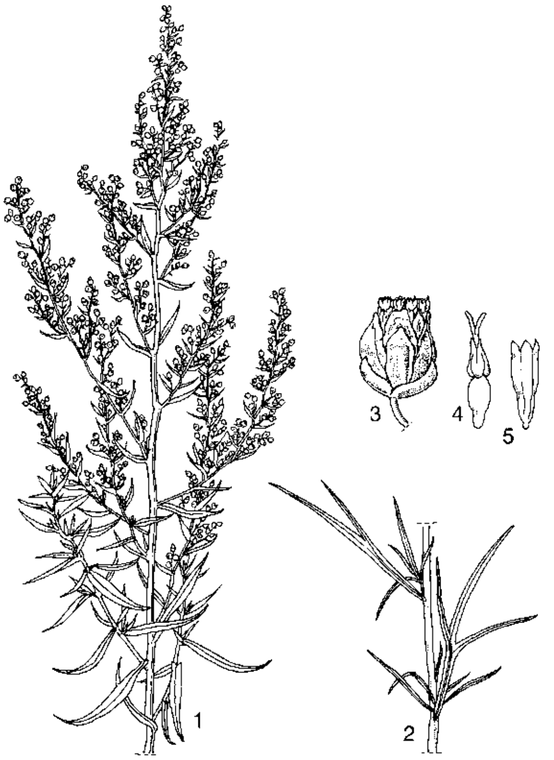
Properties Per 100 g edible portion, dried ground tarragon contains approximately: water 5–8 g, protein 23–25 g, fat 7–7.5 g, carbohydrates 43–45 g, fibre 7 g, ash 12 g (Ca 1.1 g, Fe 32 mg, K 3.0 g, Mg 0.3 g, Na 62 mg, P 0.3 g, Zn 4 mg), niacin 9 mg, riboflavin 1 mg, thiamine 0.3 mg, vitamin A 4200 IU, vitamin C 12 mg. The energy value is about 1385 kJ/100 g. The essential-oil content of dried tarragon ranges from 0.2%–1.0%.

The two cultivated types, i.e. French or German tarragon and Russian tarragon, differ in essential-oil components. French tarragon oil consists mainly of methyl chavicol (estragole), trans-ocimene + γ-terpinene, cis-ocimene, and limonene. On the other hand, the major components of Russian tarragon oil are elemicin, sabinene, trans-ocimene + γ-terpinene, methyl eugenol, myrcene, cis-ocimene, citronellyl acetate, and terpine-4-ol. There are also differences in the flavonol profile of the air-dried stems and leaves of the two types. While Russian tarragon contains patuletin glycosides, quercetin and quercetin glycosides, French tarragon possesses only quercetin glycosides.

A monograph on the physiological properties of tarragon oil has been published by the Research Institute for Fragrance Materials (RIFM).

Adulterations and substitutes *Tagetes lucida* Cav. (*Compositae*), the sweet-scented marigold from Mexico and Central America, also known as Mexican tarragon, resembles tarragon with respect to flowers and fragrance and is often used as a substitute for it. It grows well in the Philippines.

Description Perennial herb, 0.5–1.5 m tall, glabrous, strongly aromatic or almost odourless. Rhizome woody, up to 1.5 cm thick, sometimes with well developed underground shoots. Stem erect, solitary or several, branched, furrowed, lower branches not flowering. Leaves alternate, subsessile, entire, simple, olive-green, the lowest ones deciduous and sometimes ending in 2–5 narrow lobes; blade linear-lanceolate to almost linear, 2–10 cm × 1–14 mm, margin sometimes weakly serrate. Inflorescence a drooping subglobose head, 2–4 mm in diameter, aggregated at apices of stem and branches into racemes which together give a paniculate appearance; peduncle 0–5 mm long; involucre 2–4 mm long, outer bracts oblong to lanceolate, inner ones rounded-ovate, margin membra-



Artemisia dracunculus L. – 1, habit flowering stem; 2, lobed basal leaves; 3, flower head; 4, female floret; 5, male floret.

nous; outer florets usually 7(–15), pistillate and fertile, with tubular yellowish, whitish or reddish corolla 1 mm long and 2 spreading, often twisted style branches; disk florets 11–14(–20), bisexual but functionally male, corolla conical, 5-toothed, up to 2 mm long, anthers linear, pistil rudimentary with more or less connate style branches. Fruit an achene, flat-ovoid, 0.6–1 mm long, finely grooved, glabrous, brown.

Growth and development When started from cuttings, first leaves can be harvested 2–3 months after the plant has established. Although tarragon is a perennial plant and could be maintained for many years, the essential-oil content gradually diminishes in older plants. Therefore, commercial plantings are renewed every 3–4 years.

Shoot growth in tarragon is affected by daylength and cold pretreatment. Plants exposed to 16 hours of light grow 2–3 times faster than those given only 8 hours of light. Cumulative herbage production under long days is further enhanced if plants are given a cold pretreatment of 4°C for 6 weeks.

Other botanical information Tarragon is a variable species with wild and cultivated forms and its taxonomy is not yet well established. In the cultivated forms two large groups can be distinguished:
- cv. group French Tarragon (also called cv. group German Tarragon). This group comprises the most important spice cultivars and is mostly cultivated in Europe and the United States. Its cultivars are tetraploid ($2n = 36$), they seldom produce normal flowers and never viable seed. They are propagated by stem and rhizome cuttings. The leaves are glabrous, very fragrant and the major component of the essential oil is methyl chavicol. A well known cultivar is 'Epicure'.
- cv. group Russian Tarragon (synonyms: *A. dracunculoides* Pursh, *A. glauca* Pall. ex Willd.). This group comprises the much less fragrant cultivars, is more closely related to the wild forms and is mainly cultivated in northern Asia. Its cultivars are decaploid ($2n = 90$), they flower and produce viable seed normally and propagation is by seed. The leaves are mainly glabrous but bear some stellate hairs. The major components of the essential oil are elemicin and sabinene.

Several varieties have been distinguished in the wild forms, mainly on the basis of length and colour of stem, juvenile hairiness, size of flowerheads and structure of aggregate inflorescences, e.g. var. *humilis* Kryl. (20–30 cm tall, narrow paniculate inflorescence), var. *pilosa* Krasch. (densely hairy when young), var. *pratorum* Krasch. (stem up to 2 m tall, leaves partly 2-3-lobed, inflorescence long and loose), var. *redowskyi* Ledeb. (yellow-brown stem, inflorescence spreading paniculate), var. *turkestanica* Krasch. (leaves and heads large). In northern Asia, the wild plants often become troublesome weeds in pastures. Because of their strong rhizome they are resistant to trampling and difficult to eradicate while their forage value is minimal.

Ecology Tarragon is primarily a crop of temperate climates. It thrives in well-drained, light soil under full sun. It requires a soil pH of 6.3–7.8. It should be protected from excessive moisture, requiring an annual precipitation of only 300–1300 mm. It can survive light frost (wild forms even severe frost) and plant growth is stimulated by long days. In the Philippines tarragon is commercially grown in Silang, Cavite, at 600 m altitude and with average annual temperatures of 23–25°C.

In Asia and North America, wild plants occur in open, rather dry places, e.g. in meadows and steppe zones, from the plains to moderate elevations in the mountains.

Propagation and planting Propagation of tarragon is normally by stem or rhizome cuttings. Stem cuttings 15 cm long are taken from shoot tips and rooted in mist beds or in coarse river sand with regular watering. Presoaking the basal ends in 100 ppm indolebutyric acid (IBA) overnight or dipping them in 2000 ppm IBA for a few seconds enhances rooting. In rhizome cuttings, pieces of the main rhizome, 5 cm long, together with roots and a new shoot, are severed from the mature plant. Planting material is established in polybags in the nursery prior to field planting.

In vitro propagation has also been reported for tarragon using leaf and shoot tip explants. Good shoot proliferation has been obtained on media such as Linsmaier-Skoog, White, Murashige-Skoog with various addenda. Rooting succeeds well using Techniculture plugs saturated with 1 ml of a solution with 1 mg naphthaleneacetic acid (NAA) per l.

In commercial farms in the Philippines garden plots are prepared by ploughing 2–3 times and incorporating chicken manure and rice hulls before the final ploughing. Tarragon is planted at 20–25 cm distance in rows 25–40 cm apart.

In vitro production of active compounds The production of methyl chavicol and methyl eugenol, two important components of tarragon essential oil, has been demonstrated in callus cultures obtained from leaf explants. The amount detected in vitro was up to 2000-fold less than the level accumulated in the plant. The presence of exogenous NAA in the culture was inhibitory to this accumulation. The detection of the metabolites in disorganized cells revealed that differentiation of secretory structures was not an absolute requirement for the synthesis of these compounds. The low levels detected were attributed to possible volatilization, active metabolism and autotoxicity of the compounds.

Husbandry During the initial stage of growth, it is appropriate to mulch tarragon with straw. This prevents weed proliferation, conserves soil moisture and lowers the soil temperature, particularly during the dry season. Regular watering is necessary. A crop of tarragon lasts about 3 years.

Diseases and pests No serious diseases and pests have been reported for tarragon. Damage can be caused on the leaves by the rust *Puccinia dracunculina*, stalk and root rot is caused by *Sclerotinia minor* and the beetle *Cantharis lateralis* may feed on the leaves. Fungicides and insecticides easily control diseases and pests but are seldom used.

Harvesting Once the crop is well established, green leaves and tender tops may be harvested at intervals during the growing season. Per year 2–3 harvests may be obtained.

In commercial farms in the Philippines, the first harvesting is carried out 2 months from transplanting. Time of harvesting, however, is often dictated by the market demand, which is particularly high during the Christmas season.

Yield No reliable information is available on the yield of tarragon under South-East Asian conditions. Commercial plantations outside South-East Asia show an average fresh herb yield of 2.5–3.7 t/ha in the first year and 5–6 t/ha in the second year of planting. An annual essential-oil yield of 40 l/ha is possible.

Handling after harvest In the Philippines, freshly cut tarragon shoots are bundled and immediately packed in styrofoam boxes for delivery to market outlets. The dried product is obtained by air-drying the shoots under shade or by placing them in artificial dryers with temperatures not exceeding 43°C. Commercial quantities of dried herb are preferably stored in well-closed barrels.

When tarragon oil is desired the dried herb is steam-distilled for 1–1.5 hours. The oil is stored in well-filled bottles and protected from light.

Genetic resources and breeding In Europe small germplasm collections of tarragon are present in the Czech Republic, Germany, Lithuania, Portugal, Russia and Slovakia. There are no known breeding programmes.

Prospects The potential of the food service market and the prospects for culinary herbs in South-East Asia appear to be bright. The production of culinary herbs can be quite lucrative, if it is accompanied by an effective marketing system. Tarragon is one of the important culinary herbs being grown in South-East Asia for the food service market.

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

Boesenbergia rotunda (L.) Mansfeld

Vorl. Verzeichnis (die Kulturpflanze, Beiheft 2): 579 (1959).

ZINGIBERACEAE

$2n = 36$

Synonyms *Curcuma rotunda* L. (1753), *Kaempferia pandurata* Roxb. (1810), *Gastrochilus pandurata* (Roxb.) Ridley (1899), *Boesenbergia pandurata* (Roxb.) Schlechter (1913).

Vernacular names Chinese keys (En). Petits doigts (Fr). Indonesia: temu kunci (Indonesian), tumbu konci (Moluccas). Malaysia: temu kunci. Cambodia: khchiëy. Laos: kas'a:y, nè:ngx kiengz. Thailand: krachai (general), ka-aen (northern), wan-phraathit (Bangkok). Vietnam: b[oof]ng nga tru[aaj]t, c[ur] ng[ar]i.

Origin and geographic distribution *B. rotunda* is native to Java and Sumatra; it grows wild in the teak forests of Central and East Java. It is widely cultivated in India, Sri Lanka, South-East Asia (particularly in Indonesia, Malaysia and Thailand) and southern China.

Uses *B. rotunda* is principally used as a spice and a medicine. In Indonesia, Malaysia, Indo-China and India it is cultivated for its rhizomes and roots, which are consumed as an aromatic spicy flavouring for food and pickles. The rhizomes and roots are commonly used in cooking throughout Java and most of Indonesia. In some parts of Malaysia, young rhizomes and roots are eaten raw, with rice; young shoots are eaten this way in Java. The young spicy shoots are also a substitute for the rhizomes. In the Caruban district (East Java), leaves are used together with those of teak as a wrapper for fermented soya bean cake ('tempeh').

The rhizomes and roots have a wide range of applications in traditional medicine, e.g. as ingredient in post-partum tonic mixtures, as stomachic and carminative, as a remedy for coughs, indigestion, sprue and colic, and as external treatment for ringworm, rheumatic and post-partum muscular pain, swollen abdomen and difficult urination in children.

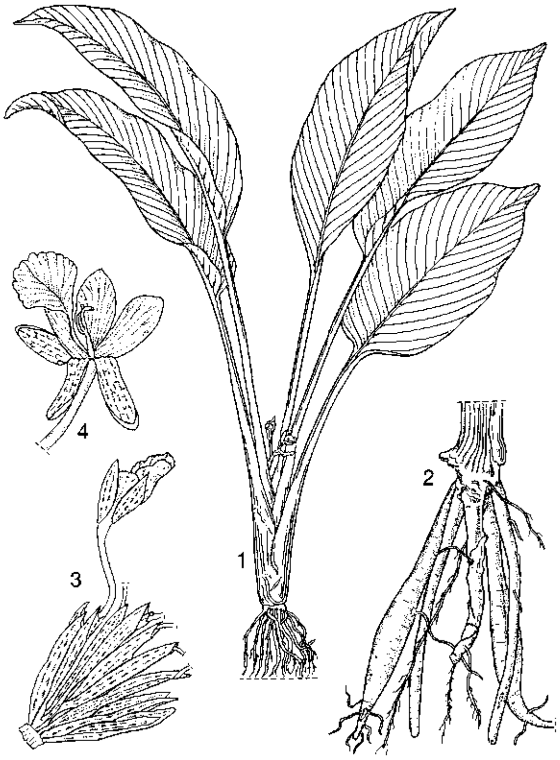
Production and international trade *B. rotunda* is commonly and widely produced, traded and consumed locally in India and South-East Asia, but no statistics are available.

Properties Per 100 g edible portion air-dried rhizomes contain approximately: water 12 g, total protein 20 g, total nitrogen 3.2 g, total sugar 12 g, soluble matter in 80% ethanol 52 g, soluble matter in water 21 g, total ash 6 g.

The constituents of the rhizomes and roots of Chinese keys include monoterpenoids (geranial and neral), flavones and flavanones (pinostrobin, alpinetin and pinocembrin) and chalcone (cardamonin). Three unusual dihydrochalcone derivatives (e.g. boesenbergin A) and three compounds related to panduratin A have also been isolated. Cardamonin (2',4'-dihydroxy-6'-methoxychalcone) is reported to be an effective anti-tumour agent.

The harvest index (fresh rhizome : total fresh plant) ranges from 0.56 to 0.64. The essential-oil content of the rhizome and roots ranges from 1–3% of dry weight, 0.2–0.5% of fresh weight. The essential oil contains the following main compounds: 1,8-cineole (18–41%), camphor (13%), d-borneol (9.2%), d-pinene (4.1%), zingiberene (2.7%), curcumin (0.9%) and zedoarine (0.7%). The essential oil from the rhizomes of Chinese keys (containing methyl cinnamate and zingiberone) has the ability to solubilize calcium kidney stones in vitro.

Description Perennial herb, 30–80 cm tall, with leafy shoots bearing 3–5(–7) erect leaves and about 3 bladeless, reddish sheaths at the base. Rhizome at the base of the leafy shoots only, composed of more or less globose joints, largely fused, up to 2 cm in diameter, yellow-brown outside, bright yellow inside, fragrant when bruised. Roots tuberous and fleshy, subclavate (like 'Chinese keys'), 5–30 cm × 0.5–2 cm, colour and fragrance like the rhizome. Leaves alternate, biseriate,



Boesenbergia rotunda (L.) Mansfeld – 1, habit flowering plant; 2, tuberous roots ('Chinese keys'); 3, inflorescence; 4, flower.

erect, hardly fragrant when bruised; sheaths not very robust, 9–19 cm long, together forming a short pseudostem; ligule broadly triangular, up to 1.5 cm long, arachnoid-pubescent, auricled, soon withering; petiole canaliculate, up to 30 cm long, glabrous; blade elliptical-oblong to broadly lanceolate, 12–50 cm × 5–17 cm, dark green, glabrous, with several raised, parallel veins and scattered dots above, pale green, glabrous to arachnoid-pubescent and densely white-dotted below. Inflorescence terminal on leafy shoot, spike-like, 10–15 cm long, almost completely hidden by the upper leaf sheaths, bearing about 10 flowers; peduncle 1–2 cm long; rachis short, crowded with distichous, equitant bracts; flowers far exserted, appearing in succession, situated in the axil of a bract and a bracteole; bracts and bracteoles oblong-lanceolate, 4 cm × 0.7 cm, green; calyx shortly tubular, about 1.5 cm long, apex bifid; corolla with an about 6 cm long white tube and 3 unequal, oblong, up to 1.7 cm long, incurved, pink lobes at apex; labellum (central staminode) patent, oblong-obovate or panduriform, 2–3.5 cm × 1.5–2.5 cm, apex crenate, undulate plicate, upper half pink, lower half white or pale pink, with red-violet dots within; lateral staminodes erect, petaloid, broadly obovate, 1.5–2 cm × 1 cm, pink; stamen with 5 mm long white hairy filament and 5 mm long yellow-white anther with narrow, bilobed, reflexed apical appendage of connective (crest), anther dehiscing longitudinally; pistil with 3-loculed, glabrous ovary 5.5 mm long, stylodes slender, style filiform, stigma protruding beyond the anther, funnel-shaped, yellow-white. Fruit unknown.

Growth and development A rhizome cutting planted in the open produces 4–5 leaves in about 1 month after planting; under shade, only 2 leaves are produced. The growth rate is fast for plants cultivated in well-drained loams, rich in organic matter. During its growth, the mother tuber emits, long, straight, swollen carrot-like roots resembling Chinese keys. Plants grown in shady locations lose their cineole content much faster than those grown in sunny places. When grown for the rhizome and roots as a spice, the life cycle of a plant is about 5 months. Plants can produce young shoots for vegetable use and rhizome and roots for medicinal use for several years. If left undisturbed a plant may develop into a gregarious community. In India plants flower in August, in Cambodia in June.

Other botanical information The genus *Boesenbergia* Kuntze comprises about 40 species, distributed throughout India and the western part of South-East Asia. The taxonomy of the genus is poorly known.

Ecology Chinese keys is found in mixed deciduous and evergreen forests, on limestone hills along streams, from sea-level up to 1200 m altitude. It grows best in a hot, humid tropical climate, on relatively fertile soils with good aeration and drainage.

Propagation and planting Propagation of *B. rotunda* is by cuttings from the old rhizome, situated immediately under the leafy shoot. The cuttings are planted at the beginning of the rainy season, preferably on hillocks, at distances of 30–40 cm × 30–60 cm.

Husbandry Provided water supply is sufficient, not much care is needed. Weeding is necessary until the plants are well established. It is recommended to apply NPK fertilizer 2 weeks and 4 weeks after planting, with a total dosage per ha of 100 kg N, 25 kg P and 50 kg K.

Diseases and pests No serious diseases and pests are known of *B. rotunda*. Occasionally larvae of *Kerana* sp. and *Udaspes* sp. feed on the leaves.

Harvesting Young shoots to be used as a vegetable can be cut from 1–2 months after planting. Whole plants are pulled up at 4–5 months after planting for use as cooking spice and traditional medicine. If not harvested within 5 months after planting, rhizomes will become woody and their quality as a spice will decrease. Specific parts of the plant, e.g. the enlarged roots for external use as medicine, can be selectively harvested later than 6 months after planting, without disturbing the growth of the plant.

Yield The average yield of fresh rhizomes and roots is about 10–30 t/ha at 4–6 months after planting. Being mainly a crop of smallholders for domestic use only, yield data are scarce.

Handling after harvest After harvesting, the parts are cleaned and washed before marketing. The mother rhizomes are kept apart for propagation.

Genetic resources and breeding No germplasm collections or breeding programmes are known to exist for Chinese keys.

Prospects Chinese keys is quite widely used as cooking spice and as folk medicine in South-East Asia but its chemical composition is still insufficiently known. Further research on the chemical constituents and biological activity is urgently needed to exploit its full potential, and germplasm collection is recommended.

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H. Ibrahim & A. Nugroho

Brassica nigra (L.) W.D.J. Koch

Deutschl. Fl. ed. 3, Vol. 4: 713 (1833).

CRUCIFERAE

$2n = 16$ (genome BB)

Synonyms *Sinapis nigra* L. (1753), *Brassica sinapoides* Roth (1830), *Sisymbrium nigrum* (L.) Prantl (1884).

Vernacular names Black mustard (En). Moutarde noire (Fr). Philippines: mustasa. Vietnam: c[ar]i den, h[aws]c gi[ows]i.

Origin and geographic distribution *B. nigra* most probably originated in the Asia Minor–Iran area, but at present it occurs wild in the Mediterranean region, throughout central Europe, in the Middle East and in the Ethiopian highlands. It is also cultivated in these areas, mainly in kitchen gardens, sometimes mixed with other *Brassica* oilseeds. Its shattering fruits make it unsuitable for large-scale, mechanized cultivation, so it has largely been substituted by brown or Indian mustard (*B. juncea* (L.) Czernjaew), which is produced large-scale on the Canadian prairies.

Uses The seed of *B. nigra* has been used as a spice and medicine since ancient times in the Middle East, India and Greece. Finely ground seeds of black mustard provide mustard meal, a neutral odourless powder which stores well if kept dry. This meal, mixed with vinegar, is the pungent condiment or table mustard known as French and English mustard. Adding vinegar to a coarsely ground mixture of seeds of black mustard and of white mustard (*Sinapis alba* L.) produces the milder German or Dutch mustard. In Europe and North America, condiment mustard used to be prepared in the home by rolling a metal ball in a bowl of mustard seed and then mixing vinegar into the resulting crushed seed. Other herbs may be added according to taste and tradition and, for a milder taste, sugar, honey or starchy substances.

There are numerous manufacturers' recipes. In cooking, mustard is mainly used to flavour meat dishes and sauces for meat, fish, salads, and snacks. In mayonnaise preparation it is also added as an emulsion stabilizer. The regulatory status of black mustard in the United States is 'generally recognized as safe' (GRAS 2760).

In traditional medicine, mustard meal mixed with water was used extensively as a plaster preparation and to prepare mustard baths to treat skin ailments, arthritis and rheumatism. The seeds are used as diaphoretic, diuretic, emetic, expectorant, irritant and stimulant. Tea prepared from the seed is used to cure sore throat and to relieve bronchitis and rheumatism. Hot water poured on crushed seed makes a household remedy for headaches and colds and a stimulating foot bath. Mustard oil is said to stimulate hair growth.

B. nigra is a copious nectar producer and yields a mild-flavoured, light-coloured honey.

Production and international trade In world trade, the combined mustards are by far the most important spice in volume, while in value they are second only to black pepper (*Piper nigrum* L.). Seeds of *B. juncea* and *S. alba* account for respectively about 40% and 60% of the world mustard trade. The importance of *B. nigra* in international trade has become minimal.

The major manufacturers and consumers of condiment mustard are the United States, Germany, France and the United Kingdom. The production of condiment mustard in the European Union in 1985 was about 130 000 t, with consumption per head ranging from 0.3 kg (United Kingdom) to 1 kg (France). Annual world trade in condiment mustard is estimated at 160 000 t.

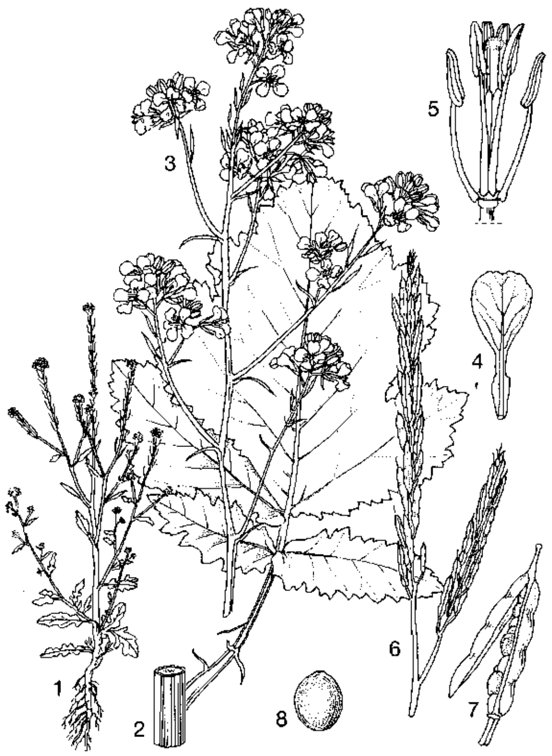
Properties Cruciferous plants are characterized by a range of glucosinolates or mustard-oil glucosides contained in the seeds and other tissues. Also occurring in the tissues is the enzyme myrosinase, which, in the presence of watery substances, splits glucosinolates into volatile or oily isothiocyanates and glucose. The glucosinolate of black mustard, called sinigrin, releases the aggressive, volatile allyl isothiocyanate which is responsible for the pungent taste of black mustard; it is also a strong irritant of the mucous membranes and skin, and is used in dog and cat repellents.

The glucosinolate content of the seed varies from 110–140 μmol/g. Per 100 g edible portion seeds contain: water 8 g, protein 29 g, fat 28 g, carbohydrates 19 g, fibre 11 g and ash 5 g (Ca 0.4 g, P 0.6 g, Fe 21 mg), β-carotene equivalent 0.6 g, thiamine 0.4 mg, riboflavin 0.31 mg, and niacin 7.3 mg. Since the whole seed is used, condiment mustard is in fact quite a complete and nutritious food. The many medicinal properties should therefore not always solely be attributed to the quite overwhelming action of the isothiocyanates.

The 1000-seed weight is 2–4 g.

Adulterations and substitutes Brown mustard (*B. juncea*) has largely taken the place of *B. nigra* for the production of condiment mustard. *B. juncea* (2n = 36) is an allotetraploid species containing the BB genome of *B. nigra* in addition to the AA genome of *B. rapa* L.; it also produces the glucosinolate sinigrin characteristic of *B. nigra*. However, in Asia *B. juncea* is most important as a vegetable and oilseed crop.

Description A much branched annual herb, 0.5–1.5 m tall, with a firm taproot. Stem erect, terete, up to 1.5 cm in diameter, glabrous or bristly hairy, green or slightly glaucous. Leaves rather variable, petiolate, in a rosette and large in young



Brassica nigra (L.) W.D.J. Koch – 1, habit flowering and fruiting plant; 2, part of stem with lower leaf; 3, flowering branch; 4, petal, 5, stamens and pistil; 6, fruiting branches; 7, dehiscing fruit; 8, seed.

plants, alternating and becoming gradually smaller further up the stem; lower leaves large, up to 16 cm × 5 cm, pinnatifid or pinnatilobed, usually with 2 lower lobes and a much larger terminal lobe, central leaves moderately lobed; lower and central leaves irregularly dentate and often partly bristly hairy; uppermost leaves narrow-lanceolate, small, entire, glabrous. Inflorescences axillary or terminal, bractless racemes, all together arranged paniculately; flowers bisexual, up to 8 mm long, 4-merous, bright yellow, on short pedicel; sepals 4, narrowly elliptical, 3–4 mm × 1.5 mm, spreading horizontally; petals 4, clawed-obovate, 6–8 mm × 2–2.5 mm; stamens 6, outer whorl of 2 shorter, inner whorl of 4 longer ones; pistil slightly shorter than longest stamens, with sessile, superior, elongated ovary and a style ending in a semi-globose stigma. Fruit a silique, 4-sided with rather flat sides, up to 2.5 cm long, with a short beak at apex, erect and closely appressed to the inflorescence axis, containing 4–10 seeds, dehiscing when ripe. Seed globose, about 1 mm in diameter, black to red-brown, minutely pitted. Seedling with epigeal germination.

Growth and development Black mustard germinates immediately after sowing; the first leaves are usually visible within 48 hours. Early growth is very rapid too. Flower initiation may start as early as 2 weeks after germination, but usually occurs after 4–6 weeks. Fruit maturation takes another 4–8 weeks. Pollination is by insects, e.g. various bee species and pollen beetles such as *Meligethes* spp.

Natural selection for earliness amongst volunteer plants may cause black mustard to develop as a troublesome weed.

Other botanical information There is some confusion in the literature about mustards. Botanically 4 species are involved:

- *Brassica carinata* A. Braun: Abyssinian or Ethiopian mustard, gommenzer, $2n = 34$, BBCC genome. Only known as a cultivated plant from the highlands of Ethiopia and northern Kenya; rarely used outside those areas.
- *Brassica juncea* (L.) Czernjaew: brown or Indian mustard, $2n = 36$, AABB genome.
- *Brassica nigra*: black mustard, $2n = 16$, BB genome. One of the 3 basic diploid cultivated *Brassica* species in the famous *Brassica* triangle: *B. nigra* ($2n = 16$, BB genome), *B. oleracea* L. ($2n = 18$, CC genome) and *B. rapa* L. ($2n = 20$, AA genome), from which many *Brassica* crops are derived.
- *Sinapis alba* L.: white mustard, $2n = 24$, SS genome. It and *B. juncea* are now the 2 most important mustard species.

Brassica L. and *Sinapis* L. are closely related and difficult to distinguish. Some easily recognizable differences are: *Sinapis* has pale green leaves, petals with short claws and fruits with bristles; *Brassica* often has grey-green leaves, petals with larger claws and smooth fruits.

Ecology Black mustard is adapted to a range of temperate and subtropical climates, but is unsuited to wet tropical lowlands. It tolerates annual rainfall of 300–1700 mm, but is grown chiefly as a rainfed crop in areas of low to moderate rainfall. The reported range of average annual temperatures is 6–27°C. While suited to many soils except heavy clays, black mustard grows best on light sandy loams of pH 5–8.

Propagation and planting Black mustard is propagated by seed. The small seed requires a level, well-prepared seedbed. Seeds may be sown about 1 cm deep in rows 20–30 cm apart at a rate of 3–4 kg/ha, or broadcast at a rate of about 10 kg/ha.

Husbandry Weeding is recommended during crop establishment, as is the application of some nitrogenous fertilizer at planting.

Diseases and pests Possible diseases include black leaf rot (*Alternaria brassicae*) and stem rot (*Sclerotinia sclerotiorum*). The crop attracts a wide range of insect pests such as seed-pod weevils (*Ceutorynchus* spp.), flea beetles (*Phyllotreta* spp.) and aphids (e.g. *Brevicoryne brassicae*). Diseases and pests are mainly controlled by using locally adapted cultivars with effective field resistance, and by appropriate agronomy and crop rotation. The use of disinfected seed is strongly recommended. Birds can cause havoc in ripening crops.

Harvesting The crop is ready for harvesting 40–100 days after sowing. Fruit ripening of black mustard starts at the base of the plants and proceeds upwards. The crop should be cut manually or by combine harvester when the first fruits mature and split. The plants should preferably be bunched and put to dry on a floor. This ensures that most seeds will be collected and that there will be no large-scale seed losses in the field and subsequent massive growth of volunteer plants causing a weed problem.

Yield Seed yield is about 300–600 kg/ha. Under good cultural practices up to 1100 kg/ha has been reported.

Handling after harvest When thoroughly dry the bunched plants are easy to thresh. The seed is put in sacks together with some husks. This keeps the relative humidity down, which is important for controlling storage insects. The seed stores well.

Genetic resources Germplasm collections are available at the national gene banks of India, the United States, Canada and the Netherlands.

Breeding *B. nigra* is cross-fertilizing. It requires a recurrent population improvement breeding scheme to develop populations with improved ecological adaptation but keeping a broad genetic variation for further improvement. However, there do not seem to be any ongoing breeding programmes.

Prospects World consumption of mustard is expanding slowly and the present production centres will be able to gradually increase supplies. *B. nigra* will remain of minor importance. Prospects for production in South-East Asia seem limited to areas with a cool season with long days.

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H. Toxopeus & I. Utomo

Capparis spinosa L. var. mariana (Jacq.) K. Schumann

Bot. Jahrb. 9: 201 (1888).

CAPPARIDACEAE

$2n = 24, 38$

Synonyms *Capparis cordifolia* Lamk (1785), *C. mariana* Jacq. (1797), *C. sandwichiana* DC. (1824).

Vernacular names Mariana caper-bush, Mariana caper, caper (En). Câprier (Fr). Malaysia: melada. Philippines: alcaparras.

Origin and geographic distribution The well-known caper-bush (*C. spinosa* L.) is distributed from the Mediterranean through the Near East to India. It was introduced early in post-Columbian times as a cultigen into the Mariana Islands, from where it spread and naturalized in Polynesia and eastern Malesia, i.e. Indonesia (Lesser Sunda Islands), Papua New Guinea (New Ireland, New Britain) and the Philippines (Luzon, Bohol). Historical notes indicate that Mariana caper-bush was cultivated in Guam in the second half of the 18th Century. The flower buds were harvested, pickled and exported as capers in the same way as the well-known Mediterranean delicacy. The Indo-Pacific population is very uniform and has developed into a form (var. *mariana*) that is, taxonomically and geographically, distinct from other forms of *C. spinosa* not found between India and Timor (Indonesia). *C. spinosa* was also introduced into Australia, where it naturalized and developed into a distinct form too.

Uses Commercial capers are the pickled flower buds of *C. spinosa*; they are used as a condiment. Capers derived from the south-European forms of the species have considerable economic importance in Mediterranean countries like France, Spain, Italy and northern Africa. The flower buds of the Indo-Pacific Mariana caper-bush (var. *mariana*) are used similarly, but Mariana caper-bush has lost importance in the Pacific and South-East Asia. Capers are characteristic of Mediterranean cuisine. They are used in salads, mayonnaise and other cold sauces. They keep their spicy taste during cooking, and combine well with grilled or stewed meat, and even better with fish. The pickled fruits are popular in southern France ('cornichons de câprier') and in Italy ('caperone' or 'taperone'). Capers have been approved for food use by the Food and Drug Administration (FDA) of the United States.

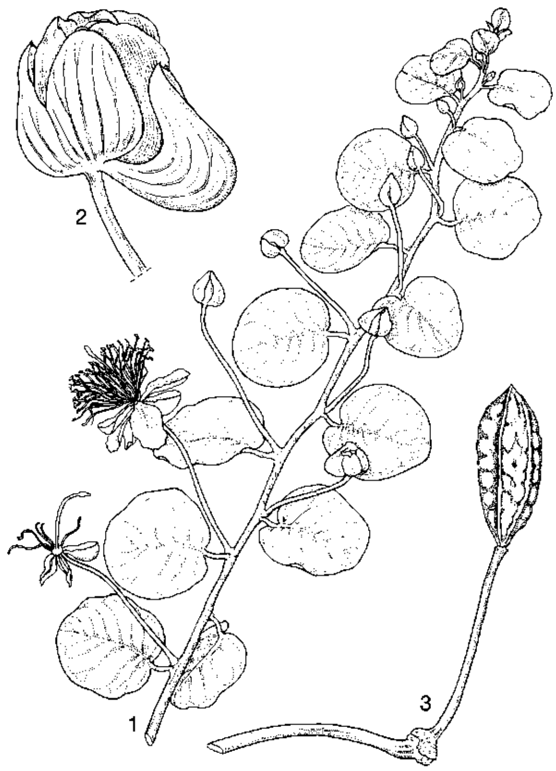
The caper-bush is also used in traditional medicine, but not in South-East Asia. The flower buds have a beneficial effect on lesions of the vascular system. Infusions or decoctions obtained from root bark are used for ailments like dropsy, anaemia, general atony and arthritis. In India, root bark is considered a purgative, tonic, diuretic, anthelmintic, emmenagogue and analgesic, and plant extracts are a common ingredient of hepatoprotective herbal drugs and traditional medicines such as Liv-52.

Production and international trade Mariana caper-bush is still reportedly cultivated in some localities in Luzon (Philippines), but for some unknown reason its cultivation did not spread further into South-East Asia. At present, capers are mainly produced in southern Europe (France, Spain, Italy), where it has long been a specialty crop. The caper-bush has been introduced into other subtropical regions for adaptation trials, e.g. in California (United States) and Argentina. World production is estimated at a few thousand t.

Properties The sharp taste of capers is similar to that of the mustards and horseradish (*Capparidaceae* and *Cruciferae* are closely allied). They have a similar effect as digestive stimulant. In capers the attractive flavour is caused by capric acid. Per 100 g edible portion, capers contain: water 79 g, protein 5.8 g, fat 1.6 g, carbohydrates 6.5 g, fibre 5.4 g, ash 1.6 g. Caper-bush contains rutin and a number of kaempferol- and quercetin-derived flavonoids. Yellow rutin crystals are present in small groups on the flower buds.

Adulterations and substitutes Capers are expensive. Substitution by flower buds of other *Capparis* spp. may happen to a certain extent. In Europe true capers are sometimes adulterated with young flower buds of *Caltha palustris* L. (*Ranunculaceae*), *Ficaria verna* Huds. (*Ranunculaceae*), *Sarothamnus scoparius* (L.) Wimm. ex Koch (*Leguminosae*), *Tropaeolum majus* L. (*Tropaeolaceae*), with young fruits of *Euphorbia lathyrus* L. (*Euphorbiaceae*) and with young fruits of the caper plant itself.

Description Shrub, up to 2 m tall, branches usually prostrate. Twigs terete, unarmed, with short, floccose, greyish indumentum which soon disappears. Leaves alternate, simple, glaucous; petiole 0.7–1.3 cm long; blade subfleshy when fresh, herbaceous when dried, ovate-elliptical to suborbicular, 1.5–7.5 cm × 2.5–5.5 cm, base truncate to rounded, apex rounded to obtuse, veins in 5–7 pairs. Flowers solitary, axillary, showy and fragrant; pedicel 4.5–7.5 cm long, glabrescent; buds conical when young, later bulging, ultimately 2–2.5 cm in diameter; calyx strongly zygomorphic, glabrescent, with sepals in 2 pairs, the posterior sepal deeply saccate, 2.5–4 cm × 1.7–2.5 cm, the other sepals subovate, 2–2.5 cm × 0.7–2.5 cm; petals 4, in 2 pairs, white, turning red-purplish, upper pair rhombic, 3–5.5 cm × 2–4 cm, with a thick fleshy base, lower pair 3–3.5 cm × 1.5–3.3 cm; stamens 100–190, 4.5–6 cm long, white to reddish; pistil on a 6–7 cm long gynophore which is



Capparis spinosa L. var. mariana (Jacq.) K. Schumann – 1, habit flowering twig; 2, flower bud (bulging before anthesis); 3, fruit on gynophore.

hairy near the base. Fruit a berry with a thin, leathery to corky pericarp, ellipsoidal, 2.5–5 cm × 1.3–1.5 cm, olive-green with distinct ribs. Seeds numerous, subglobose, 4 mm in diameter, embedded in yellow fruit pulp.

Growth and development Fresh seeds germinate readily, but germination of dried seeds is very erratic due to seed-coat-induced dormancy. The root system is very extensive and capable of penetrating deep in the soil. The xerophytic character of the caper-bush is a complex response to drought, involving osmotic adjustment, regulated stomatal opening, cell wall plasticity and increased root density. C3-physiology has been recorded for *Capparis*. Flowering starts about one year after sowing, is continuous but takes place only on one-year-old branches. Caper-bush is noctiflorous. Pollination is by insects. It begins producing after about one year, and reaches full production after 3–4 years. In southern Europe the commercial life-span is about 15 years, before it has to be replanted because of declining yields.

Other botanical information *C. spinosa* is a widespread, polymorphic, complex species in which several distinct forms have developed that have been distinguished in the botanical literature as formas, varieties, subspecies or also often as species. There has been no comprehensive study of the whole complex. The typical, spiny variety (var. *spinosa*) occurs in the Mediterranean. Only var. *mariana* occurs in South-East Asia; it is characterized by the slightly tomentose, glabrescent, unarmed twigs, the relatively large and orbicular leaves without apical spine and very large flowers with one saccate sepal. In India and the western Himalayas var. *himalayensis* (Jafri) Jacobs occurs (twigs late glabrescent, petiole 2–7 mm long, gynophore 4.5–7 cm long). In Australia var. *nummularia* (DC.) F.M. Bailey developed from an introduction different from the one in South-East Asia (twigs sometimes with short spines, leaves suborbicular with petiole 6–9 mm long, gynophore up to 5 cm long and glabrous).

Capparis L. is a large pantropical genus of about 250 species, predominantly distributed in sunny, warm and dry habitats that have seasonal climates. There are about 40 species on mainland South-East Asia and about 20 species in Malesia. Some species are used as ornamentals (showy flowers), often in hedges (spines). Some species in South-East Asia have edible fruit pulp (*C. buwaldae* Jacobs, *C. pyrifolia* Lamk, and *C. zeylanica* L.) and some are used medicinally (*C. micracantha* DC., *C. pyrifolia* Lamk, *C. sepiaria* L. and *C. zeylanica* L.).

Ecology Mariana caper-bush is xerophytic and thrives under semi-arid or seasonal conditions. It occurs in the drier parts of South-East Asia in the lowlands, often along seashores, up to 350 m altitude. It grows well at temperatures over 40°C and at an annual rainfall of 350 mm only. It is found on dry, well-drained sandy soils derived from lava or limestone. It is salt-tolerant. Other forms of *C. spinosa* grow and are cultivated under comparable conditions.

Propagation and planting No specific information is available on the agronomy of var. *mariana*, but methods applied to the caper-bush in general probably apply. The caper-bush can be propagated by seed or by cuttings. In vitro propagation is also possible. Germination is promoted by chemical scarification of seeds in sulphuric acid. Seeds are sown a few cm deep in a seed-bed. Vegetative propagation by cuttings seems better suited to intensive cultivation, for reasons of homogeneity. Cuttings should be taken from vigorous branches with a diameter of over 1.5 cm. When sufficiently developed and rooted, seedlings or cuttings are transplanted to the field at spacings of 2–2.5 m × 2–2.5 m, resulting in densities of 1600–2500 plants/ha.

Husbandry In the main production areas in southern Europe, mulching is recommended in the first year to ensure optimal rooting. Pruning is performed each winter to remove dead wood and water sprouts. The branches should be pruned severely as flowering takes place on one-year-old branches.

Diseases and pests Little is known about diseases and pests of Mariana caper-bush. In intensive cultivation in the Mediterranean area, some diseases and pests have been observed but biocides are hardly applied.

Harvesting Young flower buds are harvested at regular intervals of 8–12 days. Harvesting is very labour-intensive.

Yield Annual yields of 1–3 kg of dried flower buds per plant, or 3–4 t/ha are reported from southern Europe.

Handling after harvest Fresh buds are very bitter, dried ones are pleasantly spicy but quickly lose their aroma. Harvested buds are usually first kept in the dark for 3–4 hours and subsequently put into vinegar or salted vinegar. After 8 days they are removed from the vinegar, pressed and transferred to fresh vinegar, which process is repeated after another 8 days. Subsequently they are graded according to size by means of sieves, the smallest ones being the best quality (called 'nonpareil' capers).

Genetic resources and breeding The variability in var. *mariana* is rather small, which may be the result of a one-off introduction into the Indo-Pacific region. Institutional germplasm collections of *C. spinosa* are maintained in Italy and Spain. Caper-bush is predominantly outbreeding. The wide variability of the species as a whole offers good prospects for breeding programmes.

Prospects Although capers do not have a sizable clientele in South-East Asia at present, the food market in this region is expanding and absorbing many culinary specialties from around the world. Most communities in this region have a liking for pungent spices and also for pickles, so capers may find a footing. Due to the presence of Mariana caper-bush in the region, increased demand can be met by local production instead of relying on imports.

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H.C. Ong & J.S. Siemonsma

Carum carvi L.

Sp. pl.: 263 (1753).
UMBELLIFERAE
$2n = 20$

Synonyms *Carum velenovskyi* Rohlena (1903).

Vernacular names Caraway (En). Carvi (Fr). Thailand: hom-pom (northern).

Origin and distribution The species consists of a winter (biennial) and a spring (annual) type. The latter is indigenous to the eastern part of the Mediterranean including Egypt. The winter type is native to the mountain ranges of Eurasia and along the draining rivers flowing from them. It is cultivated in East-European countries and the Netherlands.

Unless otherwise specified it is the spring type that is described and referred to below, because of its relevance for South-East Asia.

Uses The small dried caraway fruit, an achene usually referred to as seed, has a characteristic distinct taste and pleasant smell, and is mainly used as a spice. It is one of the spicy fruits of Indian cooking. In large parts of Europe and northern America the whole fruit is used in bakery products, and for flavouring meat and various dishes.

An essential oil is obtained by steam distillation from the fruits. The oil is extensively used as a flavour component in major food products, including alcoholic (e.g. the well-known Scandinavian Akvavit) and non-alcoholic beverages, in cosmetic products such as soap, perfume and toothpaste, and in pharmaceutical preparations. In the United States the regulatory status 'generally recognized as safe' has been accorded to caraway (GRAS 2236) and caraway fruit oil (GRAS 2238). The maximum permitted level for caraway oil in food products is about 0.02%. Consumption of caraway enhances lactation of breast-feeding women. Caraway fruit and the oil are regarded medicinally as carminative and stomachic. The activity of the essential oil in a daily dose of 3–6 drops is spasmolytic, anti-microbial, and it is applied for dyspeptic complaints such as mild gastro-intestinal spasm, bloating and fullness. These qualities are attributed to the major component of the oil, carvone. Carvone has been shown to possess certain cancer-preventive properties. It is also effective as an anti-sprouting agent in stored consumption potatoes and seed potatoes, controlling most storage fungi at the same time. It is also used as disinfectant and as insect repellant. In Germany caraway plants with immature fruits are a highly regarded component in herbal meadows, producing herbal hay enhancing lactation in dairy cattle.

Production and international trade As it is a world market commodity, market forces determine the price of caraway. Since the market is usually oversupplied, caraway prices are chronically low. In times of scarcity prices increase rapidly and quite dramatically. Subsequently, production areas increase, resulting in overproduction. At the same time, in traditional areas, much of the fruit is home-grown or collected in the wild.

The major producers of winter-type caraway are the Netherlands, Poland, Hungary and Russia. The spring type is produced in Egypt and western India.

The United States is a major importer of caraway fruit and oil, with average annual imports in the early 1990s of 3000 t fruit and 4 t oil. In the United States the price of 1 kg of fruits is about US$ 1, of 1 kg oil US$ 33. Average annual world production of caraway oil is estimated at 30 t, with a total value of about US$ 1 million.

Properties Per 100 g edible portion dried caraway fruits contain: water 10 g, protein 20 g, fat 14 g, carbohydrates 37 g, fibre 13 g, ash 6 g (Ca 689 mg, Fe 16 mg, Mg 258 mg, P 568 mg, K 1.4 g, Na 17 mg, Zn 6 mg), vitamin A 363 IU. The energy value is about 1395 kJ/100 g.

Carefully produced caraway fruit of the spring (annual) type, airdried to 10–12% moisture, contains 1.5–5.0% of caraway essential oil, depending on year and soil conditions; 1000-fruit weight is 4–5 g. Fruit of the winter (biennial) type has a content of 3.0–7.0% oil, depending on year of production and time of harvesting: early harvesting gives a slightly smaller fruit and a higher oil content; 1000-fruit weight is 3.0–4.5 g. On account of its superior oil content the biennial fruit has the better quality, i.e. a stonger taste.

The oil consists largely of two monoterpenic components: d-carvone or S-(+)-carvone (45–60%) and d-limonene or S-(+)-limonene (35–55%). d-Carvone is responsible for the characteristic flavour and biological properties.

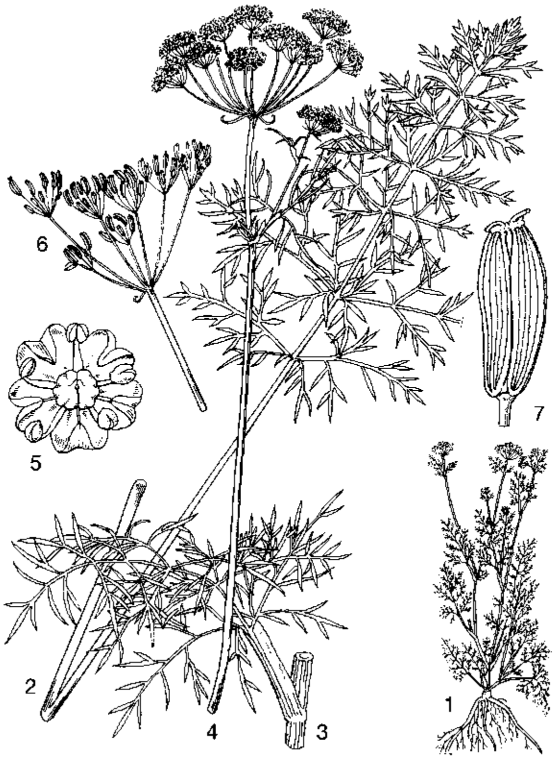
The stereoisomer L-(−)-carvone occurs in the sapodilla or chicle-tree fruit (*Manilkara zapota* (L.) P. van Royen) of South America and has a quite different taste.

Unlike dill (*Anethum graveolens* L.), the other plant parts of caraway do not contain carvone or limonene.

A monograph on the physiological properties of caraway oil has been published by the Research Institute for Fragrance Materials (RIFM).

Adulterations and substitutes Oil from the fruit of dill contains 20–50% d-carvone, and could serve as a substitute for caraway oil. Caraway oil often is adulterated with synthetic d-carvone.

Description A glabrous, erect, annual or biennial herb, 0.5–1.5 m tall. Taproot fusiform to cylindrical, strong, thick, fleshy and long. Stem terete, up to 2 cm in diameter, hollow, striate, branching in upper part. Leaves alternate, in approximately 2/5 arrangement, compound, bright green; petiole up to 13 cm long, upper ones gradually shorter, uppermost absent, all of them with a sheath with membranous margin and auriculate apex; blade subtriangular in outline, 6–15 cm × 2–8 cm, 2–3-pinnate, lowest leaf segments at least twice as long as wide, ultimate lobes linear-lanceolate to linear, 3–25 mm long. Inflorescence a compound umbel, 4–8 cm in diameter, terminal; peduncle up to 11 cm long; bracts and bracteoles absent or few, bracts occasionally leaf-like; primary rays 3–16, unequal, 0.5–6 cm long; secondary rays 6–16, unequal, up to 1 cm long; umbellets about 1 cm in diameter; flowers bisexual, protandrous, usually white, sometimes pinkish; calyx absent; petals 5, obcordate with short inflexed apex, about 1.5 mm × 1 mm; stamens 5; styles 2, recurved, with enlarged base forming the stylopodium, stigma capitate. Fruit a schizocarp, ellipsoidal, laterally compressed, 3–5 mm long, splitting into 2 mericarps; mericarp often falcate, 5-ribbed, brown, with wide, solitary vittae.



Carum carvi L. – 1, habit flowering plant; 2, rosette leaf; 3, lower stem leaf; 4, flowering umbel; 5, flower; 6, fruiting umbel; 7, fruit.

Growth and development Germination of the seed is immediate but growth of the tiny seedlings is rather slow. Seed dormancy can cause problems in Mediterranean countries. In the Netherlands flower initiation of the spring type starts 6–12 weeks after sowing, with another 4–8 weeks to maturity. The sequence of flowering in umbels and umbellets is from the outside to the inside. The inner umbellets and the latest formed umbels tend to produce predominantly male flowers. In bisexual flowers protandry is the rule and hence the plants must cross-fertilize, pollen being carried by wind and insects. Dry, sunny weather is optimal for insect activity and also for pollen dissemination, and thus for good seed set.

Other botanical information There do not seem to be any vernacular names for caraway in any of the South-East Asian countries. Burkill is the only author to mention 'jintan' as a Malay name for caraway; however, his description of caraway contains information derived from cumin (*Cuminum cyminum* L.). The fruit of the two crops is very similar in outward appearance and may easily be confused. If in doubt, bite the fruit, the taste is very different and distinctive. Jintan is clearly cumin, usually in the form of ground fruit. Caraway fruit is not marketed in ground form.

The two major cultivars of winter caraway in the Netherlands are 'Volhouden' and 'Bleija'. 'Volhouden' shatters its fruits easily at maturity, necessitating swathing prior to harvesting so as to reduce the risk of considerable losses at harvesting. However, threshing and cleaning is easy, and its fruit is well suited for use as a spice. 'Bleija' fruits are non-shattering, giving better yield security, but usually two rounds of threshing are required to get rid of fruit stalks.

Two cultivars of spring caraway have been commercially released in the Netherlands: 'Karzo' and 'Springcar', both with a non-shattering fruit.

Northern Eurasian winters are sufficiently protracted to vernalize winter caraway plants, provided the plants are of a sufficient size, i.e. have grown a taproot of at least 8 mm in diameter. Such plants require 6–8 weeks exposure to temperatures below 10°C.

Ecology Spring caraway thrives in the cool short days of the eastern Mediterranean winter and of the Indian plains. Biennial winter caraway occurs naturally in meadows, grassland, forest edges, along roads and rivers and as a weed in fields, from sea-level up to 4000 m altitude.

Propagation and planting Caraway is propagated by seed. The small seed requires an even, well-prepared seedbed. Seed is sown about 1–2 cm deep in rows 20–30 cm apart, or broadcast at a rate of 5–10 kg/ha. In Israel, a plant stand of 60 per m^2 gives the best per ha yield.

Micropropagation using in vitro culture of tissues derived from petiole, hypocotyl and seedling shoot tip has been reported.

Husbandry Weeding is recommended during establishment of the crop. Application of 75–100 kg N/ha is recommended to stimulate root development.

Diseases and pests In the Netherlands, the main disease of spring caraway is the soilborne *Sclerotinia* stem rot, which can only be controlled by wide crop rotation. As concerns potential insect pests, the carrot fly attacks caraway roots. Birds and mice can be major pests.

Harvesting The crop may be left to die and dry in the field prior to harvesting, unless the cultivar has shattering fruit.

Yield Yields in the Netherlands are in the order of 1.0–1.8 t/ha.

Handling after harvest Threshing should be done with care, to ensure that stalks and other materials are properly removed from the fruits, since the trade is very strict in this respect. The fruits should be dried (in the air or artificially at 30°C) to a moisture content of about 12%. The fruit stores and transports very well.

The essential oil is commercially extracted from the fruit by super-heated steam.

Genetic resources Accessions of spring caraway may be available from the national gene banks of Egypt and Israel. A few are in the Netherlands gene bank.

Breeding Since caraway is basically outbreeding, recurrent population improvement is basic for seed breeding. Limited breeding work is in progress in Egypt and Israel. Breeding annual cultivars adapted to European spring and summer conditions yielded the Dutch cultivars Karzo and Springcar.

Prospects Unless there is a breakthrough in the market, such as the regular use of carvone from caraway fruit in the agriculture and pharmaceutical industries, the continued overproduction and chronically low prices will remain a disincentive to invest in crop improvement. However, limited cultivation of an annual caraway cultivar locally adapted to the cooler climates of the mountainous zones in South-East Asia may supply the local medicinal and culinary demand, which is currently met from Indian sources. At the same time, caraway with its distinct flavour may in due course be a stimulating addition to the existing range of spices available in South-East Asia.

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H. Toxopeus & J.H. Lubberts

Cinnamomum Schaeffer

Bot. exped.: 268, 269 (1760).

LAURACEAE

$x = 12$; $2n = 24$ (*C. burmanni, C. cassia, C. loureirii*)

Major species and synonyms

- *Cinnamomum burmanni* (C. Nees & T. Nees) C. Nees ex Blume, Bijdr. Fl. Ned. Indië 11: 569 (1826), synonyms: *Laurus burmanni* C. Nees & T. Nees (1823), *Cinnamomum mindanaense* Elmer (1910).
- *Cinnamomum cassia* J.S. Presl, Prir. rostlin 2: 36, 44–45, t. 6 (1825), synonyms: *Laurus cassia* L. (1753), *Cinnamomum aromaticum* C. Nees (1831).
- *Cinnamomum loureirii* C. Nees, Syst. laur.: 65 (1836), synonyms: *C. obtusifolium* (Roxb.) C. Nees var. *loureiri* C. Nees ex Watt (1889).
- *Cinnamomum verum* J.S. Presl – see separate article.
- Other *Cinnamomum* species – see chapter on Minor spices.

Vernacular names General: Cassia (En). Cassia, cinnamon (Am). Cannellier (Fr). Indonesia: kayu manis. Malaysia: kayu manis. Philippines: cinnamon, kanela. Vietnam: qu[ees], long n[ax]o, re.

- *C. burmanni*. Indonesian cassia, Padang cassia, cassia vera (En). Indonesia: kayu manis (Indonesian), ki amis (Sundanese), manis jangan (Javanese). Philippines: kaliñgag (Manobo), kami (Bagobo). Thailand: suramarit (Nakhon Ratchasima). Vietnam: qu[ees] tr[eff]n, qu[ees] r[aff]nh.
- *C. cassia*. Chinese cassia, Chinese cinnamon, cassia lignea (En). Cannellier de Chine, cannellier casse (Fr). Indonesia: kayu manis cina (Indonesian). Laos: s'a: chwang. Thailand: kaeng (Chiang Mai). Vietnam: qu[ees] thanh, qu[ees] d[ow]n, qu[ees] qu[ar]ng.
- *C. loureirii*. Vietnamese cassia, Saigon cassia, Saigon cinnamon (En). Laos: kh'e:. Thailand: opchoei (Bangkok). Vietnam: qu[ees] thanh ho[as], qu[ees] qu[if].

Origin and geographic distribution *Cinnamomum* comprises 150–250 species occurring in continental Asia, Malesia, Australia, the Pacific, and a few species in Central and South America. Within the Malesian area some 90 species have been recognized.

Cassia and cinnamon are among the oldest of spices, reportedly reaching ancient Egypt by the 17th Century B.C., but it seems likely that the barks entering the cinnamon trade over the course of time have been of different botanical origin. It seems probable that the Greek and Romans had both cinnamon and cassia, but the Arab traders shrouded the sources in mystery. Cinnamon and cassia were among the first spices sought after by most 15th and 16th Century European explorers.

- *C. burmanni* is distributed in Malesia. It is cultivated in Indonesia (Java, Sumatra) and the Philippines.
- *C. cassia* occurs in South China, Burma (Myanmar), Laos and Vietnam. It has been introduced into Indonesia, Sri Lanka, South America, the southern United States, and Hawaii. It is only commercially cultivated in China and Vietnam.
- *C. loureirii* occurs naturally in the mountains of Annam (Vietnam). In Vietnam it has also been taken into cultivation.

Uses Although Ceylon cinnamon (*C. verum*) is more widely used at the household level, the dried inner bark of the 3 types of cassia is similarly used for flavouring foods, domestically and industrially. The derived bark oil (prepared by distillation) or oleoresin (prepared by solvent extraction) are used to a much lesser extent. The preferred cassia type differs from country to country. Cassia bark oils are also used in soaps and perfumes. Chinese cassia is the source of (Chinese) cassia leaf oil (usually referred to as cassia oil), obtained by distilling twigs and leaves. It is used for similar purposes as cinnamon and cassia bark oils in perfumery and flavouring, but it is of special importance in cola-type drinks.

In the United States the regulatory status 'generally recognized as safe' has been accorded to Chinese cassia (GRAS 2289), its bark oil (GRAS 2258/2290) and its leaf oil (GRAS 2292). The same holds for Vietnamese cassia (GRAS 2289), its bark oil (GRAS 2290) and its leaf oil (GRAS 2292).

The dried immature fruits of *C. cassia* are known as cassia buds or 'bunga lawang' and are used as flavouring. They have a cinnamon-like odour and sweet pungent flavour, and are extensively used in sweet pickles. In traditional customs, a pair of cassia buds are part of a potion to be drunk by bride and groom.

Powdered cassia bark is listed in the British

Herbal Pharmacopoeia as a specific remedy for flatulent dyspepsia or colic with nausea. The barks of all 3 species are well-known folk medicines for a long list of ailments such as diarrhoea, gripe, malaria, coughs and chest complaints. In European phytomedicine, cassia oil (0.05–0.2 g daily intake) is used in teas and other galenicals for its antibacterial, carminative, and fungistatic properties, and also for loss of appetite and dyspeptic disturbances.

Cinnamomum timber or camphorwood is a lightweight to medium-weight hardwood used for decorative work, furniture, and is suitable for plywood manufacture. The heavier timber is used for construction under cover. The fragrant wood is very suitable for making moth-proof chests. *Cinnamomum* trees (in Indonesia *C. burmanni* in particular) are frequently planted as wayside and shade trees.

Production and international trade

- *C. burmanni*. Only the bark is economically important. Padang (West Sumatra) is an important production area. The harvested area in Indonesia in 1998 was estimated by FAO at 60 000 ha, with a production of 40 000 t. Indonesian cassia is an important export product from Indonesia: during the years 1991–1994 the United States imported annually about 13 000 t quills from Indonesia, valued at about US$ 23 million.
- *C. cassia*. Only the bark and the leaf oil are economically important. China (Kwangsi and Kwangtung Provinces) is the main producer and exporter of Chinese cassia. The harvested area in 1998 was estimated by FAO at 35 000 ha, with a production of 28 000 t. Exports of dry bark from China during the period 1966–1976 amounted to 1250–2500 t annually. In 1987–1993 the United States imported annually about 600 t of cassia bark and 340 t of cassia leaf oil. Given the considerable domestic consumption in China, the production of leaf oil must be in excess of 500 t. In 1991–1994 cassia leaf oil fetched a price of about US$ 30–35/kg.
- *C. loureirii*. Only the bark is economically important. Vietnam is the main producer of Vietnamese cassia. The harvested area in 1998 was estimated by FAO at 6100 ha with a total production of 3400 t. Exports of dry bark from Vietnam during the period 1966–1976 varied from 5–300 t.

Cassia bark oils and oleoresins are produced in the importing countries in small quantities. Leaf oil is mainly distilled in the producing countries.

Cinnamomum timber is traded in Malaysia in the trade group 'medang' together with other *Lauraceae* genera.

Properties All *Cinnamomum* are aromatic, the aromas depending on different substances and mixtures of them. Some are characterized by cinnamaldehyde, others by eugenol, safrole or camphor.

The dried inner bark of the 4 main species is very similar in composition. It contains a steam-volatile oil, fixed oil, tannin, resin, proteins, cellulose, pentosans, mucilage, starch, calcium oxalate and minerals. The characteristic odour and flavour properties are mainly determined by the constituents of the steam-volatile aromatic oils. Of the non-steam and less volatile constituents, only coumarin contributes substantially to the organoleptic properties.

- *C. burmanni*. The essential-oil content of the bark is 1–4%. The bark oil is a colourless to brownish-yellow liquid, mainly consisting of cinnamaldehyde, and lacking eugenol. The leaf oil also mainly consists of cinnamaldehyde, but the main constituent of the root bark oil is camphor.
- *C. cassia*. Bark oil and leaf oil of Chinese cassia have similar compositions. The essential-oil content of the bark is 1–4%. The bark oil consists of 70–95% cinnamaldehyde, with only traces of eugenol. The essential-oil yield from leaves and twigs is 0.3–0.8%. The leaf oil is a dark brown liquid, consisting of 70–95% (ISO: > 80%) cinnamaldehyde, with only traces of eugenol. Cassia buds contain 1.9% essential oil (about 80% aldehydes). A monograph on the physiological properties of Chinese cassia bark oil has been published by the Research Institute for Fragrance Materials (RIFM).

  The 1000-seed weight is 370–400 g.
- *C. loureirii*. The essential-oil content of the bark is 1–7%. The bark oil is a yellow-brown liquid, consisting mainly of cinnamaldehyde, with only traces of eugenol. The leaf oil is a pale brown liquid; the composition seems to be rather different from the bark oil. The root oil is a pale brown oil, mainly consisting of cinnamaldehyde.

Adulterations and substitutes In early times, cassia was usually described as a somewhat inferior substitute for true cinnamon, but it now has its own market with, for instance, the United States having a clear preference for cassia over cinnamon, and for Vietnamese cassia in particular. Nevertheless, cinnamon and cassia barks are interchangeable in many applications, and the same applies to cinnamon bark oil, cassia bark oils and (Chinese) cassia leaf oil.

Where cinnamaldehyde is the main constituent, adulteration with synthetic cinnamaldehyde is simple, and is mainly a function of the price of the natural product. Detection methods have much improved and therefore adulteration has become less common.
Methods of distinguishing cinnamon bark oil from cassia oils are based on the presence/absence of minor components such as ortho-methoxy cinnamaldehyde, eugenol and coumarin.

Description Evergreen or deciduous aromatic shrubs or trees up to 50 m tall; bole usually branchless for up to 30 m, up to 125 cm in diameter, buttresses short or absent; bark surface smooth, rarely fissured, lenticellate, grey-brown to reddish-brown, inner bark granular, pale brown to pink or reddish-brown, with a strong aromatic smell; sapwood whitish to pale yellow. Leaves usually opposite, subopposite, alternate or arranged spirally, simple and entire, with glandular dots and aromatic when crushed, 3-veined, rarely pinnately veined; stipules absent. Inflorescence consisting of axillary or terminal cymose panicles of clusters or umbellules of flowers; flowers bisexual, rarely unisexual (and then polygamous), trimerous; tepals 6, subequal, united into a tube at base, usually hairy; fertile stamens 9, rarely 6, in 3 whorls, stamens in the outer 2 whorls introrse, in the inner whorl extrorse and with a pair of stalked or sessile glands, anthers 4-celled, rarely 2-celled; a fourth (innermost) whorl consists of 3 staminodes with slender filaments and empty anthers; ovary superior, sessile, 1-celled, with a single, pendulous, anatropous ovule, style slender, with a discoid or obscurely 3-lobed stigma. Fruit a 1-seeded berry, globose or ovoid to cylindrical, the basal part surrounded by the enlarged and indurated perianth tube often carrying persistent perianth lobes; pedicel usually not enlarged. Seed without albumen, with a thin testa; cotyledons large, flat, convex and pressed against each other; embryo minute.

Cinnamomum burmanni (C. Nees & T. Nees) C. Nees ex Blume – 1, flowering branch; 2, flower; 3, stamen of 1st and 2nd whorl; 4, stamen of 3rd whorl with glands; 5, staminode of 4th whorl; 6, fruits.

- *C. burmanni*. Evergreen shrub or small tree, up to 15 m tall. Leaves subopposite; petiole 0.5–1 cm long; blade oblong-elliptical to lanceolate, 4–14 cm × 1.5–6 cm, pale red and finely hairy when young, when older glabrous and glossy green above, glaucous pruinose below. Inflorescence a short axillary raceme; pedicel 4–12 mm long; perianth 4–5 mm long, after anthesis the lobes tearing off transversely about halfway; stamens about 4 mm long, staminodes 2 mm. Berry ovoid, about 1 cm long.
- *C. cassia*. Evergreen tree up to 18 m tall, strongly aromatic in all its parts; bole up to 70 cm in diameter; bark thick, smooth in young trees, rough in mature trees, grey; twigs brown-hairy. Leaves alternate to nearly opposite; blade oblong-elliptical, 8–20 cm × 4–7.5 cm, dark shiny green. Inflorescence 7.5–18 cm long; pedicel 2–3 mm long; flowers small, about 3 mm long, pubescent, white or whitish yellow; perianth lobes after anthesis tearing off transversely at base. Fruit ovoid to ellipsoidal, 1–1.5 cm long, black to blackish-purple. Seed ovoid, 1 cm long, dark brown with paler stripes.
- *C. loureirii*. Evergreen tree up to 8–10 m tall, similar in shape to *C. cassia*. Leaves opposite or alternate; petiole 12–15 mm long; blade elliptical to oblong, 7.5–12.5 cm × 3–5 cm, acuminate, rigid, green to dull green. Flowers very small, yellow-white. Fruit and seed similar to but smaller than *C. cassia*.

Growth and development There is little specific information on the 3 cassia species. *Cinnamomum* trees generally produce moderately deep and extensive roots. Seedling growth is rapid, with formation of a well-developed taproot followed by numerous spreading laterals. There is normally a single central stem, but the true cinnamon and cassia species are relatively low-branching. Growth takes place in flushes, young leaves often being reddish in colour, later turning green. *Cinnamomum* is open-pollinated and various small insects (e.g. flies and beetles) are the main pollinating agents. The fruits are eaten by monkeys, squirrels, bats and birds, the latter being the main seed-dispersal agents.

Other botanical information Many South-East Asian *Cinnamomum* species are used as substitutes or adulterants for the true cinnamon and the 3 main cassias of commerce. Some are minor spices (see chapter on Minor spices), others have greater economic importance as timber: *Cinnamomum iners* Reinw. ex Blume, *C. javanicum* Blume, *C. mercadoi* S. Vidal, *C. mollissimum* Hook.f., *C. porrectum* (Roxb.) Kosterm., *C. scortechinii* Gamble, *C. sintoc* Blume, and *C. subavenium* Miq.
Substitutes and adulterants of local importance in southern Asia are:

- *Cinnamomum bejolghota* (Buch.-Ham.) Sweet (syn. *C. obtusifolium* (Roxb.) C. Nees), which occurs from northern India to Indo-China, southern China and the Andaman Islands.
- *Cinnamomum impressinervium* Meissner, which occurs in the Sikkim Himalaya (India).
- *Cinnamomum tamala* (Buch.-Ham.) T. Nees & Eberm., the Indian cassia, which is distributed in India, Bangladesh and Burma (Myanmar). In India it is cultivated for bark and leaves ('tejpat'). Tejpat leaves are extensively used as a spice in India, as well as in ayurvedic preparations.

Taxonomically, the genus *Cinnamomum* is still poorly known and the literature should be interpreted with great care, as the identity of given names is often obscure. *C. loureirii*, for example, is sometimes considered as restricted to Vietnam, sometimes as distributed also in Cambodia and Laos, sometimes as also occurring in the central and northern Himalayas, and sometimes it is also confused with *C. japonicum* Siebold (native to China, Korea, the Ryukyu Islands and Japan) and with *C. sieboldii* Meissner (native to the Ryukyu Islands and widely cultivated in Japan). A thorough revision of the entire genus is badly needed.

Ecology *Cinnamomum* are mostly tropical forest trees, adapted to a wide range of climatic conditions occurring between 30°N and 30°S. They tolerate short periods of waterlogging or drought. As forest trees they are partially shade tolerant, but mature trees grow well in full sunshine. They occur on well-drained, leached hillside soils of low fertility and strong acidity (pH 4–6).

- *C. burmanni*. Indonesian cassia occurs in Indonesia from sea-level to 2000 m altitude, but in the important production area of Padang it grows best between 500–1500 m, with an evenly distributed annual rainfall of 2000–2500 mm. Light, rich sandy loams yield the best bark.
- *C. cassia*. The main production areas in China are characterized by mean daily temperatures of about 22°C and an annual rainfall of 1250 mm in about 135 wet days. The absolute maximum temperature is about 38°C and the absolute minimum is 0°C. It is grown in southern China at altitudes up to 300 m.
- *C. loureirii*. The main production areas in Vietnam have an annual rainfall of 2500–3000 mm, and lateritic soils of old volcanic origin.

Propagation and planting In the case of propagation by seed, ripe fruits should be selected from mother trees producing thick bark of good aroma. They should be bagged against birds until they are harvested. Harvested fruits are left to ferment, to facilitate removal of the pericarp by washing. Seeds are only briefly viable, and are usually planted in shaded nurseries, preferably in fine sandy soil, and watered regularly.

- *C. burmanni* is usually grown from seed, but also from cuttings. Fresh seed germinates in 5–15 days. The nursery period is about 8–12 months. Transplanting should be done carefully, because damage to roots increases the incidence of stripe canker. Recommended field spacing is 2–4 m × 2–4 m.
- *C. cassia* is usually grown from seed, but sometimes also from cuttings. Seedlings are raised in nursery beds and transplanted when 1–2 years old. Cuttings are taken from flushes when the leaves are horizontal and of firm texture. One, two or multiple leaf cuttings may be used. Field spacing is 1 m × 1 m. A density of 10 000 trees/ha is also considered optimal for leaf-oil production.
- *C. loureirii* is usually raised from seed, sometimes also by cuttings, layers, or suckers. Seedlings are transplanted when about 1 m tall at the age of 1 year.

Field spacing is a compromise between high yield of thin bark (close spacing) or lower yield of thick, high-quality bark (wide spacing). The formation of a tall straight unbranched trunk should be encouraged.

In vitro production of active compounds Callus tissue and cell suspension cultures obtained from leaves of *C. cassia* show production of (–)-epicatechin, procyanidin B2, procyanidin B4 and procyanidin C1. These compounds are precursors of condensed tannins, which are assumed to be the main components responsible for the plant's medicinal effects. Cinnamaldehyde was not synthesized by the cell cultures.

Husbandry After-planting care mainly consists of weeding. Lower branches are removed by cutting off close to the trunk. Cassia plantations generally receive only organic wastes or mulches, but fertilizer recommendations would be similar to those for true cinnamon: phosphate in the planting holes, annual applications of a 2 : 1.5 : 1.5 mixture of urea, rock phosphate and potassium chloride (40–100 kg/ha, depending on the age of the trees), and a nitrogenous top dressing at the beginning of the rainy season for good tree growth and regrowth of coppiced trees. *Tephrosia candida* (Roxb.) DC. has reportedly been used successfully as an auxiliary crop (cover crop, green manure) in Sumatra, sown 6 months ahead of planting Indonesian cassia, and lasting for about 3 years.

Diseases and pests Many diseases and pests of *Cinnamomum verum* also occur on other *Cinnamomum*. Diseases may include stripe canker (*Phytophthora cinnamomi*), pink disease (*Corticium salmonicolor*, syn. *C. javanicum*), white rot (*Fomes lignosus*), rust (*Aecidium cinnamomi*) and anthracnose (*Glomerella cingulata*). A serious witches' broom disease has recently been found on Chinese cassia in Vietnam. Control with the natural antibiotic berberine has been successful.

Ceylon cinnamon pests, which have also been reported on other *Cinnamomum* are caterpillars of the cinnamon butterfly (*Chilasa clytia*), leafminers (*Acrocercops* spp.), caterpillars of a leafwebber (*Sorolopha archimedias*), and mole crickets (*Gryllotalpa* spp.) damaging young seedlings.

Harvesting Cassia trees are sometimes destructively harvested at the age of 10–15 years, but they coppice well and are now generally grown as a coppiced bush. This entails cutting the stems low down after an initial establishment period and harvesting the bushy regrowth at regular intervals thereafter.

- *C. burmanni*. Harvesting is still mainly by removing entire trees through thinning, gradually reducing the tree density. A stand may be first thinned in the third year to produce some inferior bark. The first proper harvest is done 2 years later, subsequent harvesting by thinning is carried out annually for about 15 years. Harvesting takes place at the beginning of the rainy season. The bark is removed from the lower part of the trunk in strips of 1 m × 5–10 cm. Then the tree is felled and the bark is stripped from the upper part of the trunk and larger branches. The stumps are sometimes allowed to regrow into a new stand with 1–2 shoots per stump.
- *C. cassia*. Trees are first coppiced when 5–7 years old and 1.5–2.5 m tall, the stem being 2.5–4 cm in diameter. Stems are cut a few cm above ground level and stripped of leaves and twigs, which may be used for distillation. The stumps regrow into a new stand. Subsequent harvests take place every 3–4 years, and plantation life is 40–60 years. Some trees are left uncut for the production of cassia buds or mature fruits. The cut stems are ringed at intervals of 30–60 cm (or cut into pieces), longitudinal splits are made and the bark taken off in two pieces. The bitter-tasting epidermis is removed by scraping.

  An improved management system has been developed in Hawaii for Chinese cassia leaf-oil production. Trees are not coppiced to near ground level, but are cut and trained into a vertical framework or hat-rack structure to obtain maximum leaf and twig production.
- *C. loureirii*. Harvesting is usually done when trees are 10–12 years old. Bark is removed from standing trees, sometimes with the help of a bamboo scaffolding. Horizontal cuts are made 40 cm apart, and vertical cuts 25–35 cm apart, yielding unrolled slabs. Finally, trees are felled and inferior bark harvested from smaller branches, yielding quills. Stumps are left for regrowth.

Yield Yield data on the 3 cassia species are very scarce. For *C. burmanni*, average-sized trees yield about 3 kg of stem bark and 1.5 kg of branch bark. In a crop cycle of 10 years, the total yield is about 2 t/ha of bark.

Handling after harvest Harvested bark is dried in the sun, making it curl into reddish-brown quills. Grading is mainly by type (scraped, unscraped, quills, quillings, featherings, chips), appearance (length, colour) and volatile-oil content. Sometimes the unrolled bark slabs may undergo complicated traditional methods of curing like alternate washing and drying, and some fermentation in heaps. Slabs are tied around thick bamboo for drying and for assuming a broadly curved appearance.

Grinding is usually carried out in the consuming countries. Ground cinnamon and cassias are often blended for specific purposes.

Genetic resources Since cassia products are now derived almost entirely from cultivated sources, the pressure on the wild resource has been reduced considerably, but germplasm collections are still badly needed. About 280 accessions of cinnamon germplasm are maintained by the Indian Institute of Spices Research (IISR), Calicut, India, consisting of cultivated types and a few wild and related species. The collection has been evaluated by quality parameters.

Breeding As propagation is mainly by seed, fruits should be collected from carefully selected mother trees, with a thick bark of good aroma.

Prospects The demand for the spices cinnamon and cassia has always been satisfactory, and the prospects are still promising, as the competition from synthetic alternatives does not noticeably affect the trade. Consumption is likely to be mainly a function of population growth. The prospects for the essential oils seem to be less bright, as there are many alternatives. However, the market for Chinese cassia leaf oil, for instance, is still expanding, due to the soft-drink market. The increasing number of reports in the scientific literature describing the oil characteristics of *Cinnamomum* is evidence of the attention the genus is receiving in screening programmes for sources of commercially valuable chemical isolates. In South-East Asia, the Forest Research Institute Malaysia (FRIM) is very active in identifying species with potential for providing raw materials for local industry and farm income.

Little attention has been paid to the production of *Cinnamomum* wood or camphorwood, as plantation trees are merely valued for spice or essential oil. However, the wood is suitable for special decorative purposes, and there may be scope for multipurpose plantations including timber production. More research is needed on the silvicultural management of camphorwood plantations.

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Nguyên Kim Dao, Tran Hop & J.S.Siemonsma

Cinnamomum verum J.S. Presl

Prir. rostlin 2: 36–44. t. 7 (1825).

LAURACEAE

$2n = 24$

Synonyms *Laurus cinnamomum* L. (1753), *Cinnamomum zeylanicum* Blume (1826).

Vernacular names Ceylon cinnamon, true cinnamon (En). Cannellier de Ceylon (Fr). Indonesia: kayu manis. Malaysia: kayu manis. Papua New Guinea: skin diwai. Philippines: cinnamon, kanela. Cambodia: che'k tum phka loëng. Vietnam: qu[ees] h[oof]i, qu[ees] r[af]nh, qu[ees] Srilanca.

Origin and geographic distribution Ceylon cinnamon occurs wild in south-west India, western Sri Lanka and the Tenasserim Hills of Burma (Myanmar). Cinnamon (and cassia) were among the first spices sought after by most 15th and 16th Century European explorers. The Portuguese, occupying Sri Lanka in 1536, and the Dutch, taking over in 1656, established virtual monopolies on the trade. From a product collected from wild stands, it became a cultivated crop in Sri Lanka around 1770. It was introduced into the Seychelles in 1771, where it easily naturalized and where a sizeable production developed. Cultivation in Java (Indonesia) began in 1825 but, after initial success, declined rapidly. Subsequently, Ceylon cinnamon has been taken to many countries. It is grown in southern India, the Seychelles and in Madagascar, but Sri Lanka continues to dominate the market.

Uses The spice (Ceylon) cinnamon is the dried inner bark of *C. verum*. The major uses of cinnamon, both in whole and ground form, are for domestic culinary purposes and for flavouring processed foods (bakery products, sauces, pickles, puddings, beverages, confectionery), in perfumes, pharmaceutical products and in incense. Cinnamon bark is an important folk medicine. Cinnamon bark is astringent, stimulant and carminative. It possesses the property of checking nausea and vomiting.

The bark can further be used for the distillation of bark oil and for the preparation of solvent-extracted oleoresin. The leaves are used for distillation of leaf oil, which has a different composition than bark oil.

The oleoresin is used mainly by the flavour industry in western Europe and North America for flavouring processed foods and in the soft-drink industry.

Cinnamon bark oil is used in flavouring (processed foods, beverages, dental and pharmaceutical preparations), much less in perfumery because it has some skin-sensitizing properties. As a powerful local stimulant it is sometimes prescribed in gastrodynia, flatulent colic and gastric debility. In European phytomedicine, cinnamon bark oil (0.05–0.2 g daily intake) is used in teas and other galenicals for its antibacterial, carminative, and fungistatic properties, and also for loss of appetite and dyspeptic disturbances. The maximum permitted level in food products is 0.06%.

Cinnamon leaf oil is used in flavouring and perfumery, and as a source of its major constituent eugenol. Eugenol is used for the synthesis of vanillin, and for conversion into iso-eugenol, used for flavouring confectionary products. Cinnamon leaf oil is extensively used as a fragrance component in soaps, detergents, cosmetic and alcoholic perfumery, with a maximum permitted level of 0.8% in the perfume.

In the United States the regulatory status 'generally recognized as safe' has been accorded to cinnamon (GRAS 2289), cinnamon bark oil (GRAS 2290/2291) and cinnamon leaf oil (GRAS 2292).

The seeds contain about 30% fixed oil, used in India for candle making. The oil is obtained by boiling crushed ripe fruits.

The timber is light to moderately heavy (specific gravity 0.5–0.7), usually straight-grained, even-textured, and weak. It seasons easily but warps, splits, cracks and stains. It is suitable only as low-grade board wood.

Production and international trade Sri Lanka produces the largest quantity and the best quality of bark of Ceylon cinnamon, mainly as quills. Total harvested areas in 1998 were estimated by FAO at 24 000 ha in Sri Lanka and 3400 ha in the Seychelles, producing respectively 12 000 t and 600 t. Exports are about 6000 t annually. Most cinnamon leaf oil also originates from these countries, whereas cinnamon bark oil and oleoresin are mainly prepared in the importing countries. From 1987–1992, Sri Lanka exported annually less than 3 t of bark oil, and about 115 t of leaf oil. The United States and western Europe are the main markets for these oils. Cinnamon bark oil is very expensive (1993: US$ 385/kg), reflecting the high raw material cost. Cinnamon leaf oil is much cheaper (1994: US$ 8.25/kg), but still more expensive than clove leaf oil (1994: US$ 2.70/kg), an alternative source of eugenol.

Properties The dried inner bark of Ceylon cinnamon contains a steam-volatile oil, fixed oil, tannin, resin, proteins, cellulose, pentosans, mucilage, starch, calcium oxalate and minerals. The organoleptic properties are determined by the steam-volatile oil and the trace amounts of coumarin (non-steam-volatile). The essential-oil content of the bark varies from 0.5–2.0%.

Cinnamon oleoresin is a deep reddish or greenish brown viscous liquid, and contains the steam-volatile oil (16–65%), fixed oil, and other components dependent on the solvent. Ceylon cinnamon bark yields 10–12% oleoresin with ethanol as solvent, compared with 2.5–4.3% with benzene.

It is phytochemically interesting that the same tree produces 3 quite distinct essential oils, characterized by eugenol in the leaves, cinnamaldehyde in stem bark, and camphor in root bark.

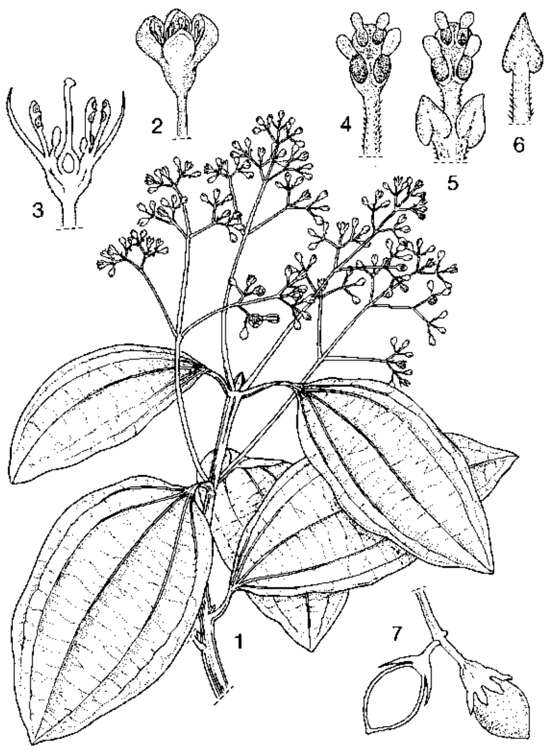
Cinnamon bark oil is a pale-yellow liquid. Apart from 50–75% cinnamaldehyde, the important components (> 1%) include eugenol (5–18%), cinnamyl acetate, linalool, 1,8-cineole, β-caryophyllene, and benzyl benzoate. The powerful characteristic note might be due to methyl-n-amylketone in combination with other aldehydes and ketones. Oil from bark chips is richer in eugenol (30–38%) and poorer in cinnamaldehyde (44%). Cinnamaldehyde is anesthetic, antipyretic, hypotensive, hypothermic and sedative.

Cinnamon leaves contain 0.7–1.2% essential oil. The leaf oil is yellow to brownish-yellow in colour. In composition it is more like clove oil. Apart from 70–95% eugenol (ISO: 75–85% phenols), important components (> 1%) include cinnamaldehyde (ISO: < 5%), benzyl benzoate, linalool, and β-caryophyllene. Cinnamon leaf oil is of special in-

terest for its antioxidant and antibacterial properties. Eugenol is strongly antiseptic.
Cinnamon root bark contains 1–2.8 % of a colourless to pale yellowish-brown oil, which has no commercial importance. The major component is camphor (60%), which crystallizes on standing.
Monographs on the physiological properties of cinnamon bark oil and cinnamon leaf oil have been published by the Research Institute for Fragrance Materials (RIFM).

Adulterations and substitutes Cinnamon and cassia barks are interchangeable in many applications, and the same applies to cinnamon bark oil, cassia bark oils and (Chinese) cassia leaf oil. Adulteration with synthetic cinnamaldehyde is simple and mainly a function of the price of the natural product. However, detection methods have much improved, and adulteration is becoming less common.
As a source of eugenol, cinnamon leaf oil has lost ground to the cheaper clove leaf oil, except when the eugenol is needed for conversion into isoeugenol (used in confectionary products).

Description Evergreen tree up to 18 m tall; bole low-branching, up to 60 cm in diameter; buttresses 60 cm tall, 70 cm deep, thin, light pinkish-brown; bark about 10 mm thick, strongly aromatic; the bark on young shoots is smooth and pale brown, on mature branches and stems rough, dark brown or brownish-grey; oil cells are located in the phloem, and are oval or round in cross-section; wood of mature trees varies from light brownish-grey to grey or yellowish-brown, without markings, more or less lustrous and faintly scented. Leaves opposite, somewhat variable in form and size, strongly aromatic; petiole 1–2 cm long, grooved on upper surface; blade ovate to elliptical, 5–25 cm × 3–10 cm, conspicously 3-veined, or 5-veined, base rounded, apex acuminate, glabrous, coriaceceous, shiny dark green. Inflorescence consisting of lax axillary or terminal panicles up to 10 cm long or longer; peduncle creamy white, softly hairy, 5–7 cm long; flowers small, 3 mm in diameter, with foetid smell, pale yellow, subtended by small ovate hairy bract; perianth 8 mm long, silky hairy, with short campanulate tube and 6 persistent tepals about 3 mm long; fertile stamens 9, in 3 whorls, with 2 small glands at the base of the stamens of the 3rd whorl; a fourth innermost whorl consists of 3 staminodes; filaments hairy, stout; anthers 4- or 2-celled; ovary superior, 1-celled, with a single ovule, style short. Fruit a 1-seeded berry, ellipsoidal to ovoid, 1–2 cm long, black when ripe, surrounded by the enlarged perianth at the base.



Cinnamomum verum J.S. Presl – 1, flowering branch; 2, flower; 3, schematic longitudinal section through flower; 4, stamen of the 1st and 2nd whorl; 5, stamen of the 3rd whorl with glands; 6, staminode of the 4th whorl; 7, fruit and schematic longitudinal section through fruit.

Growth and development Ceylon cinnamon produces moderately deep and extensive roots. Seedling root growth is initially rapid, with formation of a well-developed taproot followed by numerous spreading laterals. There is normally a single central stem, but in cultivation trees are coppiced. The uncut tree has numerous, often drooping, branches beginning low on the trunk. Growth takes place in flushes, young leaves being reddish in colour, later turning dark green. Pollination is most probably by insects, especially flies. Fruits mature in 6 months.

Other botanical information In Sri Lanka several wild and semi-wild types and local cultivars are recognized, with distinctive local names. Distinction is mainly based on aroma and therefore location-specific.

Ecology Ceylon cinnamon requires a warm and per-humid climate with a well-distributed annual rainfall of 2000–2500 mm, and average temperatures of about 27°C. It grows best at low altitudes, and is usually grown without shade, but being essentially a forest tree, light shade does no harm. The type of soil has a pronounced effect on bark quality. Fine sandy and lateritic gravelly soils rather than rocky and stony substrates are best in Sri Lanka and India, but in the Seychelles and Madagascar more loamy soils are preferred. Ceylon cinnamon is considered susceptible to salinity. A bitter product results from waterlogged and marshy conditions.

Propagation and planting Propagation is by seed or by vegetative means. Fruits are much liked by birds and the seed is easily spread, so the fruits have to be bagged for collection. Fruit pulp is allowed to rot before seeds are removed, washed and dried. Seeds quickly lose their viability. Fresh seeds germinate in 20–25 days. They are sown in nurseries or directly in the field. The nursery bed (1 m wide) should have a well-prepared rich sandy soil and be lightly shaded. Seeds are sown close together. Clumps of seedlings are transferred into bags after 4 months in the nursery and transplanted to the field after another 4–5 months. Five or more seedlings are always planted closely together in a small circle, developing into an indiscriminate clump.

Vegetative propagation is by cuttings, layering or division of old rootstocks. Young cuttings with 2–3 nodes are planted in polybags and placed under polythene cover; they are ready for field planting after 12–18 months. Old rootstocks can be divided. For this, old plants are cut down to within 15 cm of the ground, and suitable parts of the rootstock planted out with adhering soil. Harvesting can start 1–1.5 years after planting out in the field compared with 3 years for seedlings. Modern micropropagation methods have also been successfully applied to produce large numbers of plantlets.

Field spacings of 0.9–1.2 m × 0.9–1.2 m are recommended in Sri Lanka for commercial plantations, but wider planting up to 3 m × 3 m is also practised with a higher number of plants per clump.

Husbandry After-planting care mainly consists of weeding, 2–4 times a year. Stems are kept straight by pruning. Manure or plant residues are commonly applied as fertilizer, but chemical fertilizers, although recommended, are little used. Placing phosphate in the planting holes is advantageous, single superphosphate being preferable because of the small amounts of sulphur it contains. Annual application of a 2 : 1.5 : 1.5 mixture of urea, rock phosphate and potassium chloride is recommended at a rate of 40–60 kg/ha to young trees, and 100 kg/ha to mature trees. A nitrogenous top dressing at the beginning of the rainy season is advisable for quick (re)growth of (coppiced) trees. It is advisable to return processing residues to the field as mulch. Plants are coppiced for the first time after 2 years, the stem being cut to within 10–15 cm from the ground and covered with earth, allowing 4–6 shoots per stool to grow for a further 2 years before harvesting. After harvesting, all unwanted shoots and stumps are cut off the stool, which is then covered with earth, and new shoots are allowed to grow. The number of shoots per stool normally increases to a maximum at 8 years and declines after 10–12 years. A cinnamon plantation can remain profitable for 15–45 years, mainly depending on the standard of management.

Diseases and pests Stripe canker (*Phytophthora cinnamomi*) may damage trunks and branches of young trees in particular. Symptoms are vertical strips of dead bark, particularly near ground level. Root rots include black rot caused by *Rosellinia* spp., brown rot by *Phellinus lamaensis*, and white rot by *Fomes lignosus*. Pink disease (*Corticium salmonicolor*, syn. *C. javanicum*) causes pink encrustations on the stem with death of small shoots. *Glomerella cingulata* causes anthracnose. Rust (*Aecidium cinnamomi*) and other leaf and stem diseases (*Cephaleuros virescens*, *Diplodia* spp., *Exobasidium* spp., *Gloeosporium* spp., *Leptosphaeria* spp., *Pestalotia cinnamomi*) may occasionally cause damage.

In India and Sri Lanka, caterpillars of the cinnamon butterfly (*Chilasa clytia*) are destructive to new flushes, and shothole borers (*Xylosandrus* spp.) cause damage to stem and bark. Leaf miners (*Acrocercops* spp., *Phyllocnistis chrysophthalma*), gall and leaf mites (*Eriophyes bois*, *E. doctersi*, *Typhlodromus* spp.), leaf webbers (*Sorolopha archimedias*) and arboreal ants (*Oecophylla smaragdina*) cause occasional damage. Young seedlings are vulnerable to damage by agrotid larvae or mole crickets (*Gryllotalpa* spp.), and larvae of *Popillia* spp., attacking roots. Ceylon cinnamon is also attacked by root-knot nematodes (*Meloidogyne* spp.). Storage pests of cinnamon quills include *Lasioderma serricorne*, *Pyralis farinalis* and *Sitodrepa panicea*.

Harvesting Ceylon cinnamon has to be harvested during the wet season because then the cambium is active and the cortex can be easily separated from the wood. The shoots are harvested when they are 2–3 m tall and 1.2–5.0 cm in diameter. Shoots in the centre of the clump are cut low down, while those on the outside are cut higher up to ensure that new buds sprout mainly on the outside of the clump. In Sri Lanka harvest peaks are in May–June and October–November. The first harvest is of inferior quality (thick bark), but this improves in later harvests. Best quality cinnamon is obtained from thin bark from the middle part of shoots in the centre of the stool. Leaves and twigs are cut off and used for mulching, or the leaves are retained for distillation. The harvested shoots are bundled and taken to a processing unit for peeling and further preparation.

Yield The first crop, 3–4 years after planting, yields 50–120 kg/ha of quills, increasing in subsequent crops to 175–250 kg/ha, before yields decline after 10–12 years. Commercial cinnamon bark is not more than 0.5 cm thick and is of a dull pale brown colour. The inner surface is somewhat darker than the outer one and is finely striated longitudinally. By-products of the production of quills are cinnamon chips (averaging 60 kg/ha) and leaves (2.5 t/ha fresh weight). Large individual trees may yield up to 45 kg of dry bark. Average annual bark yields of 120 kg/ha have been reported for the Seychelles, and an annual yield of fresh leaves of about 1.9 t/ha, yielding 0.6–0.8% leaf oil (11–16 kg/ha). Leaf-oil yields of 35–40 kg/ha have also been reported.

Handling after harvest Peeling consists of stripping the bark for the preparation of quills from the inner bark. The outer bark is first removed and the stem then rubbed to loosen the inner bark. Two horizontal cuts are made 30 cm apart and two longitudinal slits on opposite sides of the shoot. The inner bark is then separated from the wood. Alternatively, the outer and inner bark are separated from the wood together. The strips are packed together, wrapped and left overnight for slight fermentation, facilitating the subsequent scraping off of the outer bark (epidermis, cork and green cortex). The curled pieces are assembled into compound quills of 1 m length by joining the best and longest quills on the outside and smaller pieces inside the longer ones. They are dried in the shade until they are yellowish-brown. They are sometimes bleached by sulphur treatment. The grading of Ceylon cinnamon is rather elaborate compared with the grading of cinnamon from other sources. The various forms and qualities are known as unscraped bark, scraped bark, compound quills, simple quills, quillings (broken pieces of quills), featherings (bark of twigs and twisted shoots) and chips (trimmings, shavings). Quills are further graded according to the thickness of the bark. Grinding usually takes place in the consuming countries.

Bark to be distilled for oil should not be allowed to become damp, as this encourages mould or fermentation, which affects oil composition. Bark oil is obtained by steam or hydro-distillation with cohobation, or solvent extraction of the distillate. Solvent extraction of the distillate gives the finest quality oil.

Leaves stripped from shoots, together with small leafy twigs and stems are left in the field for 3–4 days and then transported to the distillery.

Root bark oil is only produced when a plantation is uprooted for replanting. Roots are cleaned, trimmed and peeled prior to distilling.

Genetic resources and breeding There are no germplasm collections of *C. verum*. Little improvement work has been done. Since *Cinnamomum* is open-pollinated, selection, together with vegetative propagation of clonal material would be advantageous. Some selection for superior strains is carried out in Sri Lanka and the Seychelles.

Prospects The demand for the spice cinnamon (and cassia) has always been satisfactory, and the prospects are still promising, as the competition from synthetic alternatives does not noticeably affect the trade. Consumption is likely to be mainly a function of population growth. The prospects for the essential oils seem to be less bright, as there are many alternatives.

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Kingdom. pp. 180–195.

M. Flach & J.S. Siemonsma

Coriandrum sativum L.

Sp. pl.: 256 (1753).
UMBELLIFERAE
$2n = 22$

Synonyms *Coriandrum majus* Gouan (1762), *C. diversifolium* Gilib. (1782), *C. testiculatum* Lour. (1790), non L. (1753), *C. globosum* Salisb. (1796).

Vernacular names Coriander, Chinese parsley (En). Coriandre, persil arabe (Fr). Indonesia: ketumbar (general), tumbar (Javanese), katuncar (Sundanese). Malaysia: ketumbar, penjilang, wansui. Philippines: kulantro, uan-soi (Tagalog), kulantra (Bicol). Cambodia: vannsuy. Laos: phak ho:m pa:nx, phak ho:m po:mz. Thailand: phakchi (central), phakhom (northern), phakhom-noi (northeastern). Vietnam: rau m[uf]i, ng[of] ta, rau ng[of].
Note: The name 'cilantro', often used in the United States for coriander leaves, refers also to sawtooth coriander (*Eryngium foetidum* L.).

Origin and geographic distribution Coriander has its origin in the Near East. It is only known in cultivation; escapes from cultivation may become weeds. The oldest archaeological remains of coriander, dated at 6000 BC, have been found in Israel. The crop has since spread throughout the world, and different morphotypes have developed. Coriander reached South-East Asia from two directions: forms with ovoid fruits were introduced from India, while forms with small, globular fruits arrived later (after 400 AD) from China. Forms with large, globular fruits have only recently been introduced from Mediterranean or European countries.
In all South-East Asian countries coriander is grown as a culinary herb and vegetable. Cropping for its fruits is restricted to higher altitudes. In South-East Asia, as in many other parts of the world, coriander is usually grown as a small-scale horticultural crop. Large-scale production exists in southern Russia, the Ukraine and other East European countries.

Uses Coriander fruits are commonly used as a spice, being part of a large number of dishes. Ground coriander fruits are also an ingredient of spice mixtures like curry powder (containing up to 40% of coriander). In South-East Asia the leaves or the entire young plants are popular as culinary herb and vegetable, e.g. for chutneys or in soups. Taproots are also aromatic and are commonly used as a vegetable in China, Thailand and, to a lesser extent, in other South-East Asian countries. Green plants are dried for preservation and are traded on the world market as well as the fruits.
Coriander is used in folk medicine. It has been well known since antiquity. Green plants are applied in East Asia as a cure for measles. The fruits are reported to have carminative, diuretic, tonic, stomachic, antibilious, refrigerant, anticatarrhal, antispasmodic, galactagogue, emmenagogue and aphrodisiac effects. The essential oil from the fruits is used in the flavour industry, for various basic and luxury foods, to some extent in medicine too, and in cosmetic perfumery. The extraction residues are used as feed for ruminants. In the United States the regulatory status 'generally recognized as safe' has been accorded to coriander fruits (GRAS 2333) and coriander fruit oil (GRAS 2334).

Production and international trade Although coriander is cultivated and consumed all over the world, it is difficult to obtain reliable information on production and trade. The worldwide annual area of coriander is estimated at 550 000 ha, yielding about 600 000 t of coriander fruits. Most of the crop is used as a spice, but about 10% is raw material for the distillation of essential oil, 100 t of which is traded every year. The industrial extraction of the essential oil is not practised in South-East Asia, but is important in East Europe and several industrialized countries. The main producers of fruits are the Ukraine, Russia, India, Morocco, Argentina, Mexico and Romania. The main importers of coriander fruits are Sri Lanka, the United States, the United Kingdom, the Netherlands, Germany and Japan. The largest markets in South-East Asia are Singapore (import/export) and Malaysia. In 1992, Indonesia imported about 7100 t of coriander seeds with a value of US$ 3 million.
The area dedicated to coriander as a fresh culinary herb may be estimated at 20 000 ha, but this figure should be viewed with some caution, since production is mostly for household consumption or local markets. Recently a market for dried coriander leaves has emerged in some industrialized countries (e.g. the United States import these from Mexico).

Properties Per 100 g, air-dried fruits of coriander contain approximately: water 11 g, crude protein 11 g, fatty oil 19 g, carbohydrates 22.9 g (starch 11 g, pentosans 10 g, sugar 1.9 g), crude fibre 28 g, mineral constituents 5 g and essential oil

1.0 g. The essential-oil content varies between almost zero and 2%; small-fruited types have the highest content. The oil consists of several monoterpenoids. The main component (usually making up more than 60% of the essential oil) is always linalool. Other components, none of which accounts for even as much as 10% of the essential oil, are α-pinene, γ-terpinene, geranyl acetate, camphor and geraniol.

The composition of the monoterpenoids is largely genetically determined, and this chemical feature supports an infraspecific classification mainly based on morphological characters. Coriander originating from the Indian subcontinent (Indicum group or subsp. *indicum* Stolet.) has ovoid fruits, with a low content of essential oil containing little or no camphor, myrcene and limonene, but much linalool. In spite of the relatively low content of essential oil, this coriander is sometimes preferred because of its specific flavouring quality. Medium or large globose fruits with low or medium contents of essential oil (Sativum group or subsp. *sativum*) are characteristic of the coriander forms that developed in the Near East, northern Africa, the Mediterranean, Europe and the New World. Coriander with small, globose fruits (Microcarpum group or subsp. *microcarpum* DC.) developed mainly in the Caucasus and Central Asia and includes forms with the highest essential-oil content, always containing camphor, myrcene and limonene.

The content and composition of fatty oils in the endosperm of ripe fruits varies between 12–25% and is much more dependent on environmental conditions. The major fatty acid (more than 60%) is petroselinic acid (C18:1(6C)), which is an isomer of the oleic acid (C18:1(9C)) that is also present. Other components of the fatty oils are linoleic acid, palmitic acid, stearic acid, vaccenic acid and myristic acid. The high content of petroselinic acid gives the oil physico-chemical properties suitable for special technical purposes.

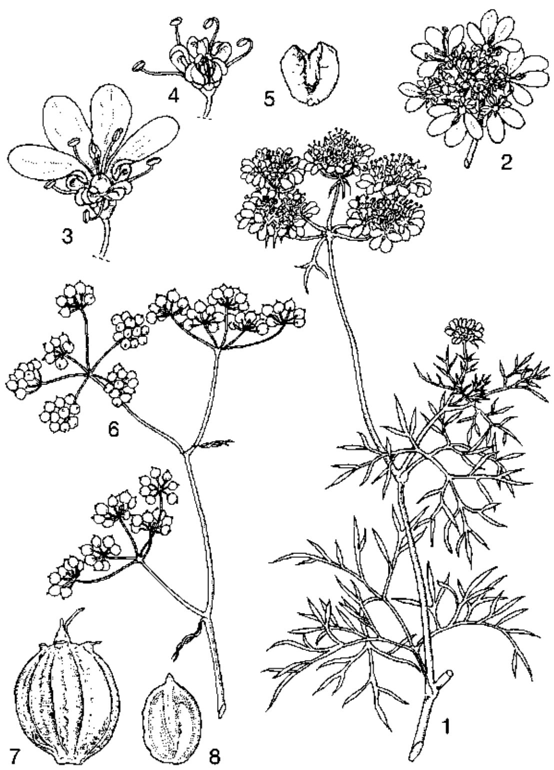
The use of coriander as culinary herb is based on volatile compounds with a bug-like odour contained in the roots, stems and leaves. Per 1 g fresh leaves about 4 mg of essential oil is present. About 41 volatile components have been detected in this foliar essential oil including alkenals in the C_9–C_{16} range, C_7–C_{17} alkanals, C_{10}–C_{12} primary alkenols, alkanols, and nonane. The aldehydes make up more than 80% of these volatile compounds. Furthermore, the green herb's notable content of provitamin A (up to 12 mg/100 g), vitamin B2 (up to 60 mg/100 g) and vitamin C (up to 250 mg/100 g) is worth mentioning.

A monograph on the physiological properties of coriander fruit oil has been published by the Research Institute for Fragrance Materials (RIFM).

The 1000-seed weight is 7–17 g.

Adulterations and substitutes The commercial essential oil is sometimes adulterated with sweet-orange oil, cedar-wood oil, turpentine and anethole or anise-fruit oil. The high esteem for the aromatic taste of green coriander is illustrated by the use of two other species as a substitute: *Eryngium foetidum* L. (*Umbelliferae*), known as sawtooth coriander and also as 'Mexican coriander', and *Persicaria odorata* (Lour.) Soják (*Polygonaceae*), known as 'Vietnamese coriander'.

Description Erect, annual, glabrous, usually profusely branching herb, up to 1.30 m tall with a well-developed taproot. Stem solid, subterete, up to 2 cm in diameter, older internodes sometimes becoming hollow, sulcate, mostly with a white bloom, light green with darker green ribs, sometimes with some violet. Leaves alternate, rather



Coriandrum sativum L. – 1, flowering branch; 2, umbellet; 3, peripheral flower with enlarged petals; 4, central flower; 5, normal (non-enlarged) petal; 6, fruiting branch; 7, fruit; 8, seed.

variable in shape, size and number, with a yellow-green, scariously margined sheath surrounding the supporting stem for up to three quarters of its circumference; petiole and rachis subterete, sulcate, light green; blade white waxy, shiny green often with darker green veins; basal 1–3 leaves usually simple, withering early, often in a rosette, blade ovate in outline, deeply cleft or parted into usually 3 incised-dentate lobes; next leaves decompound, petiole 0–15 cm long, blade ovate or elliptical in outline, up to 30 cm × 15 cm, usually pinnately divided into 3–11 leaflets, each like the blade of the simple lower leaves or again pinnately divided into 3–7 simple leaf-like lobes; all higher leaves compound, petiole restricted to the sheath, blade divided into 3 leaflets of which the central one is largest, each often variously divided into ultimately sublinear, entire, acute lobes. Inflorescence an indeterminate, compound umbel; peduncle up to 15 cm long; bracts sublinear, 0–2, up to 11 mm long; primary rays 2–8, up to 4.5 cm long; bracteoles 0–6, linear, up to 1 cm long; secondary rays up to 20, up to 5 mm long; usually each umbellet has bisexual peripheral flowers, and the central flowers are sometimes male; calyx in all flowers represented by 5 small lobes; corolla with 5 white or pale pink petals, heart-shaped, very small (1 mm × 1 mm) in male flowers, in bisexual peripheral flowers usually 3 petals are larger: 1 petal develops 2 ovate lobes of about 3 mm × 2 mm and the 2 adjacent petals develop each one lobe; stamens 5, filaments up to 2.5 mm long, white; pistil rudimentary in male flowers, in bisexual flowers with inferior ovary, a conical stylopodium bearing 2 diverging styles up to 2 mm long, each one ending in a minutely papillate stigma. Fruit an ovoid to globose schizocarp, up to 5 mm in diameter, yellow-brown with 10 straight longitudinal ribs alternating with 10 wavy longitudinal ridges, often crowned by the dry persistent calyx lobes and the stylopodium with styles; fruit does usually not split at maturity; it contains 2 mericarps which each bear on their concave side 2 longitudinal, rather wide lines (vittae), containing essential oil. Seed 1 per mericarp, with testa attached to the fruit wall. Seedling with epigeal germination; taproot thin with many lateral roots; hypocotyl up to 2.5 cm long; cotyledons opposite, oblanceolate, up to 3 cm × 4 mm, pale green.

Growth and development Some genotypes of coriander form several basal leaves, others start stem elongation immediately or after the second leaf. Flowering is protandrous and starts in the primary umbel, about 50–90 days after sowing. The peripheric florets of the umbellets are the first to flower. Coriander is cross-fertilized by insects for 50–60%; the stigma remains receptive for 5 days, pollen is fertile for 24 hours only; stamens emerge one by one. The length of the flowering period depends on the number of branches and the weather conditions, and extends up to 30 days. Thus, maturation of the umbels of different order is a successive process, and ripe fruits of the primary umbel may shatter before those of umbels of a higher degree have reached full maturity. Coriander seeds reach physiological maturity 6–7 weeks after anthesis. During ripening the aldehydic components of the essential oil disappear, and the odour of the fruits changes notably. This process continues after harvest of the fruits and is accelerated by high temperatures combined with dry weather. The time from sowing to harvesting depends very much on the genotype, and is usually between 90 and 140 days. However, since young coriander of some genotypes is frost resistant it can be cultivated as a cold-season crop over a much longer period.

Other botanical information Coriander is a very variable species, and the botanical literature contains several subclassifications into subspecies, varieties and forms. As coriander is only known from cultivation, however, the most appropriate classification would be into cultivar groups. Unfortunately, no such classification exists.

The fruit size, which is correlating with fruit weight, has proved to be a very useful trait to distinguish the two main groups (Sativum and Microcarpum), which also differ by other characters such as length of vegetation period, plant height, branching, vegetative productivity and leaf characters. Recent investigations showed that the shape of the fruit is also important, and a third group (Indicum) with ovate fruits has been described. These three main groups also differ in content and composition of the essential oil of the fruit. A further distinction into 9 ecogeographical types (European, North African, Caucasian, Central Asian, Syrian, Ethiopian, Indian, Bhutanic and Omanic) within the 3 groups is possible, which reflects very well the evolutionary pathway of the species. Chemotaxonomical investigations support such infraspecific classification.

Ecology Germination of coriander occurs at temperatures above 4°C, but is optimal at 17–20°C for genotypes with small fruits and at 22–27°C for genotypes with larger fruits. Sowing is therefore possible at any time, provided that the water supply during the juvenile period is sufficient. After stem elongation coriander is sensitive to low temperatures but resistant to drought. Long days accelerate the generative development of coriander, but the effect is only minor. For successful fruit production the temperature sum during the vegetative period should be more than 1700°C and only high temperatures together with dry weather during ripening guarantee fruits of acceptable quality. Coriander for fruit production is found in tropical highlands, subtropics and temperate regions, while in the lowland tropics it is grown as a green herb. The soil should preferably be at least a sandy loam, but the crop will also grow well on loam and clay soils with good drainage. Sole cropping and intercropping, e.g. with legumes, are practised.

Propagation and planting Coriander is propagated by seed. A heat treatment of the fruits after harvest or before sowing, either artificially or by exposure to the sun, will promote physiological ripening and break dormancy. Before sowing the fruits are sometimes split into mericarps, which enhances the germination rate and allows better distribution of the plants. For fruit production plant density should be 15–40 for small-seeded coriander, 75 plants per m^2 for large-seeded coriander, and even higher for the production of the green herb. In South-East Asia, the cultivation of coriander is limited to smallholders.

In vitro production of active compounds In vitro culture of the callus derived from the root of coriander has been shown to contain geraniol; none of the other flavouring principles associated with the spice could be detected.

Husbandry Weeding is carried out twice; the first weeding in the young crop is particularly important. When fruit production is the aim and heavy branching is developing, thinning is sometimes practised. Coriander is usually grown as a rain-fed crop, sometimes irrigation is applied during establishment. Phosphorus and potassium are often limiting nutrients, while the demand for nitrogen is not very high.

Diseases and pests Seed-borne bacterial diseases can cause considerable losses, e.g. *Pseudomonas syringae* pv. *coriandricola*. Heat treatment or chemical disinfection of fruits is possible. Fungal diseases (*Fusarium* sp., *Ramularia* sp.) can be avoided by treating the fruits with a fungicide before sowing. In India, fruit damage is reported to be caused by the chalcid fly *Systole albipennis*. Pests like the biscuit beetle (*Stegobium paniceum*) may damage stored fruits.

Harvesting For use as a green herb the entire, young plants are usually uprooted about 60 days after sowing. In the large-scale production of leaves in southern Russia, several cuts are possible if suitable genotypes are used. It is also possible to combine the harvest of fruits with some earlier cuts of leaves. For harvesting fruits, entire plants are uprooted or cut at the base when the fruits of the primary umbel are ripe and shatter when touched.

Due to the non-simultaneous ripening of the umbels of different order, plants are gathered in sheaves for further ripening and drying in the field. Threshing has to be done carefully, so that fruits do not split.

Yield For use as a culinary herb fresh coriander yields of 24 t/ha have been reported. The yield of fruits can exceed 4 t/ha. Rainfed crops usually produce 400–700 kg/ha of fruits, irrigated crops usually 2 t/ha.

Handling after harvest Split fruits are usually not accepted on the world market for medicinal purposes. Thoroughly dried fruits, stored under dry conditions, will maintain the essential oil for several years without loss. Once the fruits have been crushed, the essential oil will quickly disappear.

Genetic resources Large collections of coriander germplasm exist in Russia, Germany and the United States. These cover a large part of the variation of *Coriandrum sativum*. Nevertheless, there are still geographical gaps in the collections, notably in local cultivars from the Middle East and from South-East Asia. Several local cultivars are at risk of genetic erosion.

Species of the tribe *Coriandreae* are potentially interesting genetic resources but, with the exception of the genus *Bifora* F. Hoffm., they are not represented in the collections. This even applies to the closest relative, *Coriandrum tordylium* (Fenzl.) Bornm. from the Near East.

Breeding Considerable breeding has been conducted in East European countries and India. Coriander is a facultative cross-pollinator, with geitonogamy as the predominant mode of pollination. Many insects, including honey-bees, are involved in transferring the pollen. The main breeding objectives are high content of essential oil and disease resistance. In India, breeding has also focused on resistance to some pests. Hybridization with other species of the tribe *Coriandreae* (e.g. *Bifora* spp.) has so far not been successful.

Prospects It is expected that the market for coriander as a culinary herb will increase in industrialized countries. However, the quality parameters for this use are still unknown, and the agronomic requirements have still to be established. At present, linalool derived from petrochemicals is cheaper than linalool distilled from coriander fruits, but consumer preference for the special qualities of natural flavours may bring about a shift in demand.

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A. Diederichsen & Rugayah

Cuminum cyminum L.

Sp. pl.: 254 (1753); Gen. pl., ed. 5: 121 (1754).
UMBELLIFERAE
$2n = 14$

Synonyms *Ligusticum cuminum* (L.) Crantz (1767), *Cuminum odorum* Salisb. (1796).

Vernacular names Cumin, Roman caraway (En). Cumin, faux anis, faux aneth (Fr). Indonesia: jinten putih (Javanese), jinten bodas (Sundanese), jinten poteh (Madurese). Malaysia: jintan puteh. Burma (Myanmar): ziya. Cambodia: ma chin. Laos: th'ien kha:w. Thailand: thian-khao, yira.

Origin and geographic distribution The origin of cumin is not known exactly but is thought to be in the area extending from the south-eastern Mediterranean to central Asia (formerly Turkestan). Cumin has been known since antiquity. Its cultivation is currently most important in China, India, Morocco, Cyprus, Egypt, Turkey, Iran and southern Russia. In other parts of the world, cultivation is only occasional; in South-East Asia, only in mountainous areas (e.g. in Indonesia).

Uses Cumin fruits were highly prized in ancient civilizations as one of the best appetizers of all culinary spices. Today cumin has lost this prominent place in Europe except in some Dutch and French cheeses. However, the fruits are still used worldwide to flavour soups, rice, meat dishes, stews, cheese, bread, pickles, salad dressings, sausages, chutneys and sauerkraut. Only small quantities are needed to impart its taste to food. Ground fruits are an essential ingredient of curry and chili powder, especially in India, Egypt and Turkey. The essential oil distilled from the fruit is used as a condiment in various food products, but also in liqueurs and perfumes. In the United States cumin oil has the regulatory status 'generally recognized as safe' (GRAS 2340/2343). The maximum permitted level in food products is 0.025%.

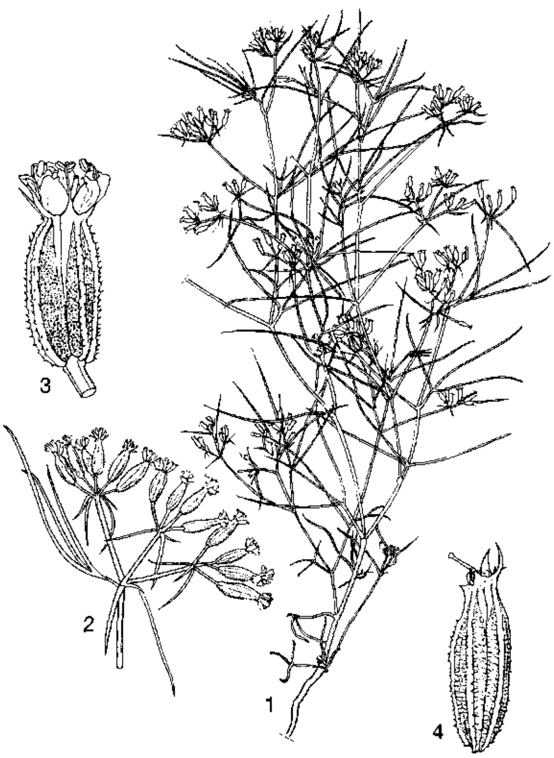
In traditional medicine the fruits are used (always in mixtures with other ingredients) as a stimulant, stomachic and astringent and to treat digestive and intestinal upsets such as diarrhoea and colic. In Peninsular Malaysia cumin is often pounded together with a variety of leaves and applied in poultices to treat a variety of diseases, although it is not obvious what good it does. The essential oil is used as stimulant, antispasmodic, carminative, diuretic, aphrodisiac, emmenagogue, and has a light anaesthetizing action. It is also used as a fungicide, insecticide and as a veterinary medicine. In Ethiopia pounded leaves are applied to the skin to treat skin disorders.

Production and international trade Annual world production of cumin fruits is estimated at 50 000 t but statistics are rare. Cumin is mainly produced by smallholders (e.g. in India, 60 000 ha). Iran, Pakistan and Turkey are the major exporters. In the early 1990s the United States imported annually about 6000 t, with a total value of about US$ 12 million. In 1993 the world production of cumin essential oil was valued at about US$ 1 million for 15 t.

Properties A fruit sample from Ethiopia was reported to have the following approximate composition per 100 g: water 7 g, protein 18 g, fat 4 g, carbohydrates 29 g, fibre 17 g, ash 6 g (Ca 605 mg, P 570 mg, Fe 175 mg), niacin 8 mg, ascorbic acid 3 mg, foreign matter (sand, etc.) 17 g. Dried cumin fruits contain 2.5–5% essential oil, usually obtained by steam distillation although hydrodiffusion gives the largest amounts. The oil is colourless at first, turning bright yellow later. Its approximate composition is: alcohols 2–5%, aldehydes and ketones 50–70%, ethers less than 1%, hydrocarbons 30–50%. Cuminaldehyde is the most important constituent, its presence varying between 20–72%. The dominant monoterpene hydrocarbons are β-pinene, γ-terpinene and p-cymene. The characteristic flavour of cumin is probably due to dihydrocuminaldehyde and monoterpenes. The odour and taste of cumin is described as strong, warm, pungent and persistent and is most popular in warmer climates (e.g. in Middle East, India and South America). A monograph on the physiological properties of cumin oil has been published by the Research Institute for Fragrance Materials (RIFM).

Adulterations and substitutes Cumin essential oil is sometimes adulterated with synthetic cuminaldehyde which is difficult to detect.

Description Erect to suberect, annual herb, 20–50(–80) cm tall, with thin taproot; all green parts glabrous but usually covered with a bloom. Stem subterete, up to 3 mm in diameter, finely sulcate, branching at all heights. Leaves alternate, compound, blue-green; petiole subterete, 2–25 mm long, finely sulcate, sheathing at base with scarious margins, upper leaves usually only with sheathing part; blade consisting of 3 slender, filiform leaflets, each leaflet often forked 2–3 times into filiform lobes up to 7 cm long. Inflorescence a compound umbel, up to 3.5 cm in diameter; peduncle subterete, up to 7 cm long, finely sulcate; bracts often as many as primary rays, sheathing at base, linear, often up to 3-forked into lobes 2–35 mm long; primary rays 2–10 per umbel, terete, unequal in length, up to 18 mm long, finely sulcate; bracteoles 3–5 per umbellet, linear, up to 25 mm long, sheathing at base, sometimes 2–3-forked; secondary rays 3–8 per umbellet, up to 6 mm long; flowers bisexual, regular, protandrous; sepals 5, narrowly triangular, unequal in length, up to 2.5 mm long; petals 5, usually all equal, oblong, up to 1.5 mm × 1 mm, whitish at base, pinkish to reddish at top, apex strongly inflexed and narrow; stamens 5 with filiform filaments 1.5 mm long; pistil with ribbed ovary, 2 styles on a conical, persistent stylopodium, stigma semiglobose. Fruit an ovoid-oblongoid, erect or slightly curved schizocarp, 3.5–6.5 mm × 1–2 mm × 0.8–1.5 mm, crowned by the persistent, sharp stylopodia and sepal bases, yellow-brown; primary ribs 8, secondary ribs prominent and alternating with and wider than primary ones, whitish setose but bristles breaking off easily; at slight pressure the fruit splits into 2 mericarps; mericarp strongly concave ventrally, convex dorsally, usually bearing one oil



Cuminum cyminum L. – 1, habit flowering plant; 2, inflorescence with umbellets, bracts and bracteoles; 3, flower; 4, fruit.

duct (vitta) below each secondary rib and two vittae on the commissural ventral side. Seed with testa adnate to the fruit wall, endosperm grey, fatty. Seedling with epigeal germination.

Growth and development Cumin takes 2–4 weeks to germinate. Flowering starts about 1.5–2.5 months after sowing and the fruits can be harvested about 1 month after flowering. Although the flowers of cumin are protandrous and cross-fertilization is the rule, self-pollination may sometimes be as high as 70%. The crop cycle is 3–4 months.

Other botanical information Cumin plants can be rather variable in numbers of primary and secondary rays in the inflorescence, in the degree of coarseness of the fruits (from glabrous to densely setose), in length of the bracts and bracteoles and in colour of the flowers and fruits. Several botanical forms have been described, but these distinctions are without much practical value as the characters are not constant. In the main areas of cultivation there are many cultivars and selections, differing in yield, fruit colour, flavour and essential-oil content. A popular cultivar from Pakistan and Iran is 'Black' (with small, dark, rather sweet fruits).

In local languages, cumin, both as a crop and a product, is often confused with caraway (*Carum carvi* L.). Caraway plants are larger with much larger leaves and umbels, with fruits more curved than those of cumin. And, most important, the taste is very different.

Ecology Cumin requires a season of 3–4 months of rather cool and dry weather with full sunlight, as can be found in semi-arid areas with a moderate winter or at higher altitudes in the tropics (up to 2200 m). The temperature range is 9–24°C and frost is not tolerated. Cumin is a short-day plant. Rich well-drained medium to heavy loams with pH of 6.8–8.3 are optimal.

Propagation and planting Cumin is grown from seed, either broadcast on carefully prepared beds (irrigated crop) or in rows (rainfed crop), and sowing rate is about 20 kg/ha. Final plant distance is about 15 cm × 15 cm. In seasonal climates cumin is grown in the dry season with additional irrigation. In India 20–50 t farmyard manure is applied per ha before cumin is sown.

Attempts to propagate cumin by tissue culture have so far failed: rooted calli do not produce shoots and excised regenerated shoots cannot be induced to form roots.

Husbandry Regular weeding of cumin is very important, e.g in India about 2–3 weedings are carried out during the first months. It is recommended to apply 100 kg NPK (5:8:6) per ha at sowing time and 30 kg N/ha as top dressing. In India 4–5 irrigations are given at intervals of 2–3 weeks. In Ethiopia *Plantago psyllium* L. (*Plantaginaceae*) is a troublesome weed as it closely resembles cumin at first glance (but it has opposite leaves and the inflorescence is not an umbel).

Diseases and pests In India young cumin plants can be attacked by *Fusarium* wilt, especially on light soils. Powdery mildew (*Erysiphe polygoni*) and *Alternaria* blight (*A. burnsii*) can cause losses as well. Crop rotation is important to reduce disease problems.

The major pests are aphids (*Myzus persicae*), a leaf-eating caterpillar (*Prodina* sp.), fruit-eating larvae of a chalcid fly (*Systole albipennis*) and the cigarette beetle (*Lasioderma serricorne*).

Harvesting Cumin is ready for harvest as soon as it begins to wither and the fruits turn yellow. Plants are preferably uprooted when wet with dew and stacked carefully to dry in the sun for 2–4 days. Threshing is done with sticks or by trampling with cattle on a threshing floor. In large-scale production the harvest is mechanized.

Yield Under normal circumstances in India the average yield of dry cumin fruits is about 100 kg/ha. Under optimum conditions with additional irrigation and application of fertilizer, yields up to 1.2 t/ha are possible.

Handling after harvest The harvested fruits of cumin are ready for use or sale after they have been cleaned of foreign matter. The fruits keep well for a long period if stored dry. On local markets cumin fruits are often sold in mixtures with other umbelliferous fruits ('spice seeds'), e.g. in Ethiopia with fennel and dill, in Indonesia with coriander. For essential-oil distillation it is recommended to use freshly harvested fruits.

Genetic resources and breeding Germplasm collections of cumin are available in India. In India breeding programmes of cumin have resulted in cultivars and selections with considerably higher yields (e.g. 'RS-1', 'S 404', 'MC 43', 'NP 1', 'NP 26' and 'NP 49').

Prospects Cumin will remain an important spice on the world market and annual demand is expected to continue to increase slightly. The feasibility of large-scale cultivation of cumin in South-East Asia is limited because it is a short-day, dry-weather, cool-season crop.

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P.C.M. Jansen

Curcuma longa L.

Sp. pl.: 2 (1753).

ZINGIBERACEAE

$2n = 63$ (triploid)

Synonyms *Amomum curcuma* Jacq. (1776), *Curcuma domestica* Valeton (1918).

Vernacular names Turmeric (En). Curcuma (Fr). Indonesia: kunyit (Indonesian), kunir (Javanese), koneng (Sundanese). Malaysia: kunyit (Malay), temu kunyit (Malay), tius (Semang). Papua New Guinea: kawawara. Philippines: dilaw (Tagalog), duwaw (Cebuano), kalawag (Ilocano). Burma (Myanmar): nanwin. Cambodia: rômiêt, lômiêt. Laos: khminz khünz. Thailand: khamin (general), khamin-kaeng (northern), khamin-chan (central). Vietnam: ngh[eej], u[aas]t kim.

Origin and geographic distribution The exact origin of turmeric is not known but it is thought to originate from South or South-East Asia, most probably from India. Turmeric is not known in a true wild state although in some places it appears to have become naturalized (e.g. in teak forests in East Java). Turmeric is a sterile triploid and is thought to have arisen by continued selection and vegetative propagation of a hybrid between the diploid wild turmeric (*C. aromatica* Salisb., $2n = 42$, native to India, Sri Lanka and the eastern Himalayas) and some other closely related tetraploid species.

India is considered a centre of domestication and turmeric has been grown there since time immemorial. Turmeric reached China before the 7th Century, East Africa in the 8th Century and West Africa in the 13th Century. It was introduced into Jamaica in the 18th Century. At present turmeric is widely cultivated throughout the tropics, but cultivation on a considerable scale is largely confined to India and South-East Asia.

Uses Turmeric is mainly cultivated for its rhizome. The major use of turmeric rhizomes is as a culinary spice. As an important constituent (20–25%) of curry powder it is widely used in Asian dishes. Young shoots and young rhizomes can be eaten fresh as a spicy vegetable. In western countries, ground turmeric is widely used in the food industry, in particular as a colouring agent in processed foods and sauces. It is also applied as a colouring agent in pharmaceuticals, confectionery and textile dyes, and is an excellent cheaper substitute for saffron. Turmeric oil and oleoresin find similar applications as the ground spice. In the United States the regulatory status 'generally recognized as safe' has been accorded to turmeric oil (GRAS 3085) and turmeric oleoresin (GRAS 3087). The maximum permitted level of turmeric oil in fragrances is 1%, but it is now rarely used.

Rhizomes are used in Asia as a cosmetic to beautify the body and face. They are an auspicious article in all religious observances in Hindu households, and have many other uses in daily life in connection with birth, marriage, and death, and in agriculture. Turmeric rhizomes are part of numerous traditional compound medicines used as stomachic, tonic and blood purifier; mixed with warm milk they are used to cure common cold; juice from fresh rhizomes is applied against many skin infections, whereas a decoction is effective against purulent ophthalmia. Recent research has found pharmaceutical activity against cancer, dermatitis, AIDS, inflammation, high cholesterol levels, and dyspeptic conditions. It also has insecticidal, fungicidal and nematicidal properties. The leaves are used in preparing a special medicinal bread in Nepal and India.

Production and international trade Turmeric enters into international trade mainly in the form of cured dried whole rhizomes. Trade in ground turmeric is less important than it used to be. India is the largest producer, with 400 000 t from 130 000 ha and dominates the international trade which is estimated at 20 000 t annually. Other producers in Asia include Bangladesh, Pakistan, Sri Lanka, Taiwan, China, Burma (Myanmar), and Indonesia. It is also cultivated in the Caribbean, and in Central and South America, with Jamaica, Haiti and Peru being the most important producing countries. All Asian producers are heavy consumers as well and some are even net importers whereas non-Asian countries export most of their production.

Trade in turmeric from Asian countries is mainly routed through Singapore. Leading importers are Iran, Sri Lanka, most of the Middle East and North African countries. Taiwan is the main supplier of Japan, whereas Jamaican turmeric goes mainly to the North American market. In the 1980s and 1990s the United States imported about 1850 t turmeric annually, with a value of about US$ 2 million.

Properties Per 100 g edible portion ground turmeric contains approximately: water 11–13 g, protein 6–8 g, fat 5–10 g, carbohydrates 60–70 g (main constituent is starch), fibre 2–7 g, ash 3–6 g (K 2.5 g, Ca 180 mg, Fe 40 mg, Mg 190 mg, P 270 mg), ascorbic acid 25 mg. The energy value is about 1500 kJ/100 g. On steam distillation the rhizomes yield 2–7% essential oil which is orange-red and slightly fluorescent. Its major constituents are: turmerone 35%, zingiberene 25% and ar-turmerone 12%. Extraction of the rhizome with ethyl alcohol, acetone or methylene chloride yields 6–10% oleoresin, which contains 35–45% of curcumin ($C_{21}H_{20}O_6$) and its derivatives demethoxycurcumin and bis-demethoxycurcumin. Curcumin gives turmeric the characteristic yellow-orange colour, the essential oil gives it the typical aroma and flavour. The contents of the rhizome are very variable and depend on the site of cultivation, type of cultivar, moment of harvest, method of processing and method of analysis.

As the pigment is extremely sensitive to light, turmeric easily discolours.

The essential oil of turmeric is comprised mainly of oxygenated monoterpenes, with smaller quantities of sesquiterpene hydrocarbons and monoterpene hydrocarbons. The relative contribution of individual components to the aroma and flavour is not well known. The aroma of steam-distilled essential oil differs in character from that of the spice and this is believed to arise from artefact formation during the distillation process. A monograph on the physiological properties of turmeric oil has been published by the Research Institute for Fragrance Materials (RIFM).

Adulteration and substitutes In India, adulteration is a serious problem in local markets and ground turmeric is more vulnerable to such a practice. It is not uncommon to find turmeric powder locally adulterated with lead chromate, yellow earth, sand, or cheap talc. However, in the international market, concern over possible adulteration relates mainly to the mixing of related *Curcuma* species containing curcuminoid pigments into turmeric rhizome material. The curcuminoid pigments appear to have a restricted occurrence in nature and have been found in only a small number of the many species of *Curcuma*. There are three other curcumin-containing species that are of real significance with regard to problems of adulteration: *C. xanthorrhiza* Roxburgh (Indonesian: temu lawak), *C. aromatica* (wild turmeric or yellow zedoary) and *C. zedoaria* (Christmann) Roscoe (zedoary). In the producing countries of Asia these three species are variously used as a source of starch, dyes and in folk medicine and as a substitute for true turmeric (not as a spice but in other applications). Identifying these species by microscopy of ground material is often difficult, particularly if the starch grains and oleoresin cells have been destroyed by boiling. Adulteration of *C. longa* by *C. aromatica* or *C. zedoaria* can be detected by chemical methods from the presence of camphor and camphene, which occur as minor components in the essential oil of the latter two species.

Description Robust, perennial, erect, strongly tillering herb (often cultivated as an annual), up to 1(–1.5) m tall. Rhizome a fleshy complex with an ellipsoidal primary tuber (about 5 cm × 2.5 cm) at the base of each aerial stem, ringed with the bases of old scale leaves and when mature bearing numerous straight or slightly curved, cylindrical, lateral rhizomes (called fingers), 5–10 cm × 1–1.5 cm, which are again repeatedly branched more or less at right angles, the whole forming a dense clump; rhizomes inside and outside bright orange, young tips white, with a spicy smell when bruised. Roots filiform, tough, sometimes very long, often swollen into an ellipsoidal tuber at the apex (2–4 cm × 1–2 cm). Leafy shoots bearing up to 10, alternate, distichous leaves, surrounded by bladeless sheaths, the conduplicate leaf sheaths forming a short pseudostem; ligule small, semi-annular, reflexed, ciliate, membranous, soon withering; petiole 0.5–10 cm long, broadly furrowed with narrow erect wings along the margins; blade oblong-lanceolate, 7–70 cm × 3–18 cm, base cuneate to rounded, apex acute-caudate, above dark green with a green midrib, below very light green, densely studded with pellucid dots. Inflorescence

Curcuma longa L. – 1, habit flowering clump; 2, rhizome.

terminal on a central leafy shoot, erect, spike-like, appearing between the leaf sheaths; peduncle terete, 3–20 cm long, densely hairy, covered by pubescent bladeless sheaths or scales; flower spike cylindrical, 5–20 cm × 3–7.5 cm, bearing numerous, spirally arranged, densely hairy bracts; bracts elliptical-lanceolate, 5–7.5 cm × 2.5 cm, in their lower part (0.3–0.5) adnate to each other, the free upper parts spreading, apex acute, slightly inflexed; the lower bracts light green with white longitudinal streaks or white margins, the larger, upper, sterile bracts (coma) white, sometimes pink-tipped; bracteoles thin, elliptical, up to 3.5 cm long, surrounding the flowers; flowers in cincinni of 2 in axils of bracts, long and narrow, 5–6 cm long, white to yellow-white, opening one at a time; calyx tubular, short, with 3 unequal teeth; corolla tubular at base, upper half much widened and with 3 unequal lobes, white; labellum (central staminode) suborbicular to obovate, 12–17 mm in diameter, with 2 small lateral lobes and a large emarginate central lobe, white with a yellow central streak; lateral staminodes 2, elliptical-oblong, 1 cm × 6 mm, creamy-white; stamen for larger part connate with staminodes, 5–6 mm × 3 mm, anther with a broad curved large spur at base; ovary trilocular with 2 erect glands (stylodes) at top; style slender, passing between and held by the anther thecae; stigma expanded. Fruit never produced.

Growth and development In the phase of establishment, sprouting of sets of turmeric is completed in 2–4 weeks, followed by a period of active vegetative growth. Flowering and rhizome development start about 5 months after planting. Active rhizome development continues until the crop is ready for lifting when the lower leaves turn yellow, at about 7–10 months, depending upon cultivar and climatic conditions.

Other botanical information The correct naming of turmeric has long been debated; now *C. longa* L. is generally accepted. In some countries, especially India, several unofficially recorded cultivars are distinguished by the names of the localities in which they are grown, some forms being preferred for spice use (e.g. Madras type), others for dyeing (e.g. Bengal type). A thorough revision is needed to establish reliable cultivar groups and cultivars. The identity of *C. longa* as a species also needs better investigation. In Asia a group of closely related species is now distinguished solely by the different colours of the bracts, corolla, leaves or rhizomes and in fact forms one complex species around *C. longa*. Other taxa of the complex are: *C. brog* Valeton, *C. colorata* Valeton, *C. euchroma* Valeton (Prosea 12), *C. montana* Roxb. (Prosea 9), *C. ochrorhiza* Valeton, *C. purpurascens* Blume (Prosea 12), *C. soloensis* Valeton (Prosea 12) and *C. viridiflora* Roxb.

Ecology Turmeric requires warm and moist conditions. It can be cultivated in most areas of the tropics and subtropics provided rainfall is adequate (1000–2000 mm) or facilities for irrigation are available. A well-distributed rainfall of 1200–1400 mm in 100–120 days is ideal. Cultivation has been extended into areas with over 2000 mm rainfall. It is grown up to altitudes of 1200 m in the Himalayan foothills but it performs better at altitudes of 450–900 m. Temperature ranges of 30–35°C during sprouting, 25–30°C during tillering, 20–25°C during rhizome initiation and 18–20°C during bulking stage have been identified as optimal. Though turmeric is grown in various soil types, well-drained, loose and friable, fertile loam or clay loam, with good organic matter status, in the pH range of 5–7.5 is preferred. It cannot stand waterlogging and alkaline soils. Gravelly, stony and heavy soils are unsuitable for the development of rhizomes. As a sciophyte it does well in partial shade and can be cropped under fruit trees.

Propagation and planting Turmeric is propagated vegetatively by rhizomes. Mother rhizomes, whole or cut into pieces, and daughter rhizomes (fingers) are generally used. As seed material mother rhizomes are better than daughter rhizomes. However, it has also been stated that large daughter rhizomes germinate better and produce higher yields than mother rhizomes. Finger rhizomes store better, are more tolerant of wet soil conditions and can be planted at a lower density. It is necessary to store seed rhizomes for 2–3 months from harvest to planting. This may be done by spreading them thinly under a covering of turmeric leaves or storing them in heaps under a layer of straw and soil.

The field should be well prepared by ploughing or digging and turning over to a depth of about 30 cm, to provide a good tilth. Large quantities of organic manure (farmyard manure, oil-seed cake, green leaves) are usually applied. The optimum is reported to be about 25 t/ha of cattle manure or compost and 65 kg/ha of N through oil-seed cake.

Turmeric is generally planted by one of two methods: the flat-bed method or the ridge and furrow method. The flat-bed method is generally better, but in sites with excessive or deficient moisture the ridge and furrow method is superior, facilitating drainage and irrigation. Ridges should be 20–25 cm high and 45–50 cm wide and the rhizomes planted at a distance of 30–40 cm, at a depth of 7.5 cm, with a seed rate of 1.7–2.0 t/ha. A spacing of 25 cm × 25 cm for the flat-bed method is optimal, a seed rate of 2.5 t/ha being recommended. However, good results have been obtained at spacings of 30 cm × 15 cm and 15 cm × 15 cm. If turmeric is intercropped, spacing is adjusted accordingly. Planting time depends on cultivar, planting material and agroclimatic conditions.

Rapid multiplication of turmeric has also been reported using in vitro culture of young vegetative buds excised from sprouting rhizomes. Plantlet formation occurred throughout the year without exhibiting the usual dormancy period of field-grown plants.

Husbandry After planting it is beneficial to mulch with leaves of *Sesbania* spp., *Crotalaria* spp., *Shorea* spp., or *Dalbergia* spp., with sugarcane trash or other locally available leaves or straw. This practice improves rhizome establishment, suppresses weeds and increases plant height and rhizome yield. It is recommended to apply a mulch of green leaves twice at a rate of 15 t/ha, at planting and 60 days after planting.

After-planting care consists of weeding, irrigation, protection against diseases and pests, and application of fertilizers. Early weeding may be avoided by the use of 2,4-D as a pre-emergence herbicide. Three to four hoeings followed by weeding at regular intervals are desirable. Earthing-up may be necessary about 8 weeks after planting.

A good soaking of the field at planting is beneficial, followed by a weekly irrigation until sprouting is completed, after which less frequent watering will be required.

Turmeric, being an exhaustive crop, requires heavy manuring for high yield. Under rainfed conditions the application of ammonium sulphate at a rate of 100 kg/ha has been reported to increase yield by nearly 100%. Response to phosphorus at a rate of up to 175 kg/ha and in combination with other nutrients has also been reported. Application of potassium significantly increases plant height, and the number of tillers, leaves, and mother and daughter rhizomes. Among micronutrients, responses to iron and zinc have been reported (50 kg each of $FeSO_4$ and $ZnSO_4$). However, recommendations of fertilizer application differ widely from place to place.

Diseases and pests Leaf spot or leaf blotch, and rhizome rot are considered the most important diseases of turmeric. Leaf spot or leaf blotch, caused by *Taphrina malucans*, is characterized by the appearance of spots on both surfaces of the leaves, 1–2 mm in diameter, coalescing freely. Infected leaves are distorted, have a reddish brown appearance and soon become yellow. The disease can be controlled reasonably by Bordeaux mixture, ethion, and zineb. Cultivars resistant to the disease are available.

Another leaf spot disease is caused by *Colletotrichum capsici*, provoking spots of variable size, enlarging to 4–5 cm × 3 cm and frequently coalescing over most of the leaf, which then dries up. In very severe infection most leaves dry up, presenting a scorched appearance, resulting in yield losses of more than 50%. The disease can be checked by spraying Bordeaux mixture once before symptoms appear. Captan and zineb, applied at monthly intervals, control the disease adequately. Planting materials should be selected from disease-free areas and treated with an authorized fungicide before planting. Excess shade and intercropping favour the disease.

Rhizome rot caused by *Pythium aphanidermatum* shows progressive drying-up of the leaves of infected plants. The base of the aerial shoots shows water-soaked soft lesions. As the disease progresses infection gradually passes to the rhizomes, which begin to rot and become soft. The bright orange colour of the rhizomes changes into brown. The disease may be confined to a few isolated plants or may occur in patches. In severe attacks the yield is considerably reduced. One of the effective control methods is eradication and burning of infected plants. In serious cases it may be advisable to disinfect the soil with an authorized fungicide. Incorporation of 1% urea into the infected soil may reduce the infection.

Pests of turmeric include shoot borers, leaf-eating insects, sucking insects and nematodes. Caterpillars of the shoot borer *Dichocrocis punctiferalis* bore into the shoot, causing the central shoot to die ('dead heart'). Monthly spraying with malathion controls the insect. The hesperiid caterpillar *Udaspes folus* is also a serious foliage feeding insect. It is recommended to spraying carbaryl, dimethoate or phosphamidon for its control.

The scale insect *Aspidiotus hartii* is a sucking insect infesting rhizomes while still in the field. It multiplies on the fresh rhizomes being kept for seed. The infested rhizomes ultimately desiccate. Control is achieved by dipping the seed rhizomes in phosalone, monocrotophos or quinalphos. Two hymenopteran parasites, *Physcus* sp. and *Adelencyrtus moderatus*, attack this insect pest.

The tinged bug, *Stephanitis typicus*, causes leaf discolouration by sucking the sap. Thrips also suck the leaves, which then roll up, turn pale and gradually dry up. The nematodes recorded in turmeric include root-knot nematode (*Meloidogyne incognita*) and burrowing nematode (*Radopholus similis*).

Harvesting Turmeric is ready for harvest 7–10 months after planting, when the lower leaves turn yellow. Harvesting is done by digging. Care should be taken not to damage the rhizomes and to ensure that the whole clump is lifted together with the dry plant. Leafy tops are then cut off, roots and adhering earth removed, and rhizomes are well washed. The finger rhizomes are separated from the mother rhizome. A few rhizomes may be used fresh and, except for those that are required for replanting, the remainder are processed.

Yield The average yield of fresh turmeric rhizomes is 17–23 t/ha if the crop is irrigated, and 6.5–9.0 t/ha under rainfed conditions. However, yields depend largely upon the cultivar. Some cultivars are capable of yielding 30–35 t/ha of fresh turmeric.

Handling after harvest To develop the attractive yellow colour and the characteristic aroma, the cleaned rhizomes are cooked in boiling water for 1 hour under slightly alkaline conditions. The cooked material is dried in the sun for 6–8 days. Hot-air dryers are also used. Dried rhizomes are polished to smoothe their exterior and also to slightly improve the colour. The polishing can be done in a simple rotating cylindrical galvanized iron drum turned by hand, or in other types of equipment. A small quantity of turmeric powder sprinkled in during polishing gives the product a good appearance.

Genetic resources and breeding A germplasm collection of 500–600 turmeric accessions is maintained in India. The average productivity and quality of turmeric are far from being satisfactory. Until recently, there has been hardly any work on crop improvement, because conventional methods of breeding are hampered by problems of sterility. Clonal selection is now being applied to exploit the naturally occurring variation, and mutation breeding is being practised. The major breeding objectives are high yield and resistance against rhizome rot.

Prospects Tumeric is an important spice in India and South-East Asia. The growing demand for turmeric as a spice and as a safe food colouring agent in local as well as international markets indicates that its prospects are good. Crop improvement, agronomic research and pest management need to be undertaken to obtain high production levels and good quality. Studies on the bioactive compounds of the rhizomes have opened up new possibilities for the use of turmeric in pharmaceutical products. Given the dominant position of India in both production and trade, it will be difficult for the crop to expand in South-East Asia for the international market. Expansion for local use may offer better opportunities.

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Elettaria cardamomum (L.) Maton

Trans. Linn. Soc. London 10: 254, t. 5 (1811).

ZINGIBERACEAE

$2n = 48, 50, 52$

Synonyms *Amomum cardamomum* L. (1753), *A. repens* Sonnerat (1782), *Alpinia cardamomum* (L.) Roxb. (1819).

Vernacular names Cardamom, true cardamom, small cardamom (En). Cardamome (Fr). Indonesia: kapulaga sabrang (general), kapol (Sundanese), kapolaga (Sundanese). Malaysia: biah pelaga. Burma (Myanmar): bala, pala, panlat. Cambodia: krako sbat. Laos: hma:k hnè:ngx. Thailand: krawan-thet (central). Vietnam: tr[us]c sa, b[aj]ch d[aaj]u kh[aas]u.

Origin and geographic distribution *E. cardamomum* occurs wild in gaps in the evergreen montane monsoon forests of the western Ghats in southern India and the western highlands in Sri Lanka. It is possibly also truly wild in Burma (Myanmar), Indo-China and Malesia, and has been introduced into other parts of the tropics. Introduction into Guatemala in the 1920s was particularly successful and a sizable production and export developed.

Uses Cardamom is the dried fruit of *E. cardamomum*. The major use of cardamom is for domestic culinary purposes. The spice is used in the form of the whole fruit, the decorticated seeds, or the ground seeds. In Asia, cardamom plays an important role in a variety of spiced rice, vegetable and meat dishes. It is used to flavour coffee and tea and is an important ingredient of curries. In the food and beverage industry it is used for flavouring confectionery, a range of baked goods, prepared savoury dishes, and a range of beverages. Locally it is a masticatory often included in the betel quid, and industrially it is used to a small extent in flavouring tobacco.

Cardamom is included in several pharmacopoeias. It is considered tonic to the heart, stomachic, laxative, diuretic, and carminative. It lessens inflammation, headache, earache, toothache, and alleviates disorders of the liver, chest and throat. Cardamom is commonly given in instances of snake bite and scorpion sting, but it is not an antidote.

Cardamom essential oil is produced in small quantities in some western spice-importing countries and also in India, Guatemala and Sri Lanka. It is mainly used in the flavouring of processed foods, but also in certain beverages such as cordials, bitters and liqueurs and occasionally in perfumery. In the United States cardamom oil is 'generally recognized as safe' (GRAS 2240/2241). The maximum permitted level in food products is about 0.01%.

Cardamom oleoresin, which is also produced in some western spice-importing countries and in India, has similar applications to the essential oil but is used less extensively. Both the oil and oleoresin tend to develop off-flavours when exposed to the air for prolonged periods, so their use is generally confined to meat products with a short shelf-life, such as sausages.

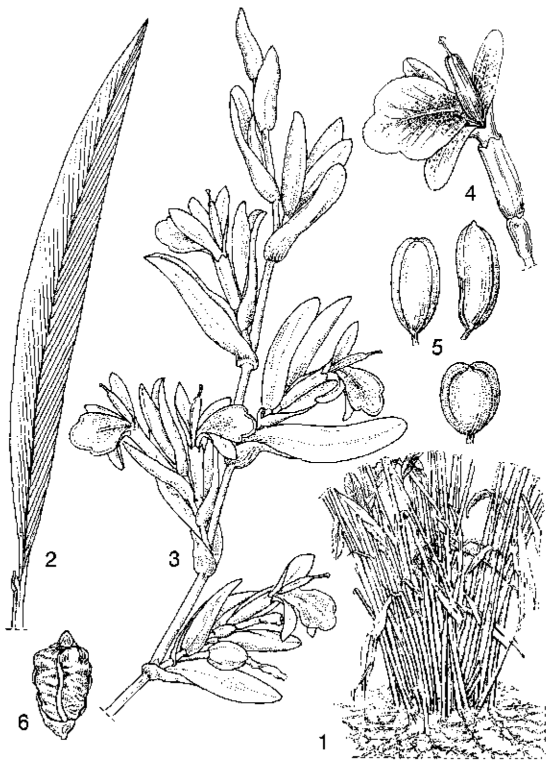
Production and international trade True cardamom is one of the highest-priced spices on the market. It is traded internationally predominantly in the form of whole fruits, to a much lesser extent as decorticated seeds. The major suppliers are Guatemala, India, Sri Lanka and Tanzania, with Papua New Guinea being a relatively new player on the world market. Average annual production in the 1990s was 10 000 t, with Guatemala providing 5000 t, India 4000 t, and the rest of the world 1000 t. The cultivated area in the 1970s was about 90 000 ha in India. The major consumers are the Arab countries in the Middle East (flavouring of coffee and tea) and the Scandinavian countries (flavouring of baked goods and pastries).

Properties The dried fruit of cardamom contains an essential oil, fixed (fatty) oil, pigments,

protein, cellulose, pentosans, sugars, starch, silica, calcium oxalate and minerals. The approximate composition of dried fruits per 100 g is water 20 g, protein 10 g, fat 2 g, carbohydrates 42 g, fibre 20 g, ash 6 g. The major constituent of the seeds is starch (up to 50%) while in the capsule (husk) it is crude fibre (up to 31%). Whole cardamom fruits usually have an essential-oil content of 3.5–7%. The essential oil is located predominantly in the seeds which comprise 59–79% of the whole dried fruit weight. The seeds of freshly harvested cardamom may contain as much as 11% essential oil, but the husk rarely contains more than 1%. Cardamom oil is best obtained by steam distillation of freshly decorticated seed. It is a colourless or pale yellow oil which darkens on exposure to light. The essential oil comprises mainly 1,8-cineole (20–60%) and α-terpinyl acetate (20–53%) together with smaller amounts of other oxygenated monoterpenes, monoterpene hydrocarbons and sesquiterpenes. This oil gives cardamom the pleasant aroma and the characteristic warm, slightly pungent taste. A monograph on the physiological properties of cardamom oil has been published by the Research Institute for Fragrance Materials (RIFM).
The fatty oil content of the fruit has been reported to range from 1–10%; the oil is predominantly located in the seed. Ten fatty acids have been identified, with the major constituents being palmitic (28–-38%), oleic (43–44%) and linoleic acid (2–16%). The relative abundance of the fatty acids apparently differs according to the cultivar grown, because high stearic acid contents (18–38%) have also been reported.
The 1000-seed weight is about 20–25 g.

Adulterations and substitutes The cardamom substitutes ('false' cardamoms) that sometimes appear in trade and may be confused with true cardamom are derived mainly from species of *Amomum* and *Aframomum* K. Schumann. The most important one in Indonesia is round cardamom (*Amomum compactum* Soland. ex Maton). Other species labelled and used as 'false' cardamoms in South-East Asia (see Chapter on 'Minor spices' and 'Spice plants with other primary use') include *Amomum acre* Valeton, *A. krervanh* Pierre ex Gagnepain, *A. ochreum* Ridley, *A. testaceum* Ridley, *A. uliginosum* J. G. König ex Retz., *A. xanthioides* Wallich ex Baker and *A. xanthophlebium* Baker. The 'false' cardamoms found outside South-East Asia include *Amomum aromaticum* Roxb. and *A. subulatum* Roxb. (Eastern Himalayas), *Alpinia globosa* Horan. (Indo-China and China), *Aframomum corrorima* (Braun) Jansen (Ethiopia), *A. daniellii* K. Schumann (Cameroon) and *A. melegueta* (Roscoe) K. Schumann (West Africa).
Cardamom oil is sometimes adulterated with 1,8-cineole and α-terpinyl acetate from cheaper sources.

Description Robust perennial herb, up to 5 m tall, growing in a thick clump, with branched rhizomes from which arise 10–20 erect leafy shoots (composed of the leaf sheaths) and numerous decumbent flowering shoots. Leaves distichous; petiole (free part) up to 2.5 cm long, sheathing at base and together with other sheaths forming the pseudostem; ligule entire, up to 1 cm long; blade lanceolate, 25–100 cm × 5–15 cm, apex acuminate, dark green and glabrous above, light green and glabrous or pubescent beneath. Inflorescence a prostrate (seldom erect) panicle, up to 1.2 m long, arising from the rhizome at the base of a leafy shoot; bracts alternate, lanceolate, up to 3 cm × 1 cm, each with an axillary, usually 2–3-flowered cincinnus; bracteole tubular, up to 2.5 cm long; flowers bisexual, zygomorphic, about 4 cm long; calyx tubular, up to 2 cm long, with 2–3 teeth,



Elettaria cardamomum (L.) Maton – 1, habit fruiting clump; 2, leaf; 3, part of inflorescence; 4, flower; 5, fruits; 6, seed with aril.

green; corolla tubular, 3-lobed, tube as long as the calyx, lobes 1–1.5 cm long, pale green; labellum obovate, 1.5–2 cm long, up to 1 cm wide, obscurely 3-lobed, white but streaked with violet; lateral staminodes inconspicuous, subulate; anther sessile, thecas about 1 cm long, parallel, connective prolonged into a short crest; pistil with 2–3 mm long ovary, style slightly longer than anther, stigma capitate, small. Fruit a globose or subcylindrical trilocular capsule, 1–2(– 5) cm long, pale green to yellow, drying brown. Seeds 15–20 per fruit, angled, about 3 mm long, rugose, dark brown, aromatic, with thin mucilaginous aril.

Growth and development Cardamom seeds germinate 5–7 weeks after sowing but germination is irregular and may continue even up to one year. Cardamom comes into bearing about 3 years after field planting, which may be 4–5 years after sowing. The economic life is 10–15 years. Flowers are self-sterile, therefore it is necessary to plant a mixture of clones. Pollination is by bees and ants. Flowering may occur throughout the year. The flowers open from the base of the panicle upwards over a long period, sometimes even more than one year. Flower buds require about 30 days from initiation to full bloom. Anthesis takes place predominantly during the early hours of the day. Pollen is shed mainly between 6 and 8 a.m., whereas the stigma is most receptive between 8 and 10 a.m. on the day the flower opens. Capsule development takes a further 110 days. After the panicles have flowered, fruited and died, the vegetative shoots bearing them also die off.

Other botanical information *Elettaria* Maton is a small genus with 3–4 species in East and South-East Asia. The botanical identity of *E. cardamomum* is no longer contentious; what is problematic is the vernacular name 'cardamom' for the spice which is often also used for many other taxa, particularly *Amomum* species (see adulterations and substitutes).

E. cardamomum is rather variable and 2 botanical varieties have been distinguished in the literature, one for the wild taxon and one for the cultivated forms:

- var. *major* Thwaites. This is the name given to the wild cardamoms that are particularly common in Sri Lanka and southern India. Plants are very robust (up to 5 m tall), inflorescences are erect, fruits elongate (up to 5 cm long) containing many large, but less aromatic seeds, which are also used like true cardamom.
- var. *cardamomum* (syn. var. *minor* Watt, var. *minuscula* Burkill). This is the botanical name for the cultivated cardamoms, which however, could better be classified and named as cultivar groups. Compared with the wild cardamoms, cultivated cardamoms are usually smaller plants (up to 3 m) with longer, prostrate inflorescences bearing more flowers producing smaller, subglobose fruits (1–2 cm diameter) with seeds that are more aromatic. The cultivated cardamoms can be grouped into many cultivar groups, the 2 most important ones being:
  - cv. group Malabar. Plants less than 3 m tall, leaves 30–45 cm long, panicles prostrate on ground 60–90 cm long, fruit small, globose, rounded or ovoid, lightly ribbed. Plants susceptible to katte virus.
  - cv. group Mysore. Plants resemble the wild cardamoms more; the fruits are fusiform, 3-angled, ribbed. They are more suited to higher elevations and show some resistance to katte virus.

Ecology Evergreen montane forest land supplies the most favourable environment for cardamom, with soils varying from deep forest loam to white quartz gravel with only a shallow zone of humus accumulation. Cardamom is a plant of the early succession stage and appears in natural or man-made forest clearings but is not found in forests with an undisturbed canopy. On sloping land it may grow well in pockets of soil among boulders. In the main production areas in southern India and Sri Lanka, cardamom is grown at altitudes of 600–1500 m. A uniformly distributed rainfall of 2500–3800 mm per year is considered optimal. The tolerable range extends from 1500–5800 mm; months with less than 125 mm rainfall have to be regarded as drought months. Drought periods during the formation of the inflorescence or during flowering will preclude seed production and cannot be overcome by sufficient precipitation at a later stage. Successive droughts in two or more years endanger the plant as a whole. Optimum annual mean temperatures are considered to be around 22°C. The diurnal temperature may vary between 10°C and 35°C. In the lowlands (annual mean temperatures >24°C) cardamom only propagates vegetatively; the plants do not grow where annual mean temperatures are <17°C.

Cardamom does not tolerate prolonged exposure to direct sunlight; about 50% is thought to be optimal. Strong winds may topple cardamom plants as their root system is weak. Desiccation by dry winds is a serious threat, especially to young seedlings, but may also affect adult plants.

The crop does best in little-disturbed soils well supplied with organic matter and, since it does not tolerate waterlogging, with good drainage.

Propagation and planting Cardamom is easily propagated vegetatively by division of rhizomes, but the transmission of mosaic virus is then a major problem. Several clones should be planted, to overcome self-incompatibility. The rhizomes of large clumps of growing plants are dug out and divided into small pieces, each with at least one old and one young shoot, which are planted in prepared holes. This method gives earlier yields than seedlings, but the supply of planting material is often limited.

For large-scale production it is common practice to sow selected seeds in specially prepared nursery beds. Cardamom seeds are best sown immediately after harvest because they remain viable for only 7–10 days. About 1 kg seed (50 000 seeds) will furnish enough plants for 1 ha in the field. The seedlings are transplanted to another nursery after 3–6 months when 15 cm tall, and are planted out in the field when 1–2 years old. The young plants are planted in pits, often 60 cm × 60 cm and 45 cm deep, which may be filled with surface soil, leaf mould, and, if possible, with some manure. Field spacing is 1.5–3 m × 1.5–3 m, leading to 1000–4000 clumps/ha. Shade is provided by planting cardamom either in montane forest after clearing the underbrush, or under planted shade trees. Cardamom is often intercropped in e.g. coffee, tea, areca nut or pepper.

Clonal propagation through tissue culture has been successful using rootstocks of seedlings raised in vitro. Differentiation of shoot buds, roots and leaves leading to the development of plantlets could be induced.

Husbandry The young cardamom plants need careful attention in their first year. They need to be sprayed occasionally with Bordeaux mixture to prevent fungal attack and they must also be weeded regularly to keep down the regenerating undergrowth. After-care consists of occasional weeding, removal of old and dying stems, mulching, regulation of shade, manuring, and gap filling. Heavy applications of organic matter are recommended, supplemented by inorganic fertilizers (per ha 45–70 kg N, 35–45 kg P_2O_5, 45–100 kg K_2O).

Diseases and pests The most important disease of cardamom in southern India is the mosaic virus known as katte or marble disease, transmitted by the banana aphid *Pentalonia nigronervosa*. Planting of diseased rhizomes is a serious source of infection. The only control measures appear to be the careful roguing of affected plants and the planting of non-affected seedlings. A nursery leaf rot, caused by *Coniothyrium* sp. or *Phyllosticta* sp., results in spotting and eventual rotting of the leaves in the nursery. The disease is worst in the wet season, but it may be controlled by timely application of Bordeaux mixture. Another disease is a rhizome or root rot causing a gradual decline in vigour of the plants. Rhizomes are often found to be rotten and covered with fungal mycelia of *Cephalosporium* sp., *Pythium aphanidermatum* and *P. vexans*. Affected plants may contain the rhizome borer *Prodioctes haematicus*. Control measures for the disease have not been properly investigated. Other diseases of minor economic importance include a leaf rust (*Uredo elettariae*) and a leaf-spot (*Chlamydomyces palmarum*).

Pests of cardamom include the thrips *Taeniothrips cardamomi*, affecting all cardamom growing districts in India. It lives in the leaf sheaths and the floral bracts. In extreme cases the flowers fail to set and this may cause a severe loss of crop. It may check fruit development and lead to malformations. The pest may be controlled by Gammexane dust containing the active principle BHC. The hairy caterpillar *Eupterote mollifera* (syn. *E. canaraica*) may appear in enormous swarms, attacking the leaves and defoliating entire clumps. It is a general forest pest which attacks cardamom incidentally, but a serious outbreak can do a great deal of damage. Collection and destruction of the pupae assists in control, as does spraying the plants with insecticides. A number of borers attack cardamom: the weevil *Prodioctes haematicus* bores into the rhizomes; the shoot and capsule borer *Dichocrosis punctiferalis* is one of the commonest stem borers in the tropics, affecting not only cardamom, but also castor, ginger and turmeric; the pod borer *Lampides elpis* is a minor pest; the tingid bug *Stephanitis typicus* may breed in numbers on cardamom leaves; there are records of attacks by some unidentified root borers and a number of polyphagous coccids and lepidopterous larvae. Damage is frequently caused by rats, monkeys, porcupines, wild pigs and birds.

Harvesting Fruits are picked when fully developed but still green. For quality it is important that the seeds within the green pods have changed colour from white to brown or black. Fully ripe fruits tend to split on drying and do not give a good colour when dry, whereas small immature fruits result in an uneven, shrivelled and badly coloured appearance. Because the fruits ripen very irregularly, they should be harvested individually at the correct stage of ripeness. They also need to be picked with care so that they are not bruised or broken. In spite of the very uneven ripening, it may be advantageous to cut whole spikes, sacrificing the very immature fruits to get the others in the best possible condition.

Yield The first small crop of cardamom is usually obtained in the third year after field planting (4–5 years after sowing). Higher yields are obtained in subsequent years continuing till the plants are 10–15 years old. The average yield of dry capsules from a well-maintained cardamom plantation may reach 110–170 kg/ha, but 45–80 kg/ha would represent the more usual level.

Handling after harvest In the usual procedure, the freshly picked green cardamom fruits are first washed to free them from adhering dirt, then the stalks are clipped off with scissors. There are several ways of drying the fruit to reduce the moisture content from about 75% at harvest to 13% for safe storage. Green fruits are usually flue-cured in special curing rooms to arrest vegetative development and fix the green colour. Sun-drying is common practice, sometimes followed by bleaching in sulphur fumes. The main resulting quality categories are: whole green cardamom (flue-cured), whole bleached cardamom (sun-dried and bleached), whole straw-coloured cardamom (sun-dried), decorticated seeds (resulting from poor processing). The market deals in cardamom under names referring to appearance rather than origin. Packing methods must take into account the requirements for quality preservation during storage, and are based on controlling the moisture content, and the avoidance of physical damage and excessive heat. In the case of green cardamom, light must also be excluded. Green cardamom should be packed in wooden boxes or tins lined with heavy-gauge black polythene, metal foil or waterproof paper. Grinding almost exclusively takes place in the consuming countries.

Cardamom oil is produced commercially by steam distillation of crushed fruits. In general, recently harvested cardamom which has not suffered excessive essential-oil loss should be employed in order to obtain a good yield. Complete distillation is necessary to obtain the full flavour character of the oil (at least 4 hours distillation to produce the full ester content of the oil). Cardamom oil deteriorates in storage, not because of evaporation losses as is the case with the spice, but because of chemical transformations.

Cardamom oleoresin is produced on a relatively small scale. Solvent extraction yield is about 10%, the essential-oil content ranges from 50–60%, and the replacement strength is about 1 kg of oleoresin to 20 kg of the ground spice.

Genetic resources A collection of cardamom germplasm is maintained by the Research Institute for Spice and Medicinal Crops, Bogor, Indonesia. A large germplasm collection is maintained by the National Repository of Plant Genetic Resources in Idukki, India.

Breeding Considerable variation occurs in cardamom, because it is cross-pollinated. Some selection work is being performed in India. Several high-yielding cultivars have been released (ICRI-1, ICRI-2, ICRI-3, ICRI-4). Careful screening of single plant selections made from indigenous cardamom, and subsequent cloning, will lead to improved planting materials, capable of outyielding the cultivated bulk cardamom. Resistance to katte mosaic and thrips should be sought by hybridization, followed by clonal propagation.

Prospects True cardamom and its derived products have a secure market without much prospect of dramatic changes. World trade in true cardamom shows a fairly small, but steady long-term growth in consumption. However, cardamom seems to be very vulnerable to diseases and pests.

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T.H. Wardini & A. Thomas

Eryngium foetidum L.

Sp. pl.: 232 (1753).
UMBELLIFERAE
$2n = 16$

Synonyms *Eryngium antihystericum* Rottler (1778).

Vernacular names Sawtooth coriander, spiny coriander, long coriander (En). Chardon étoile fétide, panicaut fétide (Fr). Indonesia: walangan (Jakarta), ketumbar jawa (Sumatra), tumbar mungsi (Javanese). Malaysia: ketumbar, ketumbar Java. Philippines: cilantro (Tagalog). Cambodia: chi baraing, chi banla, chi sangkaëch. Laos: phak ho:m th'e:d. Thailand: phakchi-farang (central), hom-pomkula (northern), mae-lae-doe (northern). Vietnam: ng[of] t[aa]y, ng[of] gai, m[uf]i t[aaf]u.
Note: Strictly speaking, the name 'cilantro' refers to sawtooth coriander, but is often used for leaves of *Coriandrum sativum* L.

Origin and geographic distribution The origin of sawtooth coriander is not known, but it is native to Central and South America, from southern Mexico to Panama, Colombia, Bolivia and Brazil and from Cuba to Trinidad. It has been introduced into Florida and the Old World tropics where it has naturalized in many places. It was introduced into South-East Asia by the Chinese, as a substitute for coriander; it is known in Indo-China, Peninsular Malaysia (since 1888), in Java (since 1896) and in Sumatra (since 1915). It is also cultivated in Central and South America and occasionally elsewhere, e.g. in Thailand, Cambodia, Vietnam, the Philippines and Japan.

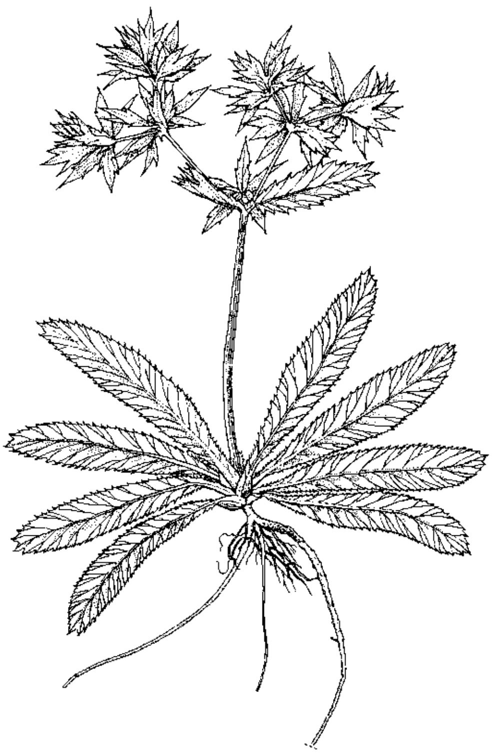
Uses The leaves of sawtooth coriander are aromatic and smell like coriander; in view of its origin it is popularly referred to as 'Mexican coriander'. Where sawtooth coriander occurs, including in South-East Asia, the fresh leaves are used as a flavouring in food, e.g. in soups, curries, stews, rice and fish dishes; tender young leaves are eaten raw or cooked, as a vegetable. Sawtooth coriander has many medicinal uses in Central and South America: a root decoction is taken as a sudorific, diuretic, febrifuge and stimulant; juice or a decoction of the leaves is used as a stimulant, as a laxative and as a remedy for colds and fever; a decoction of the whole plant is said to lower blood pressure, to be a potent emmenagogue and abortifacient, and is also used as an aphrodisiac.

Production and international trade In most places sawtooth coriander is collected from the wild or from some plants in the garden, and is used and traded locally. It is common on South-East Asian markets. Fresh plants are sold in abundance on markets in Panama. Trinidad exports sawtooth coriander to North America and Europe. No statistics are available.

Properties Per 100 g edible portion sawtooth coriander contains: water 84.5 g, protein 2.9 g, fat 0.1 g, carbohydrates 9.2 g, fibre 2.0 g, ash 1.4 g (Ca 99 mg, P 98 mg, Fe 13 mg). It is a good source of minerals; the Fe content is especially high.
Steam-distilled essential oils from the leaves and the roots (Malaysian samples) were found to contain no sesquiterpenoids, small amounts of monoterpene hydrocarbons and a large number of aldehydes in high proportions. Alkanals and alkenals dominated the aldehydes in the leaf oil and are presumably responsible for the intense aroma. The major components (>5%) were found to be (E)-2-dodecenal, 2,3,6-trimethylbenzaldehyde and dodecanal. The analytical data from the Malaysian samples differ markedly from data obtained from samples of other origins.
The root oil contains mainly aromatic and monoterpene aldehydes, with the major components being 2,3,6-trimethylbenzaldehyde (38%), 2-formyl-1,1,5-trimethylcyclohexa-2,4-dien-6-ol (20%), 2-formyl-1,1,5-trimethylcyclohexa-2,5-dien-4-ol (10%) and 2,3,4-trimethylbenzaldehyde (5%). The roots contain saponin.
An essential oil can be distilled from the seed; its major constituents are carotol (19%), (E)-β-farnesene (10%), (E)-anethole (7%) and α-pinene (8%).

Adulterations and substitutes Not only coriander leaves but also leaves of *Persicaria odorata* (Lour.) Soják, known as 'Vietnamese coriander' are used as a substitute. Young leaves of other *Eryngium* species can also be used, e.g. *E. creticum* Lamk from the Near East, *E. floridanum* Coult. from Central America and *E. maritimum* L. from Western Europe.

Description Erect, perennial, glabrous, pale to dark green herb up to 80 cm tall, often with a branched, fusiform taproot. Stem grooved, elongating before flowering and repeatedly dichasially branched at the top into various spreading branches. Leaves simple, subsessile to petiolate, in a radical rosette when young, with a foetid smell when bruised; rosette often disappearing in older plants; blade lanceolate-obovate to spatulate-oblong, 5–32 cm × 1–4 cm, base narrowly sheathing, margin spiny serrate. Inflorescence a terminal, spike-like head (reduced umbel), finally combined into a widely branched corymb, bearing 2 bracts at each ramification; bracts rigid, 1–6 cm long,



Eryngium foetidum L. – *habit of flowering plant.*

deeply incised, aculeate-dentate, strongly veined, lowest ones often like normal leaves; peduncle up to 1 cm long; involucral bracts 5–7, lanceolate, 1–3 cm × 3–7 mm, with a few spiny teeth, spreading and reflexed, subtending the head; rays absent; head cylindrical, 1–2 cm × 3–5 mm, many-flowered, arranged in dichasia, terminal on a branch or on a short peduncle in the fork; involucel bractlets linear to lanceolate, 2–3 mm long, subtending the sessile flowers; calyx tubular, about 1 mm long, with 5 small, erect, triangular teeth, persistent; petals 5, elliptical-oblong, 0.5–0.75 mm × 0.25 mm, greenish-white, apex strongly incurved; stamens 5, far exceeding the corolla, filaments white; pistil with 2 filiform styles, stylopodium absent. Fruit an ovoid-obovoid schizocarp, up to 1.5 mm × 0.75 mm, densely tuberculate, splitting into 2 semiglobose mericarps with indistinct ribs.

Growth and development In South-East Asia sawtooth coriander flowers throughout the year; plants can become several years old. In many places, including plantations, it has become a rather common weed. In Puerto Rico, plants grown under shade had fewer inflorescences with lower fresh weight than plants grown under full sunlight, but the leaf chlorophyll content increased in plants grown under low light intensities.

Other botanical information At first sight, the inflorescence of *Eryngium* with its short head-like spikes, surrounded by bracts which look like an involucre, strongly resembles a *Compositae* inflorescence. The structure of the flowers and fruits, however, is typical umbelliferous. Many *Eryngium* species are singularly decorative plants grown for their showy upper leaves, bracts and thistle-like flower heads.

Ecology Sawtooth coriander prefers a partly shaded site and fertile, not too dry soils, e.g. in meadows, plantations, waste places, along roadsides and forest edges, from the lowlands up to 1700 m altitude. Plants do not usually grow close together but appear as individual weeds.

Propagation and planting Sawtooth coriander can easily be propagated by seed. The seed, preferably freshly harvested, is sown directly in the field or first in a nursery. Propagation by stem cuttings is also possible. Sawtooth coriander can be relatively closely spaced at 12.5 cm × 12.5 cm.

Husbandry Sawtooth coriander is only cultivated on a small scale in South-East Asia, and no information is available on husbandry. As wild sawtooth coriander prefers well-drained, moist and fertile soils it will be necessary to enrich poor soils with fertilizer and to water during dry periods.

Diseases and pests No serious diseases and pests are known. In India *Cladosporium oxysporum* has been identified from leaf spots. In Indonesia sawtooth coriander is a common weed in cocoa plantations and the insect *Helopeltis theivora* has often been found on it. Ants may eat the broadcast seed.

Harvesting Individual tender leaves are harvested, leaving the topmost 3 leaves intact. On average, 10–15 leaves can be harvested per plant in 5–10 harvests at intervals of 1–2 weeks before flowering intervenes.

Yield No reliable information is available. A rough estimate for plots in the Philippines arrived at 10 t/ha of fresh leaves per harvest or 80 t/ha for the total crop.

Handling after harvest Leaves of sawtooth coriander should be marketed soon after harvesting because they wilt easily; packaging and refrigerated storage extend shelf life: packaged sawtooth coriander can be stored at 10°C for up to 2 weeks, but at 28°C for only 4 days.

Genetic resources and breeding There are no known germplasm collections or breeding programmes for sawtooth coriander.

Prospects Sawtooth coriander is commonly used as a flavouring in Thailand, Cambodia, Vietnam and China. The increasing interest in exotic dishes and the presence of Asian immigrant communities all over the world may lead to a growing market for this herb. An example is its popularization in the United States by Vietnamese refugees.

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M.H. van den Bergh

Etlingera Giseke

Prael. ord. nat. pl.: 209, 229, 251 (1792).

ZINGIBERACEAE

$x = 24, 26$; $2n = 48$ (*E. elatior, E. hemisphaerica*)

Major species and synonyms

- *Etlingera elatior* (Jack) R.M. Smith, Notes from the Royal Botanic Garden Edinburgh 43(2): 244 (1986), synonyms: *Alpinia elatior* Jack (1822), *Nicolaia speciosa* (Blume) Horan. (1862), *Phaeomeria speciosa* (Blume) Merrill (1922).
- *Etlingera hemisphaerica* (Blume) R.M. Smith, Notes from the Royal Botanic Garden Edinburgh 43(2): 245 (1986), synonyms: *Elettaria hemisphaerica* Blume (1827), *Nicolaia atropurpurea* (Teijsm. & Binn.) Valeton (1904), *Phaeomeria atropurpurea* (Teijsm. & Binn.) K. Schumann (1904).
- Other *Etlingera* species – see chapter on Minor spices (*Etlingera rosea* Burtt & Smith, *E. solaris* (Blume) R.M. Smith, *E. walang* (Blume) R.M. Smith).

Vernacular names

- *E. elatior*: Torch ginger (En). Indonesia: honje (Sundanese), kecombrang (Javanese), petikala (Moluccas). Malaysia: kantan (Malay), kechala (Iban, Sarawak), ubud udat (Kelabit, Sarawak).
- *E. hemisphaerica*: Indonesia: honje leuweung (Sundanese), honje hejo (Sundanese), honje laka (Sundanese). Malaysia: kantan liar (Malay).

Origin and geographic distribution *Etlingera* comprises about 57 species and is distributed from India, Burma (Myanmar), Thailand, Indo-China and China throughout Malesia to Polynesia and Australia. *E. elatior* probably has a wide natural distribution in Malaysia and Indonesia (Java, Sumatra) but is also widely cultivated pantropically for its aromatic and decorative flowering shoots. *E. hemisphaerica* probably originated from Java but is now also cultivated in some other parts of Malesia.

Uses *E. elatior* is the most commonly cultivated and the more valuable of the two species, but both are used very similarly. The young flowering shoots are an ingredient of curries, eaten as fresh vegetable and cooked in mixed vegetables. In Malaysia they are used for flavouring 'laksa' (a special noodle dish) and many other local dishes. Less commonly, the heart of young vegetative shoots is used for flavouring dishes or eaten raw with rice. Half-ripe fruits are also applied in cooking; ripe fruits can be eaten raw, or processed into candies. *E. elatior* is nowadays cultivated in many tropical regions as an ornamental, even on a commercial scale as a cut flower in Hawaii and Australia. In Malaysia, a decoction of the fruit of *E. elatior* is traditionally used to treat earache while a decoction of the leaves may be applied for cleansing wounds. The leaves are also used by women during confinement and mixed with other aromatic herbs in water for bathing, to remove body odour. The stem is made into matting in Sumatra. The stems also have potential as raw material for the manufacture of paper. The rhizome is reported to yield a yellow dye.

Production and international trade *Etlingera* is only traded fresh at local markets. Production is mainly derived from home gardens or semi-managed groves in secondary forest where *Etlingera* occurs naturally.

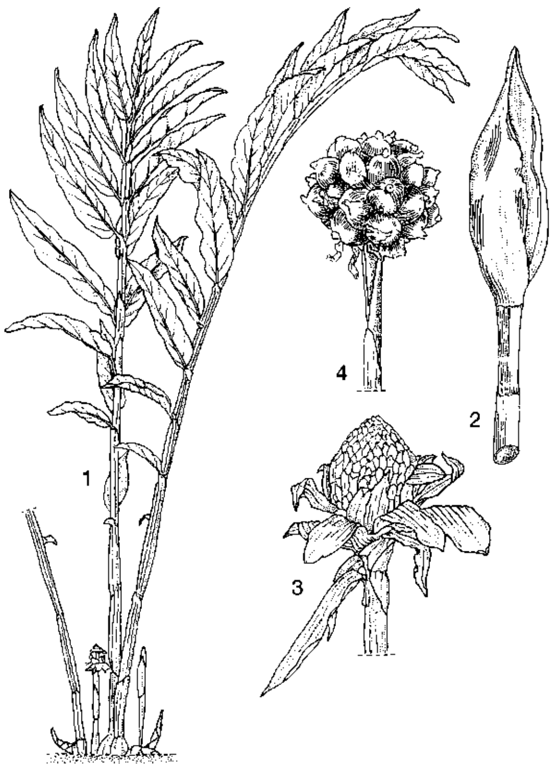
Properties Per 100 g edible portion, flowers of *E. elatior* contain: water 91 g, protein 1.3 g, fat 1.0 g, carbohydrates 4.4 g, fibre 1.2 g, K 541 mg, P 30 mg, Ca 32 mg, Mg 27 mg, Fe 4 mg, Mn 6 mg, Zn

0.1 mg, Cu 0.1 mg. The composition of the heart of young vegetative shoots is very similar. The edible part of the flowering shoots consists of the receptacle and the petals, which constitute about 45% of total weight of the harvested flowering shoot. The edible heart of young vegetative shoots makes up about 20–25% of the total weight of unpeeled shoots.

Extracts of *E. elatior* show antimicrobial activity against various pathogenic microorganisms with minimum inhibitory concentration and minimum lethal concentration in the range of 100–800 μg/ml and 400–800 μg/ml respectively. They also display cytotoxicity against Hela (human cervical carcinoma) cells: median curative dose (CD50): 10–30 μg/ml.

The essential oil obtained by steam distillation from the young flowering shoots of *E. elatior* contains about 45 compounds, the main groups being aliphatic alcohols, aliphatic aldehydes and terpenoids.

Description Robust, perennial, tillering herbs with a rhizome at or near the ground surface or embedded deep underneath. Stems usually numerous and close together, terete with thickened base, often large and erect, up to 7 m tall, consisting of tightly telescoping leaf sheaths, with leaf blades only in the upper part. Leaves distichous, alternate, on short rubust petioles, large, up to more than 2 m long. Inflorescence headlike, lateral, arising from rhizome near base of a stem, on long slender peduncle or short erect subterranean stalk; peduncle covered with persistent, distichous scales; bracts numerous, persistent, outer involucral bracts sterile, large and coloured, inner ones smaller and gradually changing into the fertile bracts; floral bracts with one flower to each, the outer ones wider than those near the centre of the inflorescence; bracteoles embracing the flowers, tubular, deeply split, 2 or 3-toothed; calyx tubular, usually with 3 short teeth, unilaterally split; corolla tubular, tube shorter or nearly as long as calyx, the 3 lobes held more or less erect; labellum short, erect or very long with lowest part erect, joined at the base to the lower part of the filament and together forming a tube, lateral staminodes absent or present as rudimentary hairy teeth or bumps; as the flower fades the labellum rolls inwards; filament very short, erect, anther large, bent forward; pistil with 3-locular ovary, style slender with broad stigma, at base surrounded by 3 shortly connate stylodes. Fruiting head globose or cylindrical, the fruits close together, globose or long-beaked, indehiscent, with thick pericarp.



Etlingera elatior (Jack) R.M. Smith – 1, habit; 2, young flowering shoot; 3, inflorescence; 4, infructescence.

Seeds numerous, angular, surrounded by a very acid aril.

– *E. elatior*. Leafy stem 2.5–5 m × 2–4 cm. Rhizome thick, cream, pinkish when young. Leaves 15–30, the lowest much smaller than the higher ones; sheath green, sometimes tinged with red, often densely pruinose; ligule broadly orbicular, about 1.5 cm long and wide, ciliate; petiole 1–2.5(–4) cm long; blade elliptical-oblong, 20–90 cm × 10–20 cm, base rounded or cordate, margins wavy, apex with a short narrow point, glabrous but very densely and finely dotted, glossy green above, underneath often purplish when young. Peduncle 0.5–2.5 m × 1.5–2.5 cm; involucral bracts elliptical, 7–18 cm × 1–7 cm, crimson-pink, fleshy, spreading with apices reflexed at flowering and near the apex with a dark red appendage; floral bracts as long as or somewhat longer than the flowers, pink (but sometimes also red, purplish or white), outer ones showing a transition from the involucral bracts becoming smaller towards the centre of the inflorescence; bracteoles deeply split, about 2 cm long, white, much smaller than the flowers; calyx 3–3.5 cm long, unilaterally split, 3-toothed; corolla pink, up to 4 cm long; labellum spatulate, about 4 cm long, deep crimson with white or yellow edges; stamen 2.5 cm long, filament white-hairy, anther red; style thin, red and hairy near the apex, stigma clavate, dark red. Fruiting head subglobose, about 10–20 cm in diameter; fruit berry-like, globose, 2–2.5 cm in diameter, with silky hairs, green when unripe, turning red at maturity. Seeds small, numerous, black-brown, with a white or pink, translucent aril.

- *E. hemisphaerica*. Leafy stem 3–7 m × 2–2.5 cm. Rhizomes robust. Leaves 15–25, the lowest much smaller than the higher ones, glabrous; sheath green; ligule broadly rounded, about 1.5 cm long and wide, woolly ciliate at the margin; petiole 1–2(–4) cm long; blade linear-elliptical, 15–75 cm × 5–15 cm, base rounded, sometimes subcordate or somewhat unequal-sided, margin woolly ciliate, apex shortly pointed, bronze-green, with numerous dots and reddish veins, underside wine red. Peduncle 35–100 cm × 1–1.5 cm, scales 5–12 cm long; inflorescence axis about 5 cm long, diameter of flowering part 7–8 cm; involucral bract broadly ovate-elliptical, 5–10 cm × 3–7 cm, red, with rounded or shortly acuminate apex with light green margin; floral bract up to 3.5 cm × 1 cm, smaller than the flower, red with pale green margin; flowers numerous, 4–7 cm long; bracteoles translucent, tinged red, up to 2.5 cm long; calyx red, 3-toothed, about 3.5 cm long; corolla 4–5 cm long, tube white, lobes red with white membraneous margins; labellum broadly ovate, boat-shaped, 2–2.5 cm long, with a rounded apex and undulate margins, dark red with yellow edges except towards the base; stamen with white filament and anther crimson on back, 9 mm long; pistil with light red style and large, crimson, shining stigma. Fruiting head subglobose, up to 12 cm in diameter; individual fruits globose or obovoid, about 5 cm × 2.5 cm, with short hairs, beak up to 1.5 cm long, velvety yellow. Seeds numerous, ovoid-angular, brownish-black with white aril.

Growth and development *Etlingera* starts flowering in the second year after planting a piece of rhizome. The inflorescence is adapted for pollination by birds, such as the sunbird *Anthreptes malacensis*.

Other botanical information The genus *Etlingera* originates from 1986 when Burtt and Smith united the closely related genera *Achasma* Griff., *Nicolaia* Horan. and *Geanthus* Val. into one genus. Several forms of *E. elatior* have been observed in the wild and in cultivation. The forms with pink involucral bracts are normally consumed as a spice. The forms with red or deep red bracts and leaves that are permanently purplish underneath, are more commonly used as ornamental or as cut flower, although the pink-bracted ones are equally popular. The white-bracted form is very rare and occurs in the wild. There are two flower types, one with a white-edged labellum (the cultivated ones) and the other with a yellow-edged labellum (the wild type).

Ecology *Etlingera* grows in primary and secondary forest, in forest edges, and in secondary vegetation near villages. It occurs mainly at lower elevations and is not found in montane forest areas. Soils rich in organic matter are preferred. *E. elatior* is tolerant of acid soils.

Propagation and planting *Etlingera* is propagated chiefly by rhizome fragments, but sometimes by seed as well. Rhizome fragments should be handled with care as the buds are rather sensitive to high temperatures and easily dry out. Since *E. elatior* can become very robust, it is planted at 1–2 m × 1–2 m in moist, relatively shaded locations, preferably near pools, streams or drains. Although *E. hemisphaerica* is seldom planted, it would need similar treatment, being equally large, robust and tillering as *E. elatior*.

Husbandry Shading of *Etlingera* seems necessary only during the establishment phase, to protect the germinating buds. Weeding is carried out during the first 3–4 months after establishment until most weeds are shaded out. *E. elatior* responds well to fertilizer applications.

Diseases and pests No serious diseases and pests are known to affect *Etlingera*. In cultivation trials in Sarawak some leaf-cutting insects were observed, but without significant damage to the crop.

Harvesting Since *Etlingera* are perennials, flowering occurs throughout the year and continuous harvesting is possible.

Yield No accurate yield data are available. There are some preliminary indications that the annual production of unpeeled vegetative shoots of *E. elatior* may easily reach 10–15 t/ha, the yield of young flowering shoots being only 0.5–1 t/ha.

Handling after harvest *Etlingera* is traded fresh at local markets.

Genetic resources and breeding There are no known germplasm collections of *Etlingera*. Some breeding work is being carried out to improve the ornamental value of torch ginger; some success in this respect has been reported with artificial intergeneric hybrids *Etlingera* × *Alpinia*.

Prospects In South-East Asia *E. elatior* is chiefly used as a spice and to a limited extent as an ornamental. It would be interesting to investigate the potential of *E. elatior* for processing (pickling, canning, juice production), the production of industrial food flavours and of other natural products such as essential oils. Since knowledge of its medicinal properties is limited, research on chemical constituents and biological activity may be worthwhile. Another possible economic application is to use stems and leaves for paper production.

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H. Ibrahim & F.M. Setyowati

Foeniculum vulgare Miller

Gard. Dict., ed. 8 no. 1 (1768).

UMBELLIFERAE

$2n = 22$

Synonyms *Anethum foeniculum* L. (1753), *Foeniculum capillaceum* Gilib. (1782), *F. officinale* Allioni (1785).

Vernacular names Fennel (En). Fenouil, aneth doux (Fr). Indonesia: adas (general), adas londo (Javanese), hades (Sundanese). Malaysia: adas pedas. Philippines: anis, haras (Tagalog). Laos: phak s'i:. Thailand: thian-klaep, phakchi-duanha (northern), yira (Central). Vietnam: ti[eer]u h[oof]i h[uw][ow]ng.

Origin and geographic distribution Fennel most probably originated from southern Europe and the Mediterranean. It is cultivated throughout the world and has naturalized in many places. It is grown throughout South-East Asia and is subspontaneous on several mountains in East Java; for example, it is common on Mt. Tengger.

Uses Fennel has been used for flavouring since antiquity; young leaves as well as fruits (referred to in the spice trade as 'seeds') are used for this purpose. The leaves are eaten raw or more commonly cooked. The leaves are also used as a potherb, especially in fish sauces and garnishing. Ground fennel fruit is often a constituent of curry powder. In Java, fennel is eaten as lalab and used to season pickles. Stem pieces are chewed for their pleasant taste. Several sweet and common or bitter fennel cultivars are applied in the food industry to flavour, for instance, beverages, candies, baked goods, meat and meat products, gravies and processed vegetables. The swollen basal parts of the petioles ('bulbs') of cv. group Florence Fennel are cooked as a vegetable like celery, mainly in Italian cooking.

All plant parts contain essential oil, which is used for flavouring and in detergents, cosmetics such as soaps, creams, lotions and luxury perfumes. Sweet-fennel oil is extensively applied in food products, including alcoholic and non-alcoholic beverages, desserts, candies baked goods, meat and meat products, condiments and relishes. The maximum permitted level in food products is about 0.3%. Bitter and sweet-fennel oils are applied in perfumery, with maximum permitted levels of 0.4%. Bitter-fennel oil is used to a limited extent and mainly in cosmetics. Anethole obtained from sweet fennel is applied as a flavouring agent and in the pharmaceutical and perfume industries but anethole from cheaper sources is usually available. The fruit residue after essential-oil distillation may be fed to cattle. In the United States the regulatory status 'generally recognized as safe' has been accorded to common or bitter fennel (GRAS 2481), sweet fennel (GRAS 2482) and sweet-fennel oil (GRAS 2483).

The medicinal use of fennel also dates from ancient times. It was mentioned by Hippocrates and Dioscorides as a diuretic and emmenagogue, and has been used as a main ingredient in the Arab and Ayurvedic medicinal systems. The fruits are widely known as a stimulant, stomachic, expectorant and carminative, and are official in many pharmacopoeias. The roots are traditionally applied as a diuretic and purgative. In Indonesia, the fruit is traditionally used in combination with the bark of *Alyxia* species, to give an agreeable flavour to medicines, but the combination is also believed to be useful in the treatment of sprue. In India, the leaves are considered diuretic, fruit juice is administered to improve the eye-sight, and hot infusions of the fruits are applied to increase milk secretion and to stimulate sweating. In Chinese herbal medicine, fennel is used against gastro-enteritis, hernia, indigestion and abdominal pain, to resolve phlegm and to stimulate milk production. In modern western medicine, fennel and fennel oil are administered as a carminative or flavouring agent in certain laxatives. In Germany, the fruits are used in phytomedicine against dyspeptic disorders, as a gastro-intestinal antispasmodic, as an expectorant and in syrups against children's coughs.

Production and international trade Few trade statistics are available for fennel alone but it is one of the most important aromatic spices in the category 'spice seeds' in the international market. It is estimated that in the period 1976–1980, annual world imports of spice seeds as a whole averaged about 50 000 t. India, China and Egypt are the main suppliers of fennel. In 1988 the United States imported 1750 t fennel fruits, valued at US$ 1.8 million. The annual value averaged US$ 3.4 million over the period 1990–1994. India alone produces annually 20 000 t fennel fruits, of which 2000 t are exported. The main producer of Florence fennel is Italy, with an area of 18 000 ha and an annual production of 400 000 t 'bulbs'.

The estimated world production of essential oil from bitter fennel is about 28 t, that of sweet fennel about 255 t. In 1993 the total value of the essential oils was estimated at US$ 700 000 and US$ 7.7 million respectively.

Properties Sweet-fennel fruits smell strongly of anise, and have a penetrating and sweet taste, whereas those of bitter or common fennel have a pungent odour and taste like camphor. Fennel 'seed' contains per 100 g edible portion: water 8.8 g, protein 15.8 g, fat 14.9 g, carbohydrates 36.6 g, fibre 15.7 g, ash 8.2 g (Ca 1.2 g, Fe 19 mg, Mg 385 mg, P 487 mg, K 1.7 g, Na 88 mg, Zn 4 mg), vitamin A 135 IU, niacin 6 mg, thiamine 0.41 mg and riboflavin 0.35 mg. The energy value is about 1440 kJ/100 g. The lipid fraction contains 9.9 g total mono-unsaturated and 1.7 g total poly-unsaturated fatty acids. The fixed oil is mainly composed of petroselinic acid 60–75%, oleic acid and linoleic acid. The fruits also contain flavonoids and stigmasterol.

The essential oil is present in secretory channels in most parts of the plant, but in mature fennel about 95% of the oil is located in the fruit. The essential oil yield after hydrodistillation of the fruits is 1.9–3.1%. The oil obtained from sweet fennel possesses a finer odour and flavour than that from bitter fennel. The major compound of sweet-fennel oil is (E)-anethole (up to 70–80%), which is responsible for the anise fragrance and sweet taste. The (E)-anethole content of bitter-fennel oil is only half that of sweet fennel, whereas the fenchone content is higher. Fenchone is considered a character-impact constituent of bitter-fennel oil.

The concentration of major compounds of the essential oil varies with plant part and development stage. In bitter fennel populations from different origins it was found that the anethole and fenchone concentrations were higher in the waxy and ripe fruits than in the stems and leaves, whereas the α-pinene concentration showed an opposite trend. Furthermore, the anethole and fenchone concentrations increased from the bud stage until fruit ripening, whereas the α-pinene and limonene concentrations decreased. The estragole concentration varied only slightly. The composition of essential oil from the roots is very different from that from the rest of the plant, with terpinolene, myristicin and apiole being the main compounds.

The residue after essential-oil distillation from fennel fruits contains 14–22 % protein and 12–18.5% fat.

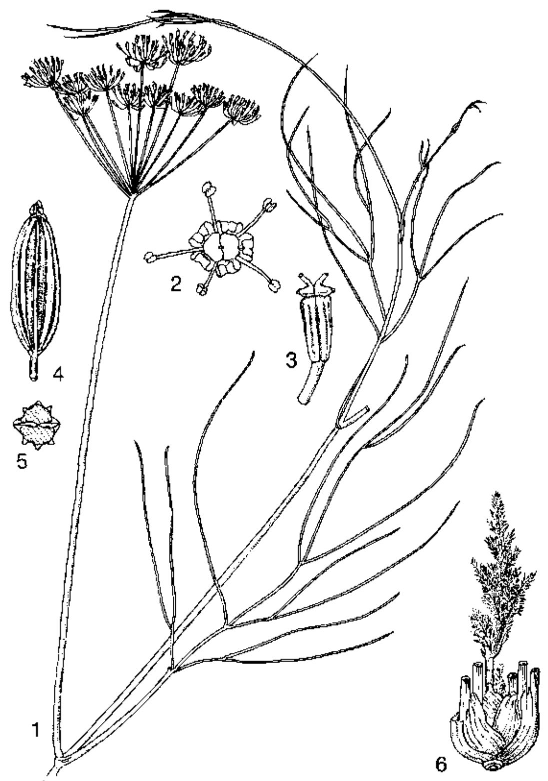
The ground spice and the essential oil have antioxidant properties, whereas the essential oil has antifungal and antibacterial activity. The essential oil also possesses antiviral activity against potato virus X (PVX), tobacco mosaic virus (TMV) and tobacco ringspot virus (TRSV), and shows spasmolytic effects on smooth muscle of experimental animals. Monographs on the physiological properties of sweet-fennel oil and bitter-fennel oil have been published by the Research Institute for Fragrance Materials (RIFM).

With respect to individual compounds, anethole is effective against *Staphylococcus aureus*, *Escherichia coli*, *Candida albicans* and *Corynebacterium* sp. and has stimulant and carminative properties. Furthermore, it is allergenic and weakly insecticidal. Long-term studies have shown that anethole is not carcinogenic. The oestrogenic activity (e.g. increasing milk secretion and promoting menstru-

ation) of fennel is probably due to polymers of anethole, such as dianethole and photanetholes. Estragole is a hepatic carcinogen in mice. In experiments with rats, limonene limited mammary tumour growth.
The 1000-seed weight is 4–8 g.

Adulterations and substitutes Commercial spice samples are sometimes adulterated with sand, stem tissue, fruit residues left after distillation, immature or mouldy fruits or with other umbelliferous fruits. Fennel fruits and those of anise (*Pimpinella anisum* L.) are often confused and substituted for each other.
Anethole-rich oil is also obtained from anise and star anise (*Illicium verum* Hook.f.). The cultivation of fennel as a source of anethole was developed in Europe to reduce the dependence on anethole obtained from star anise in Asian countries. Anethole can also be produced chemically, either by hemisynthesis from estragole (e.g. extracted from *Pinus* oil) or by complete synthesis. However, in some countries the use of synthetic anethole for food products is prohibited by law.

Description Robust, perennial, glabrous, glaucous, aromatic herb, up to 2 m tall. Stem erect, terete, longitudinally striate, profusely branched at all heights, internodes hollow when older. Leaves alternate, decompound, sheathed, lower leaves largest; leaf sheath forming an open cylinder, at base embracing the stem, 2–15 cm long, margins white scarious, sheath much larger and fleshier in Florence fennel; rest of petiole subterete, 0–10 cm longer than the sheathing part, longitudinally striate; blade triangular in outline, up to 30 cm × 50 cm, 2–6-pinnately divided into filiorm, acute, blue-green lobes 1–14 cm long; primary pinnae odd-numbered 3–19. Inflorescence a terminal, compound umbel, up to 20 cm in diameter but usually smaller; peduncle (1–)5–16(–24) cm long; primary rays 5–30(–70) per umbel, 0.5–12 cm long, unequal in length, the shortest ones in the centre; secondary rays (pedicels) (2–)10–30(–45) per umbellet, up to 1 cm long, unequal in length; involucre and involucels absent; calyx vestigial at the top of the ovary; petals 5, distinct, subovate in outline, up to 1.5 mm × 1 mm, with strongly inflexed, notched apex, yellow, with a thin membranous outgrowth on the ventral side of the midrib; stamens 5, about 1.5 mm long; pistil with inferior, bilocular ovary, 2 styles, each with a stylopodium at base and a stigma at top. Fruit an ovoid-cylindrical, usually slightly curved schizocarp, 3–8.5 mm × 2–2.5 mm, light green to yellow-brown, splitting at maturity into 2 mericarps each with 5 prominent ridges and oil-vittae between the ridges. Seed with testa adnate to the pericarp. Seedling with epigeal germination.



Foenicum vulgare Miller – 1, flowering branch; 2, flower at male flowering stage; 3, flower at female flowering stage; 4, fruit; 5, cross-section of fruit; 6, 'bulb' of Florence fennel.

Growth and development Seeds normally germinate within 2–3 weeks after sowing. Initial development is slow, with a period of 2–2.5 months from sowing to stem emergence. Flowering occurs 3–4 months after sowing, and the time from sowing to first fruit harvest is 5–7 months. Fruit yield of the second year is generally higher than that of the year of sowing. Fennel is mainly cross-pollinated, and fruit ripening is uneven. Florence fennel is generally grown as an annual.

Other botanical information The taxonomy of *Foeniculum* is not yet well established. Generally only one species (*F. vulgare*) is distinguished, which is often subdivided into 2 subspecies: subsp. *piperitum* (Ucria) Coutinho (wild taxa) and subsp. *vulgare* (cultivated taxa). The group of cultivated taxa can best be classified into cultivar groups and cultivars. Several cv. groups can be distinguished:

- cv. group Bitter Fennel or Common Fennel (other names: *F. vulgare* Miller var. *vulgare*; cultivars have fruits with a bitter aftertaste;
- cv. group Florence Fennel (other names: *F. azoricum* Miller, *F. vulgare* Miller var. *azoricum* (Miller) Thellung, finocchio; cultivars with swollen basal part of the petiole which is eaten cooked as a vegetable;
- cv. group Sweet Fennel (other names: *F. dulce* Miller, *F. vulgare* Miller var. *dulce* (Miller) Battand. & Trabut, Roman fennel; cultivars with sweet-tasting fruits.

Other cv. groups and cultivars have been distinguished on the basis of the composition of their essential oil.

Fennel is often confused with dill (*Anethum graveolens* L.), which is closely related and easily crosses with fennel. Fennel and dill can be distinguished by their odour (fennel smells like liquorice, dill smells bitter and slightly pungent) and their ripe fruits (fennel has wingless fruits, dill fruits have a wide wing). Fennel plants without fruits may be recognized by their finely dotted stems, the longer and broader leaf-sheaths and the usually shorter secondary rays in the umbel.

Ecology Fennel prefers sunny locations in fairly mild climates. In India, it is grown as a cold-weather crop in the north and does not perform well in the south, except at higher elevations. In Java, it is found at altitudes from 500 m upwards. The tops are injured by long cold spells and fennel is therefore cultivated as an annual in temperate regions. Fennel is found under conditions of 500–2000(–4000) mm mean annual rainfall and 6–12(–24)°C mean annual temperatures. Moisture stress causes the basal stalk to split. In Tasmania it has been shown experimentally that fennel (cv. C25) is a long-day plant, with umbel initiation and stem elongation occurring at photoperiods longer than 13.5 h per day.

Fennel thrives in non-acid, well-drained loams and tolerates a soil pH between 6.3 and 8.3. It is salt-sensitive.

Propagation and planting Fennel is normally propagated by seed, though vegetative multiplication by root or crown division is also possible. Seed germinates well between 15–20(–25)°C, with better germination in dark than in light, and it retains its viability for 2–3 years. Propagation through in vitro culture is also possible. Callus may be produced from explants (hypocotyl, stem or petiole) in MS medium at 25°C. From callus, plants may be regenerated through embryogenesis or organogenesis, or cell suspension cultures may be formed.

Seeds are usually sown in drills, 35–120 cm apart. Within the row seedlings are thinned to 15–50 cm when 8–10 cm tall. The sowing depth is 1–3 cm. Seed may also be sown first in a seedbed and seedlings transplanted when 7.5–10 cm tall. Transplants are often used in Florence fennel cultivation in northern temperate zones to assure a mature crop within a short growing season. The seed rate is either 3–5 kg/ha when using seedbeds and transplanting or 10–15 kg/ha for direct sowing. The seedbed should be roofed or covered with straw until the seeds germinate, about 2–3 weeks after sowing. Seedlings are ready for transplanting about 2–2.5 months later, when they are 10 cm tall.

In Indonesia, fennel is usually planted in home gardens.

In vitro production of active compounds The use of cell cultures has no importance for the production of fennel essential oil or anethole. In callus cultures and cell suspensions of fennel, hardly any or no aromatic compounds were found. In tissue colonies derived from plantlet apices very small amounts of anethole were produced.

Husbandry Fennel should be kept free from weeds, especially during the initial growth period. A fennel crop may develop a large vegetative mass (40–60 t/ha) for which ample nutrient supply is required. However, too much nitrogen should be avoided, as this may result in disproportionately high vegetative mass and poor fruit development. In India, 20–30 t farmyard manure per ha is usually applied at planting and 45 kg/ha N as top dressing. In various parts of India it has been experimentally shown that 80–100 kg/ha N and 40 kg/ha P is optimal.

Fennel is usually grown as an irrigated crop in India. Under European conditions, irrigation stimulated both crop growth and the essential oil content of the fruits. Under dry summer conditions in Tasmania, total biomass yield was increased most by irrigation during the stem elongation phase, whereas umbel dry weight and umbel oil yield were increased most by irrigation at late flowering. The anethole content of the umbel oil was not affected by irrigation.

Florence fennel may be earthed up when the shoot base starts to swell, to encourage blanching.

Diseases and pests In India the most important disease is powdery mildew caused by *Leveillula taurica*, characterized by white, powdery patches on the plant and shrivelling and shedding of fruits. Fennel is also susceptible to fungal diseases caused by *Cercospora* and *Sclerotinia* spp. Aphids are the most important insect pest.

Harvesting Tender shoots and leaves for culinary purposes should be gathered before flower-bud formation. Fruits are harvested when they are sufficiently hard and waxy in appearance, which is usually 5–7 months after sowing. Not all umbels on a plant mature at the same time. Umbels are ready for harvesting when they turn brown. If harvested late, fruits are liable to shatter; if harvested early they are immature and of lesser quality. Selective harvesting of fully mature umbels is desirable but labour-intensive. To reduce labour costs, entire plant tops can be cut when the fruits on the side branches are nearing the waxy stage. When harvesting the crop several times in a season, the best fruits and best oil quality are usually obtained from the first harvest.
Florence fennel is harvested after enlargement of the 'bulbs'. The top of the foliage is removed just before flowering, followed later on by the remainder of the plant, after which the roots are cut away. Bulbs with some foliage are cleaned of soil and debris, washed and stored.

Yield Fruit yields range from 0.5–2 t/ha, but yields are low in the first year. European fruit yields are 0.4 t/ha in the first, 1–2 t/ha in the second, and 0.6–1.5 t/ha in the third year. Average fruit yields in India are 0.5–0.7 t/ha, reaching up to 1.5 t/ha with adequate management.

Handling after harvest The harvested material should be dried carefully in the shade, since sun-drying will lead to loss of essential oil. After drying, fruits are separated from the stems and cleaned. For essential-oil production, fruits are then crushed and immediately distilled to prevent loss of oil by evaporation.

Genetic resources Many countries have some fennel germplasm in their collections. In Europe some larger collections are available in Russia (St. Petersburg, N.I. Vavilov Research Institute of Plant Industry with 128 accessions), Germany (Braunschweig, Institute of Crop Science with 72 accessions) and in France (Brion, Unité Experimentale d'Angers, Groupe d'Etude et de Contrôle des Variétés et des Semences (GEVES) with 52 accessions). As fennel is cultivated and naturalized throughout the world, there is no danger of genetic erosion.

Breeding As cross-fertilization is predominant in fennel, most cultivars are highly heterozygous and heterogeneous. High seed-yielding cultivars have been obtained in Europe and India, as well as cultivars tolerant of aphids. Present selection work on sweet and bitter fennel is mainly aimed at increased fruit yield and fruits with high anethole content. Other objectives include resistance to parasites, reduced stem size and precocity. In Europe, a range of commercial cultivars of Florence fennel is available.

Prospects Because fennel prefers mild climates and needs long days for flowering, the prospects for the crop as a source of fruits and essential oil in South-East Asia are limited. It is likely that its present role as locally used condiment for the vegetative parts, vegetable and medicine will remain, but an increase in use and cultivation is not to be expected.

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Purwaningsih, Harmida & M. Brink

Illicium verum Hook.f.

Curtis's Bot. Mag. 114: plate 7005 (1888).

ILLICIACEAE

$2n = 28$

Synonyms *Illicium anisatum* Lour. (1790), non L. (1759), *Badianifera officinarum* Kuntze (1891).

Vernacular names Chinese star anise, star anise (En). Badianier, anis étoilé, anis de Chine (Fr). Indonesia: bunga lawang (general), adas cina (general), pe ka (derived from Chinese). Malaysia: bunga lawang, adas china. Philippines: sanque, sangke (Tagalog, Cebuano). Cambodia: phka chann, pôch kak lavhav. Thailand: chinpaetklip, poikak. Vietnam: h[oof]i, hoi sao, b[as]t gi[as]c h[uw][ow]ng.

Origin and geographic distribution *Illicium verum* is only known from cultivation although semi-wild populations of abandoned plantations occur. It most probably originated from south-eastern China (Guangxi, Guangdong, Fujian, Guizhou and Yunnan) and northern Indo-China (Laos, Vietnam). Here Chinese star anise has been used as a spice and medicine for over 3000 years. It is also cultivated in Hainan, Taiwan and Japan. Cultivation in other parts of the world seems difficult. In Europe Chinese star anise was thought to originate from the Philippines because in 1578 the navigator Thomas Cavendish brought the first fruits, originating from southern China, to Europa via the Philippines.

Uses The dried ripe fruit is the Chinese star anise of commerce. Chinese star anise fruit and its essential oil are used as flavouring agents in numerous kinds of products: beverages (liqueurs, brandies), chewing gum, baked goods, gelatin, puddings, meat and meat products. In the United States the regulatory status 'generally recognized as safe' has been accorded to star anise (GRAS 2095) and star anise oil/oleoresin (GRAS 2096). The maximum permitted level of star anise oil in food products is about 0.07%. The essential oil is also used to scent soap, tobacco and dental cream. In traditional medicine a powder or decoction of the fruits is used to treat abdominal colic, lumbago arising from a deficiency in the kidney, vomiting and epigastric pain due to cold in the stomach and diarrhoea. It also has an antidiarrhoeal effect due to the prevention of intestinal fermentation. The fruit is an oestrogenic agent used to increase milk secretion, promote menstruation, facilitate childbirth, increase libido and alleviate symptoms of male climacteric. The essential oil has stimulant, antiseptic, stomachic, carminative and mildly expectorant properties. It is part of an antitussive formulation and is employed against rheumatism, body lice and bed bugs, but may cause dermatitis in susceptible people. When the essential oil is administered therapeutically as a bronchial expectorant for upper respiratory tract congestion and as gastrointestinal spasmolytic, the permitted mean daily dose is 0.3 g. The oil is used as starting material for the production of synthetic oestrogens (e.g. diethylstilbestrol, diethylstilbestrol dipropionate) and perfumes (e.g. p-panisaldehyde). The dried ripe fruits are often found in potpourris. The wood of Chinese star anise is fine-grained and suitable for pulping, but it is not recommended for forest plantations because of its slow growth.

Production and international trade China and Vietnam are the major producers and exporters of Chinese star anise fruits and essential oil, with China providing the bulk of both. In 1955–1960 annual production of Chinese star anise essential oil in China was estimated at 300–500 t. In Vietnam annual production of Chinese star anise fruits is estimated to be more than 2000 t, of which 1600 t is exported to Cuba, China and the Russian Federation. Annual export of Chinese star anise essential oil by Vietnam is 200–250 t, mainly to France, the Czech Republic and Slovakia. In China the imported star anise from Vietnam is blended with the Chinese product and exported mainly to France. In 1993 the estimated annual world value of Chinese star anise essential oil was US$ 4.5 million. Between 1994–1997 the price per kg oil ranged from US$ 6.5–10.9 on the international market.

Properties Chinese star anise contains catechins, pro-anthocyanidin, essential oil, fixed oil and mineral substances. The essential oil is obtained by steam distillation of fresh or partly dried, whole or comminuted fruits (yield of 3–3.5%) and is mostly present in the fruit wall, not in the seed. Its chief constituent is trans-anethole (70–93%). It also contains small amounts of cis-anethole, which is 15–38 times more toxic to animals than trans-anethole.

Chinese star anise essential oil is a clear, colourless or pale yellowish liquid with the characteristic anise-like odour and sweet flavour. Fresh leaves and twigs contain 0.3–0.4% essential oil which has a composition similar to the oil from the fruits and is often blended with fruit oil. Decorticated seeds contain 55% fatty oils of which the composition is approximately: oleic acid 60%, linoleic acid 20%, myristic acid 10% and stearic acid 8%.

In products with anise as the main flavouring principle, overdosage with essential oil of Chinese star anise is difficult. In products where anise is not wanted, or is wanted only as a trace component, overdosage is easily attained. The normal use level of Chinese star anise essential oil is 5–10 mg per 100 g; the minimum perceptible is 0.3–0.6

mg per 100 g. Anethole can be isolated from the oil by freezing. The French 'anisette'-flavoured brandy, a beverage with 43–45% alcoholic and saturated solution of anethole, is very popular. It separates anethole and becomes 'cloudy' when chilled below room temperature or when water is added.
A monograph on the physiological properties of star anise oil has been published by the Research Institute for Fragrance Materials (RIFM).

Adulterations and substitutes In commerce, Chinese star anise fruits (usually with 8 follicles) are sometimes adulterated with similar looking fruits from *I. cambodianum* Hance or from *I. anisatum* L. *I. cambodianum* is a wild tree from Burma (Myanmar) and Indo-China; its fruits usually consist of 12–13 follicles which contain hardly any essential oil. *I. anisatum* (Japanese star anise) is a tree of Japan and China, also cultivated as a medicinal and ornamental plant, with poisonous fruits (usually with 8 follicles); its follicles are more irregular with wrinkled sides and finer, longer apices; their odour is balsamic and the taste bitter. Chinese star anise essential oil derived from the fruit is often adulterated with the oil from the leaves and twigs which, however, is hardly different. Occasionally, small amounts of minerals or fatty oils are added. Chinese star anise products compete with those of anise (*Pimpinella anisum* L.) for some of the same market because the major essential-oil component in both is anethole. Chinese star anise oil can be distinguished from anise oil by the presence of small amounts of 1,4-cineole. Synthetic anethole is often used as a substitute for natural anethole. The amount of cis-anethole in synthetic anethole, however, is sometimes much larger than in natural anethole, which mainly consists of harmless trans-anethole.

Description Evergreen tree, 8–15(–20) m tall; trunk diameter at breast height up to 25 cm; bark white. Leaves alternate, simple, coriaceous, glandular-punctate; petiole about 1 cm long; blade elliptical to obovate or lanceolate, 5–15 cm × 1.5–5 cm, margin entire, apex acute, lower side pubescent. Flowers axillary, solitary, bisexual, regular, 1–1.5 cm in diameter, white-pink to red or greenish-yellow; pedicel 0.5–1 cm long; perianth lobes 7–12, arranged spirally; stamens 11–20, arranged spirally, with short, thick filaments; carpels usually 8, free, arranged in a single whorl. Fruit a capsule-like follicetum, 2.5–4.5 cm in diameter, consisting of an agregate of (5–)8(–13) follicles arranged around a central axis in the shape of a star (hence the name star anise); each follicle

Illicium verum Hook.f. – 1, flowering branch; 2, flower; 3, fruit.

boat-shaped, 1–2 cm long, rough, rigid, reddish-brown, containing 1 seed, splitting along the ventral edge when ripe. Seed subcylindrical to compressed ovoid, 8–9 mm × 6 mm, smooth, glossy, light brown, containing copious, oily endosperm.

Growth and development Chinese star anise starts flowering when trees are 6 years old. In the main production areas it flowers twice a year. Fruits are harvestable about 3–4 months after flowering. First harvesting is possible from 7–10-year-old trees. Full harvest is reached in the next 10 years and trees can remain productive for several decades. Quite often productive years alternate with less productive years.

Other botanical information The common names 'star anise' and 'star anise oil' are generally used for *I. verum* products. Unfortunately, several other *Illicium* species produce similar fruits which are often also named 'star anise', causing confusion and sometimes danger. Most dangerous is the existing confusion with *I. anisatum* L. (synonym: *I. religiosum* Siebold & Zucc.), whose fruits are poisonous (one of their constituents is shikimine) and are used medicinally and as insecticide and are sold in herbal medicines to treat e.g. toothache and dermatitis. *I. anisatum* occurs wild and in cultivation in Japan, southern China and Taiwan. Some differences with *I. verum* fruits are: its fruit is smaller and does not form a regular star due to the abortion of some carpels, its follicles are not swollen in the middle and are more pointed at the apex. To avoid confusion and danger it is better to use the scientific names or to use 'Chinese star anise' for *I. verum* and 'Japanese star anise' for *I. anisatum*.

Illicium L. comprises about 40 species, 5 in America and 35 in eastern Asia (7 in Malesia).

Ecology The ecological requirements of Chinese star anise are not well known. Its main cultivation areas lie in the cooler tropics and subtropics at altitudes up to 2000 m, with average annual temperatures of 12–18°C, average annual precipitation of 1000–2000 mm and with soils with a pH of about 5.8.

Propagation and planting Chinese star anise is propagated by seed. Seeds are collected from vigorous trees, 15–20 years old, and only fully matured, brown seeds are chosen. They rapidly lose their viability and should be sown in a nursery within 3 days of harvest. Soaking the seeds for 6 hours in warm water (35–37°C) stimulates germination. In the nursery seedlings have to be protected against direct sunlight. After 1–1.5 years the seedlings (at the 4th leaf stage) are transplanted to other nursery beds and set about 25 cm apart. About 3 years later they can be planted out in the field, 5–7 m apart, in well-manured planting holes.

Husbandry Regular weeding is recommended in Chinese star anise, to facilitate the harvesting of fruits and to prevent fire hazards. Mulching is applied at the end of the rainy season to retain much of the soil moisture for the coming dry season. Application of farm manure (about 7 kg per tree) and additional ammonium sulphate at the start of the rainy season is recommended.

Diseases and pests Chinese star anise does not suffer seriously from diseases or pests. The nematode *Radopholus similis* has been reported to occasionally cause some damage.

Harvesting The fruits of Chinese star anise are harvested before they are fully ripe when the essential-oil content is highest, usually in August-September. Two harvests per year are possible. Harvesting is carried out by climbing the trees and picking the fruits by hand, or by using a long pole with a little hook connected to the end to detach the fruits. In some areas in China young twigs and fresh leaves are also harvested and either distilled separately or together with fresh fruits for essential-oil production.

Yield On average, 5–10 kg fresh fruit/tree can be obtained from trees 13–25 years old, and 10–20 kg/tree from trees older than 25 years. In very good years, up to 40–45 kg/tree can be harvested. After drying, 100 kg of fresh fruit yields 25–30 kg of dried fruit. Fresh fruits yield 2.5–3.5% essential oil, dried ones 8–9%.

Handling after harvest For use as a spice harvested fruits are placed in flat baskets, exposed to the sun for about 10 days and then preserved in a cool dry place. The dried product is then traded on the international spice market. When essential oil is desired, fresh fruits, or occasionally dried ones, are steam-distilled for 48–60 hours. The oil is then stored in airtight containers at temperatures not exceeding 25°C, protected from light. Crude Chinese star anise oil in the original drums is often very impure, and may contain e.g. water, sand and fruit residues. Filtration and rectification in modern distilleries is then necessary.

Genetic resources and breeding Some germplasm collections of *I. verum* are maintained in China and Vietnam. There are no known breeding programmes for *I. verum*.

Prospects Cropping techniques and distillation methods applied for Chinese star anise should be improved substantially to enhance yield and quality of fruits and oil. The potential for cultivating Chinese star anise in other South-East Asian countries needs further investigation.

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Vu Ngoc Lô

Laurus nobilis L.

Sp. pl.: 369 (1753).

LAURACEAE

$2n = 48$ (most common number in a polyploid series of 36, 42, 48, 54, 60, 66, 72)

Synonyms *Laurus undulata* Miller (1768).

Vernacular names Laurel, bay-laurel, sweet bay (En). Laurier (Fr). Philippines: laurel, pamInta-dahon (Cebuano).

Origin and geographic distribution *L. nobilis* originates from the eastern Mediterranean and Asia Minor, where natural stands still provide a considerable part of the laurel leaf production. A chemically distinct form is native to China. *L. nobilis* is grown and occasionally naturalized throughout the drier tropics, subtropics and warm temperate areas. It is also cultivated as a garden and pot plant worldwide.

Uses In classical Greece *L. nobilis* was dedicated to the god Apollo and its leaves were used to make wreaths given in honour to heroes and poets. Later, its name is found in words such as 'laureate' and 'baccalaureus' from which the word 'bachelor' has been derived. Laurel was also used medicinally and was said to protect against lightning.

Laurel leaves, also commonly called bay-leaves, and to a much lesser extent the berries, are now primarily used for culinary purposes. The leaves are applied as seasoning, imparting an excellent fragrant aromatic flavour with notes of lemon and clove to meat, game, poultry and fish dishes, syrups, sauces, stocks and stews. As fresh leaves are rather bitter, they are usually dried, but the widely used old dry leaves are considered a poor substitute for leaves that have been dried for a few days only. Laurel leaves are one of the few spices that should be added early in cooking as the taste gradually intensifies. They should be removed before serving the dish as they remain fibrous and their sharp edges can cause internal injuries. Crushed or powdered laurel leaves are an essential ingredient of mixed pickling spices and are used industrially in meat products, sauces, vinegar and pastries. In industry, an essential oil steam-distilled from the leaves is used similarly. In Italy and Turkey laurel leaves are used for packaging liquorice. Such large amounts were formerly used in this way that in Scandinavia nearly all the laurel leaves used for household purposes were recycled liquorice packaging material, and their somewhat sweeter flavour became accepted as the true flavour of laurel leaves. Leaves are also placed in containers of cereal products, to repel insects.

Laurel leaf oil plays a minor role in perfumery to provide a masculine note. It is used especially in bath products. In the United States the regulatory status 'generally recognized as safe' has been accorded to laurel leaves (GRAS 2124), laurel leaf oil (GRAS 2125) and laurel leaf oleoresin (GRAS 2613). Laurel fruits yield a fatty oil that also contains aroma components. It is occasionally used as a culinary herb oil and in perfumery (GRAS 2612). *L. nobilis* has a long history of medicinal use. The fruit oil is still included in some pharmaceutical preparations. Both leaves and berries are traditionally considered as astringent, stomachic, stimulant and narcotic. A decoction of the leaves is used for treating problems of the urinary organs and dropsy. It is also considered a powerful emmenagogue. The seed oil is used to treat rheumatic pains.

Several cultivars of laurel are grown as ornamentals. On the other hand several ornamentals referred to as 'laurel' aren't true laurels, and some are even poisonous. Laurel can be sheared into distinctive shapes making it a popular container and garden plant. In South-East Asia *L. nobilis* is only planted as an ornamental, mainly at higher elevations in the highlands. Laurel wood is occasionally used for posts. The flexible twigs were formerly used to make hoops for small barrels.

Production and international trade World trade in dried laurel leaves exceeds 2000 t per year. Turkey is the major producer and exporter (about two-thirds of world trade). The import of dried leaves of laurel in Western Europe is estimated at 800 t annually. Small quantities are also imported from Morocco, Albania and Israel.

Properties The leaf of laurel has a pleasant odour and its taste is characteristically strong, pungent and aromatic. The bitterness of fresh leaves is easily removed by drying. Per 100 g, dried laurel leaves contain: water 4.5–10.0 g, protein 7.6–10.6 g, fat 4.5–8.8 g, carbohydrates 65 g, ash 3.7–4.2 g (Ca 1 g, P 110 mg, Na 20 mg, K 530 mg, Zn 40 mg, Fe 530 mg), thiamine 0.10 mg, riboflavin 0.42 mg, niacin 2 mg, ascorbic acid 47 mg, and vitamin A 6185 IU. The energy value is 1725 kJ/100 g. The essential oil from the leaves (up to 3%) comprises over 140 components with 1,8-cineole predominating (up to 50%). The catechin content of the leaves is high and is preserved by drying. Oil from China is characterized by eugenol. The oil is colourless with strong aromatic, stimulant and narcotic properties. It has a warm, fresh, penetrating, camphor-like odour resembling eucalyptus and a distinctly sweet, soothing and cooling, medicinal, spicy, peppery flavour with good persistence and bitter aftertaste. The fresh buds and young leaves contain 3-octulose (D-gluco-L-glycero-3-octulose), a compound rarely found in nature. The seeds contain about 25% fatty oil comprising at least 20 fatty acids with lauric acid (11–52%), palmitic acid (5–17%), oleic acid (15%–40) and linoleic acid (17–23%) as the main constituents. The petroleum ether extract of the fruits contains several characteristic compounds, e.g. 10-hydroxyoctacosanyl tetradecanoate, 1-docosanol tetradecanoate and 11-hydroxytriacontan-9-one. A monograph on the physiological properties of laurel leaf oil has been published by the Research Institute for Fragrance Materials (RIFM).

Adulterations and substitutes 1,8-Cineole, α-terpinyl acetate and methyl eugenol are used to reinforce the essential oil.
In Indonesia, leaves of *Syzygium polyanthum* (Wight) Walpers ('salam') are commonly used in the same way as laurel leaves at higher latitudes. The words laurel and bay occur in the names of many plants that are not related to *L. nobilis* and that are no substitutes for it. Examples are: bayberry (*Myrica pensylvanica* Loisel.), California bayberry (*M. californica* Cham. & Schlecht.), California bay (*Umbellularia californica* (Hook. & Arn.) Nutt.), mountain laurel (*Kalmia latifolia* L.), sheep laurel (*K. angustifolia* L.), bay rum tree or West Indian bay tree (*Pimenta racemosa* (Miller) J.W. Moore), cherry laurel (*Prunus laurocerasus* L.) and loblolly bay (*Gordonia lasianthes* (L.) J. Ellis).

Description Aromatic, usually dioecious, evergreen tree or shrub, 2–15 m tall, in cultivation usually pruned to less than 3 m; bark blackish-brown. Branchlets terete, young ones dark brown, nearly glabrous or with soft hairs. Leaves alternate; petiole 0.5–1.5 cm long, violet-red when fresh, glabrous or with sparse soft hairs; blade oblong-elliptical to oblong-lanceolate, 3–15 cm × 2–5 cm, coriaceous, entire, base cuneate, margins somewhat undulate, apex acute to acuminate or obtuse, dark green above, pale green beneath, glabrous on both sides but glandular-punctate, with 10–12 pairs of lateral veins prominent on both sides. Inflorescence an axillary, 4–5-flowered

Laurus nobilis L. – *1, flowering branch; 2, female flower; 3, male flower; 4, inflorescence; 5, fruit.*

umbel, solitary or mostly 2–5 arranged in a fascicle or short raceme; peduncle 2–12 mm long, glabrous or with soft hairs; bracts 4, rounded, inner ones 0.7–1 cm long, outer ones smaller, coriaceous, glabrous outside, with silky hairs inside; pedicel 2–5 mm long, with soft hairs; tepals 4, ovate-oblong to rounded, 4.5–6 mm long, obtuse, with soft hairs on both sides; flowers yellowish green; male flower with 8–12 fertile stamens, outer whorl eglandular, second and third whorls with 2 sessile, reniform glands at middle of filaments, anthers ellipsoidal, 2-celled, introrse, pistillode present; female flower with 4 staminodes bearing an appendage at apex of connective, ovary 1-celled, style short, stigma somewhat enlarged. Fruit a globular to ellipsoidal drupe, 1–2 cm long, dark violet to glossy black at maturity.

Growth and development Pruning studies in laurel indicate that leaf growth is fast during the first 30–40 days, becoming slower in the next 15–20 days and generally ceasing after about 60 days. Leaves may remain on the tree for 1–3 years. The essential oil accumulates in the palisade and mesophyll cells of the leaves and reaches a content of 1–3% on a fresh weight basis. The content increases during early summer and reaches its maximum in midsummer.

Other botanical information The chromosome number of *L. nobilis* is very variable. The existence of a polyploid series with chromosome numbers 36, 42, 48, 54, 60, 66 and 72 has been demonstrated. It has been postulated that most cultivated forms of *L. nobilis* are autotetraploid with basic chromosome number $x = 12$, and that this basic chromosome number may be of masked or ancient polyploid nature with $x' = 6$. Apomixis has been observed in tetraploid laurel.

There are many ornamental cultivars of laurel, e.g. 'Aurea', the golden or variegated laurel, 'Crispa' with undulating leaf margins, 'Angustifolia' with narrow leaves.

Ecology Laurel, which occurs naturally in Mediterranean maquis and forest vegetation, is very adaptable, growing well at average annual temperatures from 8–27°C and with an annual precipitation of 300–2200 mm. Light frost is tolerated. More severe frost may kill the aboveground parts, but plants may regrow from their basal parts. Its light requirements are high. A decrease in temperature may reduce leaf size and oil content of the leaves. Leaves from trees grown at or near sea-level are reported to contain more oil than those from trees grown on inland hills. Although well-drained, deep and fertile soils are preferred, growth is satisfactory on a wide range of soils with a pH of 4.5–8.3. Waterlogging is not tolerated.

As a potted plant, laurel grows well with at least 4 hours or more per day of direct sunlight. Day temperatures of at least 18°C and night temperatures of 4–13°C are best. The soil must be slightly moist at all times.

Propagation and planting Information on the propagation of laurel is contradictory. In Italy seed is preferred, as cuttings are reported to root poorly, elsewhere cuttings are preferred as they result in more uniform plantings. Mature shoots 10–12 cm long with apical buds are taken as cuttings; they grow more vigorously than cuttings with only lateral buds. Root cuttings can be used if treated properly, e.g. dipped in fungicide immediately after they are taken. Marcotting is sometimes practised to obtain plants for ornamental purposes. The seeds are soaked in warm water for 12–24 hours before sowing. Only fresh seed should be used, as viability is lost rapidly. Shading and mulching the seedbeds promotes germination and early seedling growth. Germination takes 3–4 months and seedlings can be transplanted when 2 years old.

The appropriate planting distance depends on the method of harvesting and availability of water. For smallholders harvesting manually an initial spacing of 3 m × 3 m, gradually thinned to 6 m × 6 m is recommended. In commercial plantations in Israel with provisions for irrigation the spacing is 2–3 m, whereas in Russia hedges planted at 0.5 m × 2 m are used in plantations that are harvested mechanically.

Husbandry Laurel can be intercropped with annual crops during the first 2–4 years. This will not only provide additional income to the grower but also reduce weeding requirements. Leaf residues after distillation of oil may serve as mulch and as protection against frost. As an ornamental, laurel is often grown in containers filled with equal volumes of sand, loam and peat. Transplanting is only necessary once every few years.

Diseases and pests There is little information on the economic damage in laurel caused by diseases and pests. Diseases are far more important than pests and are often widespread. The two most damaging diseases of laurel are root rot caused by *Phytophthora* spp. and leaf-spot by *Colletotrichum* spp. *Phytophthora cinnamomi* causes yellowing and wilting of leaves and dieback of twigs. Severe attack may be fatal in both young and mature plants. Affected plants should be uprooted, burnt and replaced by healthy stock. *Colletotrichum nobile* causes brown spots to develop on the leaves and become progressively larger. A general but low level of infection is common. Though it results in little damage to the leaves, it affects leaf oil content more severely. Routine spraying is necessary in severely affected areas, but care must be taken to avoid fungicide residues on harvested leaves. In Italy, scale insects and psyllids cause some damage.

Harvesting Leaves of laurel are harvested in summer or autumn in temperate regions. Plants established from cuttings in spring can be harvested for the first time in the autumn of the same year if irrigated or in the following year if rainfed. Up to three harvests can be made annually, but two cuts have been shown to give the highest yield. Harvesting is usually done manually, early in the day. In Russia systems have been developed to mechanically harvest laurel grown in hedges. When berries are harvested they are mostly picked at the same time as the leaves.

Yield The yield of laurel leaves is strongly affected by the frequency of harvesting and irrigation. Rainfed trees harvested twice a year yield up to 5 t/ha of dried leaves per annum. In Russia, cutting twice at a height of 40 cm yielded 5 t/ha of dried leaves, twice as much as from cutting only once a year at a height of 8–10 cm. Yields of 9 t/ha of fresh leaves (5 t/ha of dried leaves, as leaves lose about 40% moisture upon drying) have been obtained under intensive management and irrigation, even from one harvest per year.

Handling after harvest Laurel leaves are dried in thin layers in trays in a sheltered area for 12–15 days. The leaves are pressed lightly under boards to prevent curling. Steam distillation of leaves yields laurel leaf oil; an essential oil can also be distilled from the berry.

Genetic resources and breeding There are no known germplasm collections and breeding programmes of laurel. There seem to have been no attempts to extend the cultivation of laurel into new areas such as South-East Asia.

Prospects The demand for selected dried herbs, including laurel leaves, on the major European markets is expected to grow much faster in the industrial food and institutional catering sectors than the relatively stable growth rate in the retail sector. However, most of the user countries are quality conscious and new exporters should be able to provide dried herbs of high quality, particularly in terms of cleanliness and absence of pesticide residues, if they are to successfully penetrate the market, which is currently not short of supplies.

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I.B. Ipor & L.P.A. Oyen

Lippia graveolens Kunth

Nov. gen. sp. 2: 267 (1818).
VERBENACEAE
$2n$ = unknown

Synonyms *Lippia berlandieri* J. Schauer (1847).

Vernacular names Mexican oregano, Mexican marjoram, Mexican wild sage (En). Marjolaine du Mexique, origan marjolaine (Fr). Philippines: oregano, karabo (Cebuano).

Origin and geographic distribution Mexican oregano is native in the area extending from the southern United States to Nicaragua. It is cultivated in Central America.

Uses Mexican oregano is an important spice in Mexico and Central America, where the fresh or dried leaves, as well as the flowers, are used as a culinary seasoning. It is particularly suited to flavour fish, sausages, tomato sauces and other dishes requiring a strong oregano flavour. In the United States, it is often employed in Mexican-style food (e.g. chili con carne) and in Italian-style food (e.g. pizza). A herbal tea can be made from the dried leaves. In the United States the regulatory status 'generally recognized as safe' has been accorded to Mexican oregano (GRAS 2827).

The essential oil, obtained from the plant by steam distillation, has largely replaced the herb in the food industry. The oil is used to flavour relishes. Mexican oregano extract is applied as a flavour component in many food products and drinks. The maximum permitted level in food products such as condiments and milk products is about 0.3%.

In Mexico, leaf decoctions of Mexican oregano are credited with anti-diabetes properties, and are used against dysentery, as an intestinal antiseptic, a febrifuge and to regulate menstruation. If taken during pregnancy, they may cause abortion. A syrup from the leaves is used against coughs and colds.

Production and international trade Mexican oregano is mainly produced and exported by Mexico. The annual oregano production in Mexico in the early 1990s was estimated at 3000 t, of which about 2000 t was exported to the United States, 600–800 t consumed locally, and the remainder exported to other smaller markets. The United States import price of Mexican oregano is usually only half to two-thirds of that of oregano (*Origanum vulgare* L.) from Greece.

Properties The fresh plant contains per 100 g: water 69.2 g, protein 5.0 g, fat 1.5 g, carbohydrates 17.6 g, fibre 4.1 g, ash 2.6 g (Ca 649 mg, P 56 mg, Fe 5.32 mg), carotene 8.38 mg, thiamine 0.39 mg, riboflavin 0.04 mg, niacin 1.64 mg and ascorbic acid 62.0 mg.

The leaves of Mexican oregano have an intense oregano aroma and the flavour is stronger, sharper and more pungent than that of *Origanum* species. The essential-oil content is about 3–4%. The principal compounds of the essential oil are thymol (40–60%) and carvacrol (3–25%). Published analyses of the essential oil vary widely, both quantitatively and qualitatively. Thymol and carvacrol have strong fungicidal, anthelminthic and irritant properties. The aerial parts and roots of Mexican oregano also contain lapachenole, which is carcinogenic and may contribute to its antifertility activity.

Adulterations and substitutes Mexican oregano shipments have been found adulterated with herbs such as sumac (*Rhus coriaria* L.), and all United States imports now have to be tested for its presence.

Various other *Lippia* species are harvested from the wild and are used as oregano in Mexico and Central America, and they are probably also incorporated into export materials. They include *L. affinis* J. Schauer, *L. cardiostegia* Benth., *L. formosa* T.S. Bandeg., *L. fragrans* Turcz., *L. micromera* J. Schauer, *L. origanoides* Kunth, *L. palmeri* S. Watson and *L. umbellata* Cav. Species from other genera are sometimes also called Mexican oregano and used similarly, e.g. *Monarda fistulosa* L. var. *menthaefolia* (Graham) Fernald, *M. austromontana* Epling and *Poliomintha longiflora* A. Gray.

Description Aromatic, slender shrub or small tree, up to 9 m tall. Branchlets slender, straggling, brittle, densely resinous-punctate, hairy, with flaky bark. Leaves opposite; petiole 2–20 mm long, appressed pubescent; blade oblong to ovate or elliptical, 1–7 cm × 0.5–3.5 cm, base rounded, margin regularly crenate with closely set blunt teeth, apex rounded or acute, upper and lower surface velvety hairy and resinous-glandular. Inflorescence a compact, nearly globose or cylindrical spike, 4–12 mm long, usually in groups of 4–6 in leaf axils; peduncle as long as the petiole; flowers fragrant, white to yellow, small, sessile in the axil of a bractlet; bractlets plainly 4-ranked, conduplicate-carinate, narrow lanceolate, 3–8 mm long, imbricate, connate at base, hirsute-tomentose, resinous-glandular; calyx small, persistent, 3–6 mm long; corolla salverform, tube 3–6 mm long, limb spreading and 4-parted; stamens 4, didynamous, inserted at about the middle of the corolla tube; pistil with 2-celled ovary, short style and thickened stigma. Fruit small, dry, included in the calyx, dividing into 2 nutlets at maturity.

Lippia graveolens Kunth – 1, habit; 2, flowering shoots.

Growth and development Mexican oregano usually flowers from July to September in Mexico. In areas where wild Mexican oregano is harvested regularly, plants are often not taller than 1 m.

Other botanical information Several other *Lippia* species in addition to those mentioned under 'Adulterations and substitutes' have uses for food and medicine. *L. alba* (Miller) N.E. Brown (anise verbena, licorice verbena) is a slow-growing shrub, native to temperate and tropical Central and South America. Its fresh leaves have an anise aroma reminiscent of lemongrass (*Cymbopogon citratus* (DC.) Stapf) and the herb is valued as a flavouring of soup, meats, fish and for making tea.

It is grown as an essential-oil crop in Argentina and is widely cultivated elsewhere as a medicinal, aromatic and ornamental plant. *L. dulcis* Trévir. (synonym: *Phyla scaberrima* (Juss. ex Pers.) Moldenke), (Mexican lippia, sweet lippia), a perennial herb native to Central America, is used in Central America as a medicine against bronchial ailments. The essential oil contains the very sweet sesquiterpenoid hernandulcin, but the potential use for sweetening purposes is limited, because the main constituent of the oil is the toxic compound camphor. Camphor may also be responsible for the reputed abortifacient activity of Mexican lippia. *L. micromera* (Spanish thyme), a shrub native to South America, is used in the Caribbean as a culinary herb and medicinal plant. As is the case for Mexican oregano, there is no information on the cultivation or use of these *Lippia* species in South-East Asia.

Ecology Mexican oregano is adapted to arid conditions and prefers full sun. It is susceptible to frost, especially under wet conditions. In its native habitat, Mexican oregano grows on rocky-clay roadsides, hills, bushy slopes and cliffs. For cultivation, well-drained, moderately fertile soils are optimal. In pots, a free-draining, medium-fertility, loam-based mixture is recommended.

Agronomy Mexican oregano is propagated by seed, by basal or nodal softwood cuttings or by semi-hardwood cuttings. It is predominantly collected from the wild. In cultivation, high soil fertility or ample fertilizer application and abundant water supply result in increased leaf size but reduced flavour. In the southern United States it is grown as an annual. In Mexico, harvesting starts mid-September, when foliage is at its maximum, and it continues until the first frosts occur, usually in November at higher altitudes. Harvested shoots and leaves are used fresh or dried and stored in airtight containers. It is recommended to dry the branches upside down and away from direct light. In Mexico, picked leaves are generally spread on the ground and dried in the sun for 4–5 days. Grinding may lead to loss of chemical components and ground material has less aroma and freshness.

Genetic resources and breeding There seems to be some danger of genetic erosion, because natural Mexican oregano populations in Mexico are overharvested. It is not known if germplasm collections and breeding programmes exist.

Prospects At present, Mexican oregano is not cultivated in South-East Asia. However, interest in oregano is increasing in Japan and other Asian countries, including Malaysia, the Philippines and Thailand. This is largely due to the popularity of fast-food chains, which offer Italian and Mexican-style dishes flavoured with oregano. With respect to export production, the prospects for Mexican oregano are less promising than those for *Origanum* species, because the latter have a wider market and fetch higher prices on the world market. For both types of oregano, only clean material of acceptable colour is exportable, and new producers must be aware of the strict quality specifications.

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H.C. Ong & M. Brink

Myristica Gronov.

Fl. orient.: 141 (1755).

MYRISTICACEAE

x = unknown; $2n = 44$ (*M. argentea*)

Major species

- *Myristica argentea* Warb., Bot. Jahrb. 13: 311 (1891), synonym: *M. finschii* Warb. (1897).
- *Myristica fragrans* Houtt. – see separate article.
- *Myristica succedanea* Reinw. ex Blume, Rumphia 1: 186 (1837), synonyms: *M. radja* Miquel (1864), *M. schefferi* Warb. (1897), *M. speciosa* Warb. (1897).

Vernacular names General: Nutmeg (En). Indonesia: pala. Malaysia: pendarah, pianggu

(Malay), kumpang (Sarawak). Papua New Guinea: nutmeg. Philippines: duguan. Burma (Myanmar): mutwinda. Thailand: chan-pa. Vietnam: nh[uj]c d[aaj]u kh[aas]u.

- *M. argentea*: Papua or Papuan nutmeg, long nutmeg, Macassar nutmeg (En). Noix de muscade mâle, noix de muscade longue (Fr). Indonesia: pala Irian (general), pala lelaki (Java), henggi (Irian Jaya). Malaysia: pala papua.
- *M. succedanea*: Halmahera nutmeg (En). Indonesia: pala patani (Ternate), pala onin (Ternate), pala utan (Bacan).

Origin and geographic distribution *Myristica* consists of about 100 species. The main centre of origin is New Guinea, and from there it has spread eastward and westward. At present it is found from southern India and Sri Lanka, throughout South-East Asia towards northern Australia, the Solomon Islands, Fiji, Tonga and Samoa.

- *M. argentea* probably originated in Irian Jaya, where it occurs both wild and cultivated. In the wild, it is confined to the Bomberi peninsula of Irian Jaya, while its cultivation has spread along the coast, also into Papua New Guinea. Occasionally, it is also cultivated in the Moluccas.
- *M. succedanea* is found wild and cultivated in the northern Moluccas (Ternate, Tidore, and Bacan; in Halmahera it is said to be cultivated only).

Uses The main products of *Myristica* are the shelled dried seed (nutmeg) and the dried aril (mace) which are used as spice or condiment to flavour foods, pickles, sauces and puddings. These spices derive from various *Myristica* species but most of the nutmeg and mace in trade is from *M. fragrans*, with *M. argentea* as a good second. *Myristica* is also used in traditional medicine, and the seeds were formerly used in pharmaceuticals and cosmetics. The pericarp of the fruit of some species is edible, and numerous *Myristica* species are used as timber. The wood has a reddish brown colour and is usually soft and not durable. *M. argentea* and *M. succedanea* and possibly also other species have been tried as a rootstock for *M. fragrans*. The red sap (kino), present in the bark of most species, can be used as a dye that gives a permanent brown stain.

- *M. argentea*. The shelled seeds are used like those of *M. fragrans*. The aril enters the market as 'Macassar mace'. Medicinally the seed is used in Indonesia to induce hypnosis, to suppress fever and coughs, to treat diarrhoea, as an aphrodisiac and as a purgative (on the traditional medicine market, seed of *M. argentea* has replaced seed of the Moluccan *M. fatua* Houtt. but the vernacular names have remained the same). The volatile oil is used in the perfume and soap industry. A minor use of the fruits is the preparation of jelly from the husks and pickled husks, while confiture is obtained by sweetening young fruits or thinly sliced husks of unripe fruits.
- *M. succedanea*. The small shelled seeds are used like those of *M. fragrans*.

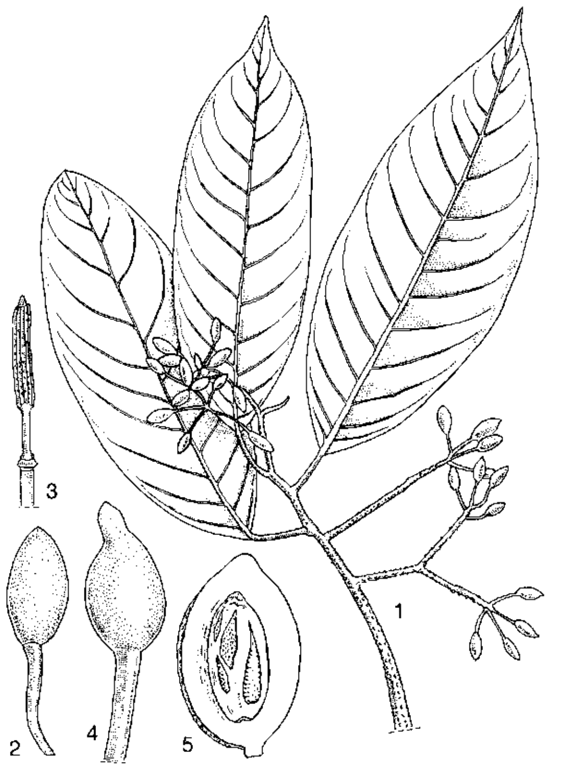
Production and international trade By far the most important *Myristica* species is *M. fragrans*. There is some cultivation of *M. argentea* in Irian Jaya and Papua New Guinea. The products of some other species are gathered in forests when prices are favourable. For 1959, the production of *M. argentea* in Irian Jaya was estimated at 300 t of dry seed and 60 t of dry mace. Recent production and trade figures are only available for *M. fragrans*. Prices of the products of *M. argentea* and other species are lower than those of *M. fragrans*, and overproduction of the latter also limits the market for other *Myristica* species.

Properties Nutmeg and mace contain essential oil and fat or nutmeg butter. Nutmeg butter is highly aromatic, orange-coloured, and consists mainly of trimyristin. The amount of fat in the seeds of *M. argentea* is similar to that in *M. fragrans* but the fat is brighter. The essential oil and the nutmeg butter contain myristicin, which is hallucinogenic and poisonous. The myristicin content of *M. argentea* is only 0.13% compared with more than 2% for seeds of *M. fragrans*. As the psychotropic activity of nutmeg (euphoria, hallucinations) seems to be linked to myristicin, *M. argentea* will probably have less effect than *M. fragrans*. The safrole content of *M. argentea* (0.5%) is higher than that of *M. fragrans* (0.3%); safrole has been reported to be a possible carcinogen. The lignan meso-dihydroguaiaretic acid, isolated from the aril of *M. argentea*, shows strong antibacterial action against *Streptococcus mutans*, which causes tooth caries. In mice, an aqueous extract of the seeds depresses motoric activity and caffeine-induced excitement, and prolongs spontaneous and pentobarbital-induced sleep; it also inhibits brief tonic spasms caused by pentobarbital before hypnosis.

Adulteration and substitutes All *Myristica* spp. of which the seed and aril are used as spice can be used as cheaper substitute or as adulteration of the true nutmeg *M. fragrans*. For South-East Asia the most important substitutes are *M. argentea* and *M. succedanea*. Ground nutmeg from

M. argentea can be identified by its high safrole content.

Description Dioecious, small to large evergreen trees up to 35(–45) m tall; bole cylindrical, up to 70(–100)cm in diameter, plank or flying buttresses and stilt roots often present; bark surface usually fissured, sometimes flaking, brownish or occasionally black and brittle, inner bark pinkish to reddish brown; crown monopodial, often pyramidal with spreading radial limbs; twigs striate, with or without lenticels. Leaves distichous, simple and entire, petiolate; blade elliptical to elliptical-lanceolate or elliptical-obovate, up to 50 cm long, often glaucous and glabrous or glabrescent or with persistent indumentum of dendroid and/or scale-like hairs below; secondary veins often sunken above, straight or curved, tertiary venation finely reticulate and forming a close network; stipules absent. Inflorescence an axillary panicle with flowers in cymes or subumbels reduced to short woody knobs, female inflorescence usually less branched or more compact; bracts small, caducous, bracteoles persistent, usually embracing the base of the flower on one side; flowers actinomorphic, small, pedicelled, often fragrant; perianth elliptical to flask-shaped or campanulate, white to yellow, generally 3-lobed, often with reflexed lobes, glabrous or variously hairy outside, usually glabrous inside; male flower with an androecium of 6–30 anthers fused with their back to a central column and with their sides to each other; female flowers with a superior, globose to subglobose, 1-celled, glabrous or hairy ovary, stigma sessile, minutely 2-lobed. Fruit globose to ovoid, pyriform or oblong, with thick fleshy wall, orange-yellow, or rusty brown, eventually splitting into 2 halves, 1-seeded. Seed ellipsoidal, enclosed in a red to orange aril which is laciniate to the base or nearly so, seed-coat hard; kernel with ruminate endosperm containing oil and much starch. Seedling with hypogeal germination; leaves arranged spirally.



Myristica argentea Warb. – 1, leafy twig with male inflorescences; 2, male flower bud; 3, staminal column; 4, female flower bud; 5, half fruit showing seed with aril.

- *M. argentea*. Tree 15–20(–25) m tall; bark dark or blackish grey with very small scales; sap red; older twigs rugose by conspicuous wart-like lenticels. Leaves chartaceous; petiole 1.5–2 cm long; blade mostly elliptical-lanceolate, 10–20 (–25) cm × 4–6(–10) cm, cuneate at base, lower surface silvery by short cobweb-like indumentum, midrib and 9–13 pairs of veins sunken above, prominent beneath. Male inflorescence 2–5 cm long, slender, simple or mostly forked once, bearing 3–5 flowers; pedicel slender, 1–1.3 cm long; perianth ellipsoidal, 7–11 mm × 5 mm, medium brown, subglabrous; female inflorescence 1–1.5 cm long, main axis usually simple, but sometimes bifurcate; pedicel 8 mm long; perianth ovoid-ellipsoidal, 8–10 mm × 5–5.5 mm with a beak-like apex; ovary flask-shaped, 3–4 mm × 7 mm, light brown-tomentose. Fruit ellipsoidal, 4.5–8.5 cm × 4.5–5.5 cm, slightly narrowed at both ends, glabrescent, yellow with some brown pustules. Seed oblong-cylindrical, up to 4 cm long, broadening at the base, shiny black-brown; aril thin, red.
- *M. succedanea*. Tree 8–15 m tall with stilt roots and a pyramidal crown; twigs stoutish, slender towards the top. Leaves subcoriaceous; blade broadly elliptical, elliptical-lanceolate, oblong-lanceolate, less often oblong-ovate or oblanceolate, 9–22 cm × 4–11 cm, shiny dark green above, silvery minutely hairy but late glabrescent beneath with veins brownish or reddish-brown; veins 10–18 pairs, from faint to impressed above, prominent beneath. Male inflorescence rusty-tomentulose, usually bifurcate, main axis

1–2 cm long; pedicel 0.7–1 cm long; flower oblongoid, 7–10 mm × 4 mm, medium brown-tomentulose outside, cream-coloured and glabrous inside, fragrant; female inflorescence shorter than the male, 0.5–1 cm long, simple or occasionally bifurcate; pedicel 1 cm long; flower ovoid, 7–10 mm × 5 mm, fragrant, ovary rusty-tomentulose. Fruit subglobose to ovoid-ellipsoidal, 7 cm × 4 cm, tomentulose becoming glabrous; hull 1 cm thick. Seed broadly oblongoid, 3 cm × 2.5 cm, aril red, endosperm aromatic.

Growth and development After germination the testa remains around the cotyledons and they are shed together later on. The taproot, hypocotyl and plumule are freed from the testa by elongation of the cotyledonary petioles. The seedling stem grows in flushes, and develops cataphylls early in the growing season. Leaves produced at the end of the growing season are largest and form a pseudo-whorl. The shoot ends in a usually 'open' terminal bud from which the orthotropic growth proceeds in the next season. Branching occurs from the axils of the pseudo-whorled leaves, causing pseudo-verticillate branching from the main stem. The branches are usually more or less horizontal or somewhat drooping; they ramify to various degrees and in the periphery of the crown may carry twigs with inflorescences. The branch phyllotaxis is distichous. The general growth form of *Myristicaceae* is according to Massart's architectural model. Strong erect-growing renewal shoots may be produced after severe damage to the crown, showing dispersed phyllotaxis. In many *Myristicaceae* the flowers are pollinated by bees. The fruits are commonly dispersed by birds, including pigeons and hornbills.

Other botanical information The vernacular names of many *Myristica* spp. are derived from the word blood, referring to the blood-red sap that exudes when the bark is slashed.

Many *Myristica* spp. of freshwater swamp or peat-swamp forest have stilt roots, but these do not seem to develop when they grow in drier conditions. Therefore stilt roots are not a useful characteristic for identification.

For an easy distinction with the true nutmeg (*M. fragrans*) the following characters can be useful: *M. argentea* has rough twigs with numerous lenticels and larger leaves with a silvery undersurface; the seed is longer and the aril is thinner and less divided. *M. succedanea* has stouter twigs and larger leaves and flowers, but its seed is smaller; the leaves are more coriaceous than those of *M. argentea*. Outside the region the following species are occasionally used as a spice: *M. castaneifolia* A. Gray (original spelling *castaneaefolia* A. Gray; synonyms: *M. macrophylla* A. Gray; *M. macrantha* A.C. Smith) in the Fiji Islands; *M. dactyloides* Gaertner (synonyms: *M. laurifolia* Hook.f. & Thomson, *M. diospyrifolia* A. DC.) in Sri Lanka; *M. malabarica* Lamk in western India; and *M. muelleri* Warb. in north-eastern Queensland (Australia).

Ecology Most *Myristica* spp. are inhabitants of lowland, tropical, evergreen rain forest up to 800 m altitude, though there are several mountain species as well. They usually form part of the second storey, though some reach the canopy top. *M. argentea* grows on slopes below 700 m altitude. *Myristica* is susceptible to strong winds, because of its superficial root system; in 1960, *M. argentea* plantations in New Guinea were severely damaged by storms. The areas in New Guinea where *M. argentea* thrives are also used for the cultivation of *M. fragrans*. Except where cultivated, *M. succedanea* is a tree of mountain forests and probably rare nowadays. *Myristica* can be grown on various soil types.

Propagation and planting *Myristica* is usually propagated from seed collected from under the tree. The seed dries out easily, loses its viability rapidly, and cannot be stored. Shading is beneficial in the early growth stages. In New Guinea, trees are traditionally planted at distances of 3–4 m. Correct spacing is important, as trees flower at the end of the branches. Therefore, planting distances should be such that branches of neighbouring trees never meet. Full-grown trees of *M. argentea* can reach a height of 25 m and a spread of 10–12 m. In the first 20 years of their life cycle, the trees do not occupy all the space, and interplanting with other crops is an option.

Husbandry Traditionally, the products of *M. argentea* were gathered from the forest when prices were high, but by the end of the 19th Century some cultivation had started. Young wild plants from the forest were planted in abandoned shifting cultivation plots, resulting in extensive plantations after some decades, estimated at 1000–1500 ha. It is considered a semi-cultivated crop, the trees grow in the forest, but are individual property. Mature trees of *M. argentea* are always cultivated unshaded in New Guinea. During the period of harvest, weeds are removed from under the trees.

Harvesting The seed and mace of *M. argentea* should be treated in the same way as the products of *M. fragrans*, and should be harvested continuously. Traditionally, however, there are only two harvests of *M. argentea* in New Guinea: one in January and one in April.

Yield Adequately spaced and healthy female trees of *M. argentea* on average yield about 2000 fruits per year, the best trees 4000, and not adequately spaced trees only 300. At plant densities of 100 female trees per ha, each producing 2000 fruits per year, the annual yield amounts to 1200 kg seeds and 335 kg mace per ha.

Handling after harvest Traditionally, harvested fruits of *M. argentea* are peeled, and the mace is loosened, flattened and dried. Seeds are dried in the smoke of a fire, either in the house or in a special 'pala house'; they usually leave New Guinea unshelled and unsorted.

Genetic resources and breeding *Myristica* spp. are threatened by general deforestation activities, but they are seldom selectively logged for timber. Because of outbreeding, the variability within species is large. The Research Institute for Spice and Medicinal Crops (RISMC), Bogor, Indonesia, has a collection of 39 morphotypes (450 trees) of *Myristica* spp. However, they have not been utilized for breeding. There are no known breeding programmes elsewhere.

Prospects As the market for true nutmeg and mace is limited, it is unlikely that *Myristica* spp. that yield similar products of lower quality will become important in the near future.

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N.W. Utami & M. Brink

Myristica fragrans Houtt.

Nat. hist., part 2 (plants), fascicle 3: 333 (1774).
MYRISTICACEAE
$2n = 44$; the chromosomes are holokinetic, i.e. with the spindle attached along their whole length

Synonyms *Myristica officinalis* L.f. (1781), *M. moschata* Thunb. (1782), *M. aromatica* Lamk (1788).

Vernacular names Nutmeg (En). Noix de muscade (Fr). Indonesia: pala, pala Banda. Malaysia: pala. Philippines: duguan. Singapore: pokok pala. Burma (Myanmar): mutwinda. Cambodia: pôch kak. Laos: chan th'e:d. Thailand: chan-thet (central), chan-ban (northern). Vietnam: nh[uj]c d[aaj]u kh[aas]u.

Origin and geographic distribution Nutmeg is only known from cultivation but it most probably originated in Indonesia from the southern Moluccan Islands, especially Ambon and Banda. Nutmeg and mace (the dried aril) spread from there and became known throughout South-East Asia. The first record in Europe, in Constantinople, dates from 540 AD. By the end of the 12th Century nutmeg and mace were generally known in Europe. The further history of nutmeg is closely related to an aggressive colonial history. In 1512, the Portuguese discovered Banda and obtained a monopoly on nutmeg. In the 17th Century they were ousted by the Dutch who took over the monopoly, and held to it rigorously, even by extirpation of trees grown elsewhere, to keep the prices high. In 1772, the French broke the monopoly, and the British ended it in 1802, during their rule of Indonesia. In those days centres of cultivation came into being in other parts of the tropics; they all disappeared again, some due to diseases. In 1843 some plants were introduced into Grenada (West Indies); this led to large-scale production on that island, which has become the second largest producer after Indonesia.

At present the main centre of cultivation is Banda and surrounding islands. Nutmeg is cultivated on a smaller scale on other Indonesian islands, notably North Sulawesi (Manado), western Sumatra, West Java and in Irian Jaya. Sri Lanka, India (Kerala) and the island of Pinang off Peninsular Malaysia also have sizable acreages. The crop has also been dispersed to many other per-humid or humid tropical regions and enters the world market also from there, albeit on a small scale.

Uses The nutmeg products, dry shelled seed (nutmeg) and dried aril (mace) are sold as spices whole or ground. In most countries grated nutmeg is used in small quantities to flavour confectionery but in western Europe it is also used in meat dishes and soups. Mace is preferably used in savoury dishes, pickles and ketchups. Essential oils (mostly nutmeg oil from the seed and mace oil from the aril, but also from the bark, leaf and flower) and extracts (e.g. oleoresins) are often used in the canning industry, in soft drinks and in cosmetics. Nutmeg quality 'BWP' (broken, wormy and punky) and mouldy nutmegs are often used for distilling essential oil. In the United States the regulatory status 'generally recognized as safe' has been accorded to nutmeg (GRAS 2792), nutmeg oil (GRAS 2793), mace (GRAS 2652), mace oil (GRAS 2653) and mace oleoresin (GRAS 2654). Nutmeg oil is extensively used as a flavour component in major food products; the maximum permitted level in food is about 0.08%. The essential oil has insecticidal, fungicidal and bactericidal activity. Nutmeg can be used as a narcotic with hallucinogenic effects but it is dangerous; the consumption of two ground nutmegs (about 8 g) is said to cause death, due to its myristicin content. On Zanzibar nutmegs are chewed as an alternative to smoking marihuana. Medicinally, nutmeg is said to have stimulant, carminative, astringent and aphrodisiac properties. Young husks (pericarps) are made into confectionery (jellies, marmalades, sweets and preserves, very popular in West Java and Malaysia). Old husks can be used as substrate to grow the popular edible mushroom 'kulat pala' (*Volvariella volvacea* (Bull. ex Fr.) Sing), which possesses a light nutmeg flavour. Nutmeg butter, a fixed oil obtained by pressing the seeds, is used in ointments and perfumery.

Production and international trade Annual world production of nutmeg is about 17 000 t and of mace 3000 t. Approximately 60% of the nutmeg and mace entering the world market is produced in Indonesia and 30% in Grenada. Small quantities from Sri Lanka are also traded internationally. In 1994 Indonesia produced 14 000 t nutmeg and mace from 67 000 ha, and exported 7900 t nutmeg and 1400 t mace.

Major importers are the United States, Germany, the Netherlands, Great Britain and Japan. Prices are approximately: nutmeg US$ 7/kg, mace US$ 13.5/kg.

Since July 1987 the Grenada Cooperative Nutmeg Association and the Indonesian Nutmeg Association have reached an agreement on yearly sales on the international market. Indonesia is allowed to sell 6000 t of nutmeg and 1250 t of mace, and Grenada 2000 t of nutmeg and 350 t of mace.

Properties Per 100 g edible portion nutmeg contains approximately: water 10 g, protein 7 g, fat (nutmeg butter) 33 g, essential oil 5 g, carbohydrates 30 g, fibre 11 g, ash 2 g (Ca 0.1 g, P 0.2 g, Fe 4.5 mg). Nutmeg butter is a highly aromatic, orange-red to red-brown fat with the consistency of butter at ambient temperature; it can be obtained by pressing the nutmeg under heat; it contains mainly trimyristin and a high proportion of essential oil which is difficult to separate. Nutmeg essential oil is pale yellow to almost water-white with a fresh, warm spicy, aromatic odour; its major components are: monoterpene hydrocarbons (61–88%, e.g. α-pinene, β-pinene, sabinene), oxygenated monoterpenes (5–15%) and aromatic ethers (2–18%, e.g. myristicin, elemicin, safrole). Differences in oil composition influence the nutmeg flavour considerably: East Indian oils have a stronger nutmeg flavour because of a greater proportion of myristicin and safrole than the West Indian oils, which are richer in elemicin. Sri Lankan oil resembles West Indian oil. Commercial nutmeg extract from Papua New Guinea was found to be rich in safrole, but this may be due to adulteration with extract or oil from other *Myristica*, possibly *M. argentea*.

Per 100 g edible portion mace contains approximately: water 16 g, fat 22 g, essential oil 10 g, carbohydrates 48 g, P 0.1 g, Fe 13 mg. The red pigment in mace is lycopene and is identical with the red colourant in tomato. Mace essential oil is colourless to pale yellow, much resembling nutmeg oil; it is produced in very small quantities.

Nutmeg and mace oleoresins can be prepared by extracting with organic solvents and they contain essential oil, fixed oil and other extractives soluble in the chosen solvent. Hydrocarbon solvents result in a higher fixed-oil content than polar solvents such as alcohol and acetone. Nutmeg and mace oleoresins are considered to possess a more true odour and flavour than the corresponding essential oils and are preferred in food industries. Nutmeg oleoresin is a pale to golden-brown viscous liquid, clear and oily or opaque and waxy, becoming clear on warming to 50°C, graded on volatile-oil content (ml/100 g) as 25–30, 55–60, 80 and 80–90. Mace oleoresin is an amber to reddish-amber clear liquid and graded on volatile-oil content as 8–24, 40–45, 50 and 50–56.

The hallucinogenic properties of nutmeg have been ascribed to the aromatic ethers safrole, myristicin and elemicin. It is assumed that they are ammoniated and metabolized in the body to the potent ecstasy-like amphetamines MDA (3,4-methylenedioxy amphetamine), MMDA (3-methoxy-4,5-methylenedioxy amphetamine) and TMA (trimethoxy amphetamine) respectively.

Monographs on the physiological properties of nutmeg oil and mace oil have been published by the Research Institute for Fragrance Materials (RIFM).

Adulterations and substitutes Seed of several other *Myristica* species can be found as adulteration or substitute of the true nutmeg, e.g. of *M. argentea* Warb. (the Papua nutmeg, wild and cultivated in Irian Jaya and Papua New Guinea); *M. castaneifolia* A. Gray (from the Fiji Islands); *M. cinnamomea* King (from Malaysia, Singapore, Sumatra, Borneo and the Philippines); *M. crassa* King (from Thailand, Malaysia, Singapore and Sumatra); *M. dactyloides* Gaertner (from Sri Lanka); *M. elliptica* Wallich ex Hook.f. & Thomson (the swamp nutmeg, widespread in west Malesia and Thailand); *M. fatua* Houtt. (from Kalimantan, Sulawesi, the Moluccas and the Philippines); *M. malabarica* Lamk (the Bombay nutmeg from the west coast of peninsular India); *M. muelleri* Warb. (Australia, north-eastern Queensland); *M. succedanea* Blume (the Halmahera nutmeg, wild and cultivated in the northern Moluccas); and *M. womersleyi* J. Sinclair (from New Guinea). In Africa, seed of the calabash or African nutmeg *Monodora myristica* Dunal (*Annonaceae*) and on Madagascar the clove-nutmeg *Ravensara aromatica* Gmelin (*Sonneratiaceae*) are used as substitutes of nutmeg. In South America the Brazil nutmeg *Cryptocarya moschata* Nees & Martius (*Lauraceae*) and in the United States the Californian nutmeg *Torreya californica* Torr. (*Taxaceae*) are similarly used.

Description A dioecious evergreen tree, 5–13(–20) m tall, cone-shaped if free-growing, exuding a sticky red sap when wounded. Twigs slender, 1–2 mm in diameter towards the top. Leaves alternate, simple, exstipulate, chartaceous; petiole about 1 cm long; blade elliptical to lanceolate, 5–15 cm × 3–7 cm, base acute, margin entire, apex acuminate, aromatic when bruised. Inflorescences axillary, in umbellate cymes, male ones usually many-flowered, female ones 1–3-flowered; flowers fragrant, glabrescent with sparse, very minute tomentum, pale yellow, with a 3-lobed perianth; male flowers with a slender pedicel less than 1 mm thick, a usually slightly narrowed perianth at the base, and 8–12 stamens adnate to a column; female flowers with a superior, sessile, 1-celled ovary with a single basal ovule, which is normally anatropous to hemi-anatropous. Fruit peach-shaped, berry or drupe-like, 5–8 cm long, fleshy, yellowish, splitting open into 2 halves when ripe, containing 1 seed. Seed ovoid, 2–3 cm long, with a shiny dark brown, hard and stony, furrowed and longitudinally wrinkled shell, surrounded by a laciniate red aril which is attached to its base; kernel with small embryo and ruminate endosperm which contains many veins containing essential

Myristica fragrans Houtt. – 1, flowering and fruiting branch; 2, opened female flower; 3, staminal column; 4, seed with aril; 5, seed without aril; 6, section through seed without aril.

oil. The mace of commerce is the dried aril and the nutmeg is the dried kernel of the seed, often called nut.

Growth and development Nutmeg seeds should be planted immediately after collecting, before they dry out. Seed in the shell takes some 4–6 weeks to germinate; without shell it may germinate in half that time. Vigorously growing trees may reach an average height of 3 m and a girth at 40 cm height of 16 cm in 4 years. Nutmeg is a slow grower, but growth can continue for up to 60–80 years; full production is reached in 15–20 years. Depending on the soil and climate a tree may ultimately reach a height of 20 m and occupy 100 m^2. Under continuously per-humid or humid conditions, development of new shoots and leaves is also continuous.

The tree is characterized by a very superficial root system, although it may form a taproot penetrating the soil for over 10 m, provided it reaches no water table. Such a pen root does not develop in vegetatively propagated trees.

Usually a tree takes 6 years until first flowering, but if growing vigorously this period may be shortened to 4 years. In female trees a positive correlation exists between trunk diameter of young trees and later productivity. Male trees have a slightly smaller diameter, so keeping only the largest saplings may reduce the percentage of male trees. Flowering is probably induced by short dry periods. Anthesis is usually in the very early morning (3–5 a.m.) and pollination is normally effectuated by insects, especially moths. The fruit develops in 6 months if few fruits are growing, but takes up to 9 months if there are many fruits on the tree. Fruiting is more seasonal in regions with a pronounced dry season. Nutmeg is not strictly dioecious. Male trees show different degrees of femaleness, varying from no fruits at all to as many fruits as a good female tree.

Other botanical information *M. fragrans* is a very variable species, morphologically and chemically. Although there are no officially registered cultivars there are many local cultivars (e.g. Rumphius distinguished 5 cultivars). Like many members of *Myristicaceae*, a wounded nutmeg tree exudes a light red, sticky sap (kino). Such bleeding seems to exhaust the tree.

Ecology Nutmeg needs a warm and humid tropical climate, with average temperatures of 25–30°C and average annual rainfall of 2000–3500 mm without any real dry period. Flowering can be adversely affected by temperatures above 35°C and by hot dry winds. Frost always damages or kills the tree and makes commercial production impossible. Therefore, in the tropics the crop can only be grown below 700 m altitude. The superficial root system makes the tree very susceptible to wind damage. The crop can grow on any kind of soil provided there is sufficient water but without any risk of waterlogging. Preferred soils are those of volcanic origin and soils with a high content of organic matter with pH 6.5–7.5.

Propagation and planting Nutmeg is usually propagated by seed, resulting in equal numbers of male and female trees. The seedlings reveal their sex at first flowering, which usually occurs some 6 years after planting. Therefore 2–3 seedlings are usually planted on the same spot. Male trees are then cut out and excess female trees may be transplanted to positions where there are no female trees. It is generally thought that to optimize production in plantations, only 10% of the trees should be male trees. Male trees should be distributed regularly through the plantation to secure pollination.

Several techniques have been tried to determine the sex of seeds or seedlings at an early stage, in order to prevent planting excess male seedlings. The oldest recorded method was to feed the fruits to pigeons, in the belief that the sex of the pigeon who ate and excreted the seed would then determine the sex of the tree. The form and venation of leaves, shape of seeds and form of branches have also received attention. First reports, however, were never followed by conclusive later publications. There has been a search for sex chromosomes that would enable young seedlings to be sexed. The hypothesis has been put forward that the female sex is heterogametic to the effect that 4 of the supposed 8 sex-chromosomes exhibit facultative nucleolar properties. This is especially evident in female meiosis where these 4 chromosomes orientate to one side. This is not the case in male meiosis. If it were true, seedlings could be 'sexed' by counting the chromosomes with facultative nucleolar properties in growing root tips. This hypothesis, however, has not been tested in practice, as the chromosomes are very small (0.4–1 μm) and isodiametric, so sexing would require skill and experience.

Planting distance for full-grown trees should be around 10 m × 10 m. Trees reach this size only after some 20 years of growth. Normally, however, trees are planted at approximately 6 m × 6 m and thinned later as the need arises. In areas with strong winds, protective measures should be taken.

Other methods of propagation have been developed to circumvent the problem of dioecy. Air layering was developed in Grenada. After about 3–5 months the rooted watershoot is cut off and planted in a nursery. After a period of growth it is hardened off and planted in the field. This method succeeds in 60–70% of cases. Another more successful method, also developed in Grenada is approach grafting. In this method the rootstock is hung in a pot in an especially selected mother tree. Other methods, such as budding on (male) seedlings or on other species of the same family have also been tried; they are usually less successful and there are no reports on their long-term results. Propagation by tissue culture is possible but is relatively expensive.

Husbandry Young nutmeg plants are usually planted under 50% shade. With increasing age this shade can be reduced progressively and after 6–7 years the plants can grow without any shade at all, provided the soil is covered well, preferably by a cover crop.

Flowers are formed on young tops of branches, so in order not to hamper flowering the branches should not touch other trees.

Well-spaced trees may continue production for over 80 years. In nutmeg groves the lower branches usually are cut off to facilitate collection of dropped seeds, but if left on the tree, these branches would remain productive.

Very little is known on fertilizer application. Usually no fertilizer is used. On the island of Banda, plantations on volcanic soils have remained productive for hundreds of years.

Diseases and pests The only fungal disease of major importance is *Stigmina myristicae* (syn. *Coryneum myristicae*), a dry rot that causes the fruits to open when still young. Consequently the arils and seeds remain underdeveloped and are worthless. The conidia are spread by wind and rain. Another disease in nutmeg plantations is soft rot of fruits caused by *Colletotrichum gloeosporioides*; it also causes young unripe fruits to open prematurely. Root rots, caused by *Fomes noxius* and *Fomes lamaoensis* may cause considerable damage.

The most serious pest is the scolytid beetle *Phloeosinus ribatus* which bores through bark and cambium above and below ground level, causing dieback and death; this insect is blamed for the collapse of nutmeg production in Singapore and Pinang in the 1860s; other damaging borers are *Xyleborus fornicatus* and *X. myristicae*. Larvae of *Stephanoderes moschatae* and *Dacryphalus sumatranus* attack the nutmeg itself, resulting in the wormy seeds used for nutmeg butter and oil. The coffee bean weevil *Ataecerus fasciculatus* is the most serious pest of stored nutmeg and mace. Except for the use of lime in Indonesia, chemical control of diseases and pests is rarely practised as it is too expensive for smallholders and the degree of economic damage is usually too small to warrant control.

Harvesting Harvesting is possible year-round in non-seasonal climates; in seasonal climates some peaks may occur. In Indonesia, especially on Banda, fruits are harvested when they are open. Harvesting is done with a small basket on a long pole, to which a sharpened piece of iron is attached. In Grenada seeds with attached aril are collected after they have dropped from the split fruit. Mace on the ground is very easily infested by all kinds of small animals and insects. The labour-intensive way of harvesting in Indonesia diminishes losses, especially of mace.

Yield Annual production per female tree differs widely: excellent trees may produce yearly about 5000 fruits but trees with about 1000 fruits are fairly common. With 250 female trees per ha (spacing 6 m × 6 m) and at 5 g per dry shelled seed, nutmeg production is about 1250 kg/ha. At an air-dry weight ratio of 1 mace to 4 nutmegs, mace production reaches approximately 300 kg/ha.

Outside Banda and Grenada, however, nutmeg is only grown in small numbers by smallholders. There are hardly any yield figures available for such plantings.

Handling after harvest After harvest the seed is removed from the fruit and subsequently the aril is separated from the seed. The seed is dried, often above a slow-burning and smoking fire or, if only small quantities are available, in the sun. The fire deters insect attack. In the sun there is a danger of overheating, through which the fat in the seed may melt, resulting in broken kernels at shelling. When properly dried the kernel rattles in the shell. Then the shell is cracked to free the dry kernel (the nutmeg). Nutmegs from Indonesia are often white because they have been treated with lime, to protect against insect attack. Nutmegs are graded according to quality, size and weight. A number of commercially accepted grades are recognized. In Indonesia and Grenada sound nutmegs are graded as 80s or 110s, according to size in numbers per pound (lb, 454 g). Mixtures of sizes are exported as 'sound unsorted'. Alternatively, in Indonesia nutmeg is graded into 5 groups accord-

ing to the number of nuts per 500 g: A (75–80), B (80–90), C (90–105), D (105–125) and E (125–160). Indonesia also exports substandard nutmegs of 2 types: 'sound shrivelled' and 'BWP' (broken, wormy and punky). Indonesia exports 2 grades for essential-oil distillation, containing 8–10% essential oil and 12–13% essential oil, respectively.
The aril is also dried, mostly in the sun, to give the mace of commerce. After drying it is stored in the dark to change its colour from the original red to orange-yellow. It is also sorted into different qualities, mainly whole, broken and fine.

Genetic resources *M. fragrans* is not known in a wild state. The largest variability is probably found in Banda and a number of close relatives occur on the neighbouring islands. All other plantings throughout the world have been derived originally from plants from this region. There are no known substantial germplasm collections.

Breeding The slow-growing female trees possess only 1-ovuled flowers. This makes the nutmeg a difficult target for breeding. However, the very limited market for nutmeg products makes breeding efforts uneconomical. As is to be expected in a predominantly outbreeding plant, the variability is great. Plants differ considerably, not only in such aspects as vigour, productivity and sex-ratio, but also in size, colour and shape of leaves, flowers and fruits. In 1940 selection programmes started in Indonesia, but the results were lost during the second World War. In Grenada, some promising trees have been brought together in special plantings. Quick results will probably be achieved by selection and vegetative propagation of highly productive females.

Prospects The present annual world consumption of nutmeg and mace (some 20 000 t) could be produced on a well-managed 20 000 ha, and possibly even less. Unless the demand expands, there are few prospects for improved or increased production.

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Nigella sativa L.

Sp. pl.: 534 (1753).
RANUNCULACEAE
$2n = 12$

Synonyms *Nigella cretica* Miller (1768), *N. indica* Roxb. ex Fleming (1810).

Vernacular names Black cumin, small fennel, love-in-a-mist (En). Cumin noir, nigelle cultivée, toute-épice (Fr). Indonesia: jinten hitam. Malaysia: jintan hitam.

Origin and geographic distribution *N. sativa* is probably indigenous to the Mediterranean region and the Middle East up to India. Black cumin has long been cultivated and is mentioned in ancient Hebrew, Greek and Roman texts. It is cultivated in the subtropical belt extending from Morocco to northern India and Bangladesh, in East Africa and in the former Soviet Union. In Europe, North America and South-East Asia it is cultivated on a minor scale, mainly for medicinal purposes.

Uses The seeds of *N. sativa* are used as a spice.

Whole or crushed seeds are mixed through dough or sprinkled on bread in Sri Lanka, India, the Middle East, Turkey, the former Soviet Union, Egypt and Ethiopia. Crushed seeds impart a black colour to the bread. Black cumin is an essential ingredient of semi-sweet breakfast rolls and coffee cakes known as 'choereg' in the Middle East. The seeds are used to flavour a variety of dishes ranging from sauces, curries, pickles and meat dishes to vegetables, fruit pies and other confections and in flavouring vinegar and alcoholic beverages. In Arab countries a few seeds mixed with honey are taken as a sweet.

In Islamic tradition *N. sativa* seeds are reputed to be a panacea. They also play an important role in Western herbal medicine, and consequently the seeds are traditionally used to treat numerous diseases, e.g. headache, rheumatic pains, asthma and coughs. Crushed seeds in vinegar are applied in skin disorders such as ringworm, eczema and baldness. *N. sativa* is also applied as a galactagogue, emmenagogue, vermifuge and diuretic and to aid discharge of pus. The pounded seeds are used against nausea and in parts of northern India to induce abortion. The seed is reported to have anthelmintic and carminative properties. A powdered mixture of seeds of *N. sativa* with *Trigonella foenum-graecum* L., *Lepidium sativum* L., *Commiphora* sp. and the dried leaves of *Cleome droserifolia* (Forssk.) Delile, *Ambrosia maritima* L. and *Centaurium pulchellum* (Sw.) Druce, administered as tea, is used in Egypt to treat diabetes.

In the United States the regulatory status 'generally recognized as safe' has been accorded to black cumin (GRAS 2342) and black cumin oil (GRAS 2237).

The seeds are said to protect woollen goods and linen against insects. Although less popular than *N. damascena* L., *N. sativa* is also grown as an ornamental.

Production and international trade Although *N. sativa* seed is traded internationally, no statistics on production and trade are available.

Properties The odour of crushed black cumin seeds is reminiscent of lemon with a suggestion of carrot; the taste is strong, pungent and peppery, but also aromatic and nutty. To others it somewhat resembles oregano. The seed contains numerous esters of unsaturated fatty acids and terpene alcohols (7%) and about 0.5% essential oil. The essential oil is a yellow liquid with an unpleasant smell that tastes like juniper berries. The main components of the essential oil are thymoquinone (25–50%), p-cymene and α-pinene, further traces of carvacrol, anethole and α-terpineol.

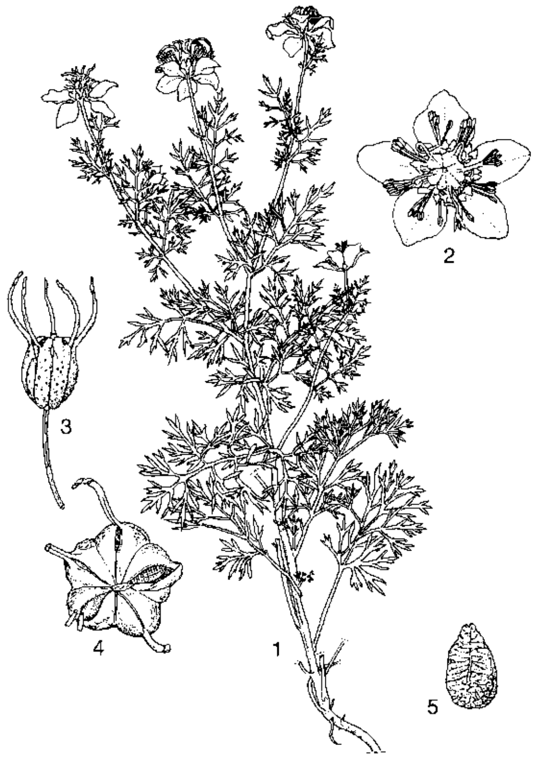
Per 100 g edible portion, *N. sativa* seed contains approximately: water 4 g, protein 22 g, fat 41 g, carbohydrates 17 g, fibre 8 g, ash 4.5 g (Na 0.5 g, K 0.5 g, Ca 0.2 g, P 0.5 g, Fe 10 mg), thiamine 1.5 mg, pyridoxine 0.7 mg, tocopherol 34 mg and niacin 6 mg. The fatty oil is composed of eicosenoic acid (0.5%), linoleic acid (about 60%), linolenic acid (0.3%), myristic acid (0.3%), oleic acid (about 25%), palmitic acid (about 12%) and stearic acid (3%).

The seed also contains tannins, the alkaloids damascenine, nigellone, nigellimine, nigellimine-N-oxide and nigellicine, the sterols cholesterol, campestrol, stigmasterol, β-sitosterol and α-spinasterol. Further it contains about 1.5% of the glucoside melanthin, which on hydrolysis yields the toxic malanthogenin.

The effectiveness of *N. sativa* seeds in the treatment of several diseases has been confirmed experimentally. The lipid part of the ether-extracted seeds exhibits galactagogue action in buffaloes, goats and rats. Aqueous extracts have a bronchodilatory effect explaining the effectiveness of *N. sativa* against cough. The effect is attributed to thymoquinone, but other compounds also play a role. Powdered seeds are as effective as commercial niclosamide against the tapeworms *Taenia saginata* and *Hymenolepis nana* in children. Powdered seeds have also been found to be effective against the tapeworm *Moniezia expansa* in sheep. Extracts of the seeds are currently being tested for their effect against rheumatism and related inflammatory diseases, in reducing the side-effects of chemotherapy in the treatment of cancer and in invigorating the immune function in humans.

Adulterations and substitutes A high ratio of eicosadienoic acid to eicosamonoenoic acid combined with a high level of C_{20} fatty acids is highly characteristic of the seed oils of *Nigella* and could serve as a criterion for identifying genuine black cumin seed oil.

Description Erect annual herb, up to 70 cm tall, with a well-developed yellow-brown taproot and numerous feeder roots. Stem profusely branched, subterete, ribbed, sometimes hollow when old, puberulous, light to dark green. Leaves alternate; stipules absent; petiole strongly broadened at base, light green, only present in basal leaves, 1–6 cm long, ribbed, puberulous; blade up to 7 cm × 5 cm in outline, bi-, tri- or even multi-pinnately dissected into short, thin sublinear, divergent, slightly pilose lobes, which are normally green but



Nigella sativa L. – 1, habit; 2, flower (top view); 3, fruit; 4, dehiscing fruit (top view); 5, seed.

sometimes turn reddish brown. Flowers terminal, solitary; pedicel (2–)4–8(–11) mm long, puberulous, ribbed; all flower parts inserted on a pale yellow, fleshy, depressed-conical receptacle, about 2 mm in diameter, visible as an orange-brown ring below the carpels in fruit; sepals 5, petaloid, ovate, 13–17 mm × 6–12 mm, apex obtuse, tapering basally into a 2–3 mm long claw, papillose to pilose, pale green when young, sometimes partly reddish, inside pale blue-white when older; petals (6–)8(–11), with short claw, blade 2-lobed, lobes enclosing nectar-pocket, dorsal lobe 3.5–5.5 mm × 2.5–4.5 mm, apex bifid, greenish-white with violet lines, ventral lobe oblong, 2.5–4 mm long, violet at base, white at apex; stamens in (6–)8(–10) groups of 3–7 stamens each, each group forming a spiraloid line on the receptacle, filaments linear, 3–9 mm long, violet-blue to pale blue, anthers yellow; pistil lobed, composed of 3–7 white-granular carpels, almost connate at base, forming a compound ovary 4–9 mm long with free stigmas. Fruit a ribbed, oblongoid, tuberculate capsule, 6–16 mm × 5–12 mm, greyish-green to brown at maturity, many-seeded, with persistent stigmas. Seed 3(–4)-sided, obpyramidal, 3 mm × 1.5–2 mm, rugose-tuberculate, dark black, with a carrot-like smell; embryo minute, embedded in copious, fatty endosperm.

Growth and development Germination is epigeal. In temperate climates black cumin starts flowering about 100 days after sowing and seed reaches maturity 50 days later. In warmer climates, flowering may start 8–10 weeks after germination. Flowering is protandrous and pollination is believed to be mainly by insects. In older flowers the stigmas bend down and self-pollination may occur.

Other botanical information *N. sativa* is a rather variable species but quite easily distinguishable from the other 13 species in the genus because of its blue, petaloid sepals, not involucrate flowers, three-sided seeds, tuberculate capsular fruits with carpels united to apex. Some subdivisions into forms or varieties have been made on the basis of seed colour, branching habit and hairiness, but these have no practical value. Sometimes a botanical division between wild and cultivated taxa is proposed, in which the wild plants are more hairy with smaller flowers and more tuberculate fruits. A cultivar classification would be appropriate for the cultivated plants, but as far as is known, no such system exists.

In the literature there is much confusion about the vernacular names that are used for *N. sativa*. 'Black cumin' is also used for seeds of the cultivar 'Black' of cumin (*Cuminum cyminum* L.) and for the seeds of *Bunium persicum* (Boiss.) B. Fedtsch. from the Middle East which are also used as a condiment. The appellations 'small fennel' or 'fennel flower' (alluding to the finely cut leaves) could lead to confusion with true fennel, *Foeniculum vulgare* Miller. 'Love-in-a-mist' usually refers to the ornamental species such as *Nigella damascena* L., originating from southern Europe and cultivated worldwide for its attractive blue flowers which are surrounded by an involucre of green leaf lobes; the seeds (also black) are not usually used as a condiment.

Ecology *N. sativa* is a hardy crop and can grow under a wide range of temperatures, from 5–25°C, the optimum being about 14°C. In Ethiopia, it is cultivated as a rainfed crop in the highlands at 1500–2500 m altitude. It is successfully grown in most kinds of soil with pH 5–8.

Propagation and planting *N. sativa* can easily be propagated by seed. Germination is promoted by darkness and high temperatures. Seed is broadcast as seedlings are too fragile for transplanting, but seed may also be sown in peat blocks. A row spacing of (15–)25–40 cm is common. In Ethiopia, *N. sativa* is often intercropped with barley and wheat.

Husbandry *N. sativa* responds favourably to fertilizers. Application of fertilizer at a per ha rate of 80 kg N, 17.5 kg P and 33 kg K has been reported to give seed yields of 1 t/ha.

Diseases and pests There are no serious diseases in *N. sativa*. A minor leaf-spot is caused by *Cercospora nigellae*. Empty carpels may be caused by borer larvae. Larvae of *Spodoptera litura* may bring about 15–20% economic damage, but they can be controlled by applying 0.05% monocrotophos followed 10 days later by 0.2% carbaryl.

Harvesting Since fruits of *N. sativa* dehisce easily, they should be harvested before they are completely dry.

Yield Information on yields of *N. sativa* is scanty; yield levels have been reported of up to 1 t/ha in experiments.

Handling after harvest The seeds of *N. sativa* can be removed by light threshing. They must be stored under dry conditions to maintain their characteristic spicy flavour. Under normal dry room conditions, seed remains viable for 2–3 years. Broken seeds deteriorate rapidly, due to the activity of lipases.

Genetic resources and breeding Since *N. sativa* is cultivated in a very wide area, it is not at risk of genetic erosion. A small germplasm collection is maintained at the Western Regional Plant Introduction Station, United States. Studies have been initiated to compare the chemical and morphological characteristics of different provenances of *N. sativa*.

Prospects The widespread use of *N. sativa* in oriental cooking and in traditional medicine ensures future interest in the crop. The current interest in herbal medicine, together with the interest being shown in the crop by the pharmaceutical industry may boost the importance of *N. sativa*. Crop production needs to be improved through agronomic and breeding research.

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I.B. Ipor & L.P.A. Oyen

Ocimum basilicum L.

Sp. pl.: 597 (1753).
LABIATAE
$2n$ = 48, 50–74

Vernacular names Sweet basil, French basil, Réunion basil (En). Basilic commun (Fr). Indonesia: selasih, kemangi (general), surawung (Sundanese). Malaysia: kemangi, selasi jantan, selasi hitam. Philippines: balanoy, solasi (Tagalog), kamangi (Culion). Cambodia: chi neang vong. Laos: phak 'i:x tu:x. Thailand: horapha. Vietnam: h[us]ng gi[or]i, [es] tr[aws]ng, [es] t[is]a.

Origin and geographic distribution Sweet basil probably originated in western Asia and occurs naturally or naturalized throughout the tropics (including South-East Asia), subtropics and warm temperate areas. It was already being cultivated in Egypt 3000 years ago and made its way from the Middle East to Greece, Italy, and the rest of Europe. It reached England in the 16th Century and North America in the early 17th Century. Sweet basil is now cultivated throughout the world.

Uses Sweet basil is a popular savoury herb. Both fresh and dried leaves are used to impart a fragrant, warm and sweet flavour with pungent and clove-like notes to dishes and drinks. The leaves complement many soups and salads and vegetable dishes and have a special affinity with tomatoes, e.g. in tomato paste, pasta sauces and even in a bloody Mary. Lamb is also often flavoured with basil leaves. In Italian cooking the leaves are used in pizzas, pasta, chicken and cheese dishes and in the famous pesto. In France the leaves are particularly popular in omelettes and soups. Sweet basil leaves should be added towards the end of cooking to best retain their flavour. The leaves are a source of essential oil and oleoresin mainly applied in industry to flavour baked goods, sauces, pickles, vinegar and meat products and to modify the flavour of chartreuse liqueurs. The oil is also used in cosmetics, dental and oral products and occasionally in perfumes. In the United States the regulatory status 'generally recognized as safe' has been accorded to sweet basil (GRAS 2118), sweet basil oil (GRAS 2119) and sweet basil oleoresin (GRAS 2120).

In medicine a decoction of the leaves is applied as stimulant and carminative and to treat vomiting, cough, chronic dysentery and diarrhoea. In Vietnam sweet basil is used to treat fever and malaria. The mucilaginous seed enters into the preparation of non-alcoholic drinks and in medicine. The essential oil is used to repel bugs and flies. Purple-leaved selections are popular ornamentals, but many are as aromatic as green-leaved ones and may be used similarly.

Production and international trade Sweet basil is grown commercially mainly in the Mediterranean, the United States, Madagascar and neighbouring islands, India and Thailand. Reliable data on production are hardly available. World production of sweet-basil essential oil was estimated in 1992 at 42.5 t, valued at US$ 2.8 million.

Properties Commercial sweet basil leaves contain per 100 g fresh material approximately: water 87 g, protein 3 g, fat 1 g, carbohydrates 5 g, fibre 2 g and ash 2 g. The seed is rich in protein and fat, but contains little carbohydrates. The major types of sweet basil in trade are 'French basil' (also called 'sweet basil') and 'Réunion basil' (also called 'Egyptian basil'), and 'Bulgarian basil'. Sweet basil leaves owe their flavour and fragrance to their volatile oil content (about 1.5 per cent). The volatile oil of French basil oil has a soothing, sweet-spicy, slightly green and fresh aroma with a faint balsamic undertone and a lasting sweetness. Only minute amounts of the oil are needed in foods and perfumes; its minimum perceptible concentration is 0.4–1.0 ppm. Réunion basil is more coarse-herbaceous with a slightly camphoraceous top note. The major components of French basil oil are methyl chavicol and linalool, Réunion basil oil contains mainly methyl chavicol with little linalool. The essential oil of plants of other provenances may have different characteristics.

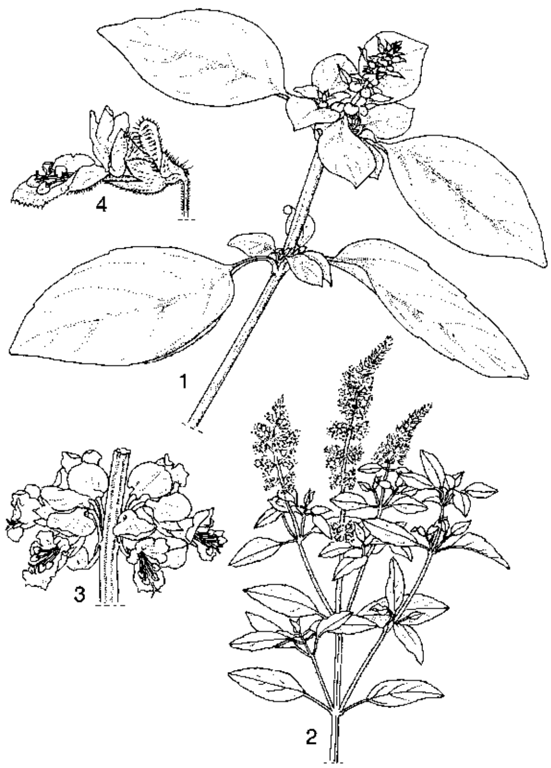
The oil possesses antiseptic properties against a number of Gram-positive and Gram-negative bacteria and inhibits the activity of several fungi. An alcoholic extract of *O. basilicum* has some anti-HIV-1 activity in vitro.

A monograph on the physiological properties of sweet basil oil has been published by the Research Institute for Fragrance Materials (RIFM).

The 1000-seed weight is 0.8–1.3 g.

Adulterations and substitutes Linalool is sometimes added to Réunion basil oil to mimic French basil oil. It is, however, a poor, easily recognized substitute for the much richer true product.

Description Aromatic, erect or ascending, annual or short-lived perennial herb, up to 1 m tall, with a brown, thick taproot up to 6 mm and many secondary roots. Stem quadrangular, up to about 6 mm thick, much branched, glabrous or pilose when young, light green to dark purple, base sometimes somewhat woody. Leaves simple, decussately opposite; petiole 1–2(–4.5) cm long; blade ovate to elliptical, 1–5(–8) cm × 0.5–2(–4) cm, base attenuate, margin entire to crenate-serrate,



Ocimum basilicum L. – 1, flowering shoot; 2, shoot in full bloom; 3, section of the inflorescence; 4, flower.

apex acuminate, densely glandular punctate, light green to purplish-green, glabrous to slightly pilose. Inflorescence terminal, lax, up to 30 cm long, composed of decussate, 3-flowered cymes, appearing as verticils 1–3 cm apart; bracts oblanceolate to rhombic, 3–11 mm × 1–3 mm, pilose; pedicel 3–4 mm long, strongly recurved at top, densely white-pilose; calyx bilobed, tubular, with a flat suborbicular upper lobe 3.5 mm in diameter (in fruit 4.5 mm) and a canaliculate lower lobe 3.5 mm long (in fruit 4.5 mm) which is sharply 4-toothed at top with the 2 central teeth longest, densely glandular punctate, tube densely long-haired inside above the ovary; corolla tubular, two-lipped, 5–8 mm long, pilose outside, whitish-purplish, white or creamy yellow, upper lip 4-lobed and strongly recurved at top, lower lip entire, ovate; stamens 4, didynamous, exceeding corolla by 2–4 mm, 2 outer ones longest and near their base with a fleshy, downward directed, glabrous to pilose outgrowth up to 1 mm long; pistil with a 4-lobed ovary, a gynobasic style up to 9 mm long at top splitting into 2 stigmatic lobes up to 1 mm long. Fruit composed of 4 distinct nutlets enclosed within the tube of the persistent calyx; nutlet ovoid, 1–2 mm × 1 mm, black to dark brown; in water the nutlet-wall produces a thick white slimy coating within some minutes.

Growth and development Once established, seedlings grow rapidly. When plants have reached a height of 50–70 cm, branching starts. Pinching out the tip during active vegetative growth encourages further vegetative growth. Flowering starts 3–4 months after planting and occurs year-round in the tropics and in summer in temperate areas. Sweet basil is mainly autogamous, but 5–10% outcrossing occurs.

The volatile oil is contained in glandular hairs on the leaves. The hairs are formed in young meristematic leaves and their number does not increase during expansion of the leaves.

Other botanical information Although one of the oldest herbs known, sweet basil is not well understood taxonomically and is in need of a thorough worldwide revision to clarify its real identity. Opinions differ concerning its delimitation from other *Ocimum* species and still more about its classification below species level.

For South-East Asia, Flora Malesiana distinguished 3 other *Ocimum* species:

- *O. americanum* L. (syn. *O. africanum* Lour., *O. canum* Sims, *O. brachiatum* Blume); hoary basil, occurring wild and cultivated; by some considered as identical to *O. basilicum*, being a slightly smaller-flowered wild form of it; primarily used as a vegetable.
- *O. gratissimum* L. (syn. *O. suave* Willd., *O. viride* Willd., *O. viridiflorum* Roth); shrubby basil, occurring wild and cultivated, best known from Africa; relatively easily distinguishable from the other species because here the lower lobe of the calyx closes the mouth of the fruiting calyx; primarily used as an essential-oil plant.
- *O. tenuiflorum* L. (syn. *O. sanctum* L.); holy basil, only known from cultivation; distinguishable from other species because the pedicel is situated transverse to the rachis of the inflorescence); primarily used as a minor spice herb.

O. basilicum is very variable and comprises taxa differing in morphology, chromosome number and chemical content. Many subclassifications have been made, with subspecies, varieties and forms. A classification into cultivar groups and cultivars would be preferable for cultivated plants, but remains to be made.

In the literature the most commonly encountered variety names and their actual taxonomic positions are:

- var. *anisatum* Benth.: now considered to be the hybrid *O.* ×*citriodorum* Vis., which originates from a cross between certain chemotypes of *O. basilicum* and *O. americanum*, producing plants that smell of anise;
- var. *basilicum* (including var. *album* Benth., var. *densiflorum* Benth., var. *glabratum* Benth., var. *majus* Benth.): two forms occur – one with thin flat leaves and one with thicker convex leaves (synonym var. *lactucaefolium* sensu Darrah);
- var. *difforme* Benth. (syn. var. *crispum* (Thunb.) E.A. Camus): leaves laciniate, bullate, thick or crisped;
- var. *minimum* sensu auct.: considered a separate species *O. minimum* L. with all parts smaller and woody stem (perennial plant);
- var. *pilosum* Benth.: has been transferred to *O. americanum* L. var. *pilosum* (Willd.) A.J. Paton;
- var. *purpurascens* Benth.: upper part of plant purple;
- var. *thyrsiflorum* (L.) Benth. (syn. *O. thyrsiflorum* L.): inflorescence densely branched and with lax verticils.

Several chromosome counts indicate a diploid chromosome number of 48 for *O. basilicum*. However, a number of studies of *Ocimum* germplasm found a complex polyploid series with chromosome numbers for *O. basilicum* ranging from 50–74. The chromosome counts do not directly match the morphological or chemotaxonomical classification. At least 6 chemotypes are recognized in *O. basilicum*. An important source of variation is the presence or absence of a single gene that controls the formation of phenolic aroma products, e.g. methyl chavicol (estragole). In 1996, a study based on 16 selections recognized 5 chemotypes with as major essential-oil components: (1) methyl chavicol; (2) linalool; (3) a mixture of methyl chavicol and linalool; (4) linalool and eugenol; and (5) a mixture of methyl eugenol and methyl chavicol. Type 3 may or may not contain considerable amounts of geraniol. Other studies have found selections rich in methyl cinnamate and camphor. In trade a few selections are recognized based on their fragrance and chemical composition: French basil, a sweet and flavourful strain rich in linalool and methyl chavicol and free of camphor notes; Réunion basil, richer in methyl chavicol but with less linalool; and Bulgarian basil characterized by methyl cinnamate.

Widely grown cultivars and cultivar groups of sweet basil are: 'Sweet', 'Genovese', 'Large-leaf' and 'Mammoth'; examples of purple-leaved cultivars are: 'Dark Opal' and 'Purple Ruffles'. *O. basilicum* cultivars with a different aroma and taste are: 'Lemon-scented', 'Sweet Dani', 'Cinnamon Basil', 'Spicy Bush', 'Camphor', 'Anise' and 'Licorice'.

Ecology Sweet basil can adapt to a wide range of conditions favourable for vegetable production. In the Philippines, sweet basil is widely distributed in settled areas from Batanes to Mindanao at low and medium altitudes up to 1000 m and often grows spontaneously in open wastelands. In Java it occurs naturalized up to 450 m altitude and is cultivated up to 1100 m. It thrives in the field as well as indoors or as a pot plant. Sweet basil is susceptible to frost and is grown as a tender annual in temperate areas. In the tropics and subtropics it can be grown as a short-lived perennial. Seed germinates well between 13–25°C. Growth occurs between 5–30°C and is optimal at about 20°C. It needs at least 5 hours of daily direct sunlight, whereas indoors it needs 12 hours of artificial light. It is a particularly robust plant in areas of high light intensity. Plants grown under direct sunlight exhibit more vigorous leaf production, formation of more numerous branches and inflorescences and more extensive root proliferation than those grown under partial shade. Flowering is little affected by photoperiod, but long days appear to favour floral initiation. Sweet basil is susceptible to both water stress and waterlogging at any stage of development.

Sweet basil grows best on fertile, light, well-drained soils and has relatively high nitrogen and water requirements. A pH tolerance of 4.3–8.4 has been reported, but 5.5–6.5 is optimal. The crop benefits from applications of manure or compost.

Propagation and planting Sweet basil is propagated by seed or cuttings. Seeds remain viable for over 10 years if refrigerated. The tiny seed is sown evenly at a depth of 2–10 mm in germination boxes on a previously moistened medium consisting of equal parts of compost or farm manure, garden soil and river sand. Watering should be done gently using a hand sprayer. In the tropics seeds take 4–6 days to germinate, at lower temperatures 8–14 days. Seedlings are sometimes transplanted into polythene bags or cups upon emergence of the first pair of true leaves. When seedlings are 5–8 cm tall, they are transplanted into the field, planted in rows 30–45 cm apart and 20 cm between plants. Transplanting is sometimes postponed until seedlings are 15 cm tall. In mechanized cultivation rows may be spaced at 60–90 cm with 15 cm between plants. Seedlings are then trimmed to encourage branching and growth. In Italy sweet basil is often direct-seeded in greenhouse beds. Sweet basil can also be propagated using stem cuttings. Stem sections with 4–5 leaf pairs cut right below the fifth node from the shoot apex are suitable. Roots develop within 3–4 weeks.

Husbandry Weed control in sweet basil is important for good growth. In the United States no herbicides are registered for use in sweet basil and weeding is mechanical or manual. Mulching with straw or black polythene sheeting also gives effective weed control. When grown for the leaves, flowering branches should be removed regularly to promote branching and continued growth. Plantings for essential-oil production are often staggered, to ensure a prolonged harvesting period.

Diseases and pests Until recently few diseases and pests were reported to seriously affect sweet basil. However, intensified cultivation and increasing restrictions on the use of fungicides have led to severe outbreaks of diseases. In countries where no fungicides are registered for use in sweet basil, e.g. the United Sates, prevention through cultural measures is the only means of controlling diseases. Basil wilt caused by *Fusarium oxysporum* f. sp. *basilici* can devastate a crop. Initial symptoms are brown streaks on the stems, but plants grow normally until 15–30 cm tall, then become stunted and suddenly wilt from the apex downwards. Only French basil is seriously affected, other types show some resistance. The disease is spread through macroconidia dispersed by soil particles and during harvest; seed-borne inoculum is held responsible for long distance transmission. Disinfection of seed with benzimidazoles effectively controls seed-borne infection. The *Fusarium* strain may survive in the soil for 8–12 years. Biological control through antagonistic fungi, including antagonistic strains of *F. oxysporum*, is being developed. Basal rot is caused by *Rhizoctonia solani*, to a lesser extent by *Microdochium tabacinum* and below 20°C also by *Sclerotinia* spp. *Rhizoctonia* causes damping-off in rapidly expanding circular patches. It spreads rapidly through the soil. Grey mould caused by *Botrytis cinerea* is very common in sweet basil. Young plants grown from stem cuttings are particularly susceptible and the disease may kill all the leaves and buds of affected plants. Susceptibility diminishes gradually with time. Black spot (*Colletotrichum* spp.) causes dry necrotic spots to develop on the leaves. An increase in outbreaks of black spot in Italy has been associated with reduced use of fungicides against grey mould.

Few pests are recorded in sweet basil. In Thailand the larvae of the *Ocimum* leaf folder (the Lepidoptera *Syngamia abruptalis*) cause some damage by feeding inside folded leaves. The generation time of this insect can be as short as 1 month. In the United Kingdom, birds are reported to cause extensive damage to seedlings after transplanting.

Harvesting When grown for fresh or dried leaves, sweet basil is best harvested just prior to the start of flowering. Leaves and shoots may be harvested when 15–20 cm long, 80–110 days after transplanting. In temperate areas 1–2 cuts may be taken, in warmer areas 3–5 cuts per year are possible. Plants should be cut 10–15 cm above the ground, leaving 2–4 pairs of leaves to ensure good regrowth and allow subsequent harvests to be taken at 15–20 days. For essential oil production, sweet basil is harvested in full bloom.

Yield Reported yields of fresh sweet basil leaves range from 5–20 t/ha. The yield of essential oil is about 40 kg/ha. Very productive beds were observed in the Philippines, where inflorescences were continuously removed, the first harvest took place about 50 days after sowing, and harvesting continued for 18 months at intervals of 3–4 weeks, yielding an estimated 7 t/ha of fresh leaves per harvest (85–140 t/ha in 18 months). In India where flowers and leaves are sometimes distilled separately, a good crop yields about 13 kg of flower oil and 27 kg of leaf oil.

Handling after harvest Before processing, leaves and branches of sweet basil are washed, and cleaned by removing all weeds and extraneous material. To maintain their aroma and colour, leaves should be dried at temperatures not exceeding 35°C. Dried leaves are chopped to specific sizes and graded. For essential oil, sweet basil is usually dried for 1–3 days in the field. In Italy, dried leaves are preserved in olive oil. They turn black, but keep their flavour for several months. Most essential oil is obtained by steam distillation.

Genetic resources Many germplasm collections of *Ocimum* spp. including *O. basilicum* are maintained, in the United States e.g. at the United States Department of Agriculture (USDA) North Central Regional Plant Introduction Station, Ames, Iowa, United States. In Europe there are large germplasm collections at the Vavilov Research Institute of Plant Industry, St. Petersburg, Russia (169 accessions), the Gene Bank of the Institute for Plant Genetics and Crop Plant Research, Gatersleben, Germany (95 accessions) and at the Gene Bank Department of the Research Institute of Crop Production, Olomouc-Holice, Czech Republic (56 accessions).

Breeding Most breeding work in sweet basil aims at developing resistance against *Fusarium oxysporum* and to a lesser extent at developing cultivars with a desirable flavour.

Prospects Although sweet basil is only a minor crop in terms of area, it is an important spice and its popularity is still growing. Sweet basil is an important ingredient of the popular Thai cuisine. Its importance in various prepared foods and the increasing popularity of health foods, including pastas and other Italian foods, also contributes to the steadily growing popularity and increasing demand for this herb.

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N.O. Aguilar, Pham Truong Thi Tho & L.P.A. Oyen

Origanum L.

Sp. pl.: 588 (1753); Gen. pl., ed. 5: 256 (1754).
LABIATAE
$x = 15$; $2n = 30$ (*O. vulgare*)

Major species and synonyms

- *Origanum majorana* L., Sp. pl.: 590 (1753), synonyms: *Majorana hortensis* Moench (1794), *Origanum majoranoides* Willd. (1800), *O. dubium* Boissier (1879).
- *Origanum vulgare* L., Sp. pl.: 590 (1753), synonyms: *O. hirtum* Link (1822), *O. gracile* Koch (1848), *O. viride* (Boissier) Halacsy (1902).

Vernacular names

- *O. majorana*: Marjoram, sweet marjoram (En). Marjolaine (Fr).
- *O. vulgare*: Oregano, wild marjoram (En). Mediterranean or European oregano (Am). Origan (Fr). Philippines: oregano, suganda, torongil de Limon.

Note: Commercially the term 'oregano' has a wide meaning and includes more than 60 species of different genera and families.

Origin and geographic distribution *Origanum* is predominantly a Mediterranean genus, especially of the eastern part (more than 75% of the species). *O. majorana* originated in Cyprus and adjacent southern Turkey; it occurs subspontaneously in former Yugoslavia, Italy, Corsica, southern Spain, southern Portugal, Morocco and Algeria; it is also cultivated in those areas and in many countries in Europe, America and Asia, including South-East Asia. *O. vulgare* most probably originated in the Mediterranean, but is widely distributed now from the Azores, Madeira and the Canary Islands, throughout Europe and the Mediterranean to West and Central Asia and Taiwan. It is also cultivated in many countries of the world, including South-East Asia (e.g. Indonesia, the Philippines) where it is more important than *O. majorana*.

Uses Most *Origanum* species (especially their leaves and flowers) have been used since ancient times as culinary and medicinal herbs, as ornamental garden plants and some also as producers of a dye. The use as culinary herb of both major species mentioned here is most important. Marjoram has a delicate and sweet flavour. The fresh leaves are used as a garnish for salads while the dried herb is popular for seasoning soups, stews and poultry dishes. In the United States the regulatory status 'generally recognized as safe' has been accorded to marjoram (GRAS 2662), marjoram oil (GRAS 2663) and marjoram oleoresin (GRAS 2659). The oil is extensively used as a flavour component in major food products; the maximum permitted level in food is about 0.004%. The maximum permitted level as a fragrance constituent in perfume compounds for soaps, detergents, cosmetic and extrait perfumes is 0.6%.
Oregano has a stronger and more robust flavour than marjoram. It is popularly known as the 'pizza' herb because of the dependence of the dish on oregano for full flavour. It combines well with any tomato dish. The regulatory status of oregano in the United States is 'generally recognized as safe' (GRAS 2660). The essential oil is used for scenting soap and as an ingredient in liqueur and wine. In the Philippines, oregano is one of the most important herbs used in first-class hotels, restaurants and fast-food establishments. The fresh herb is more popular and expensive than the dried herb. Both herbs are also used to make a kind of tea, and a good quality honey can be obtained from the flowers. The sap of oregano also yields a red dye.
Medicinally, oregano is less important than it used to be. It was, for example, used as a stimulant, carminative, tonic and to cure asthma, coughs, indigestion, rheumatism, toothache, headache and spider bites. Although its use as culinary herb is currently most important, there is renewed interest in the bactericidal, fungicidal, antiviral, nematicidal, insecticidal and anti-oxidant activities of *Origanum* essential oils. In some places stored plant products are traditionally pro-

tected against insect damage by spraying with *Origanum* essential oil or powdered dried herb.

Production and international trade Annual consumption in the United States, Japan and some major markets in Europe in the late 1970s varied from 880–1685 t for marjoram and 2070–2820 t for oregano. In later years consumption increased considerably. The average annual import of oregano in the United States alone between 1991–1995 amounted to 4000 t, of which about 80% came from Turkey, the rest mainly from Greece, Israel and Morocco. Average annual export of oregano from the largest producer Turkey in the years 1989–1995 amounted to 4500 t. Annual consumption in the 1990s amounted to 500 t in France, 600 t in Germany, 500 t in United Kingdom and 150 t in the Netherlands. The value of world production of essential oil in the 1990s was US$ 2.1 million for marjoram and US$ 0.4 million for oregano.

In the Philippines, oregano is cultivated mainly for the fresh herb market. The area of cultivation is very small. Annual consumption (based on purchases of several food service establishments in Metro Manila) is about 1.6 t, mainly as fresh herb (about 75%).

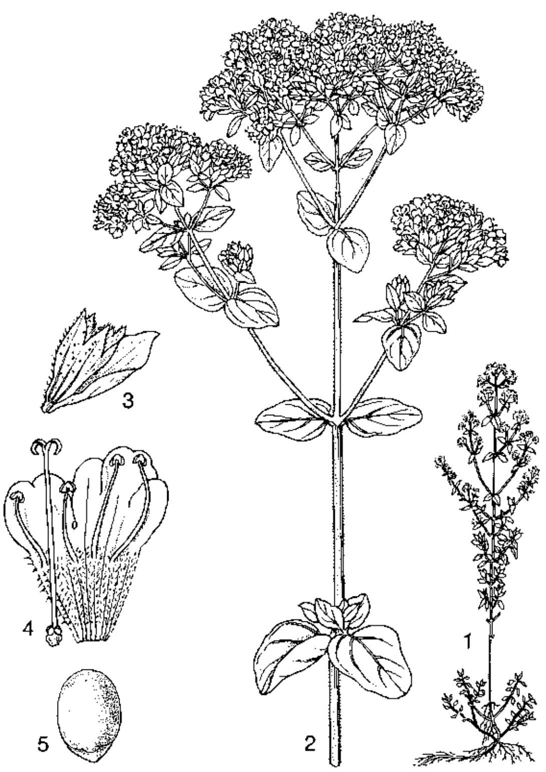
Properties There have been many chemical analyses of marjoram and oregano, especially of their essential oils. Variation in published figures is large, mainly due to different methods of analysis, wide differences in origin and developmental stage of the material used, and often questionable identity of the samples analysed. The figures presented here are intended to give an indication, and should be interpreted with great care. Per 100 g edible portion dried marjoram leaves contain approximately: water 8 g, protein 13 g, fat 6 g, carbohydrates 40 g, fibre 20 g, ash 12 g (Ca 2.0 g, Fe 83 mg, K 1.5 g, Mg 350 mg, Na 80 mg, P 310 mg), vitamin C 50 mg. The energy value is about 1140 kJ/100 g. A yellow or greenish-yellow essential oil can be obtained by steam distillation. The fresh herb yields 0.3–0.4% essential oil, the dried herb 1–6%. The major constituent of the essential oil is terpinen-4-ol. A monograph on the physiological properties of marjoram oil has been published by the Research Institute for Fragrance Materials (RIFM).

Per 100 g edible portion the composition of dried, ground oregano is approximately: water 7 g, protein 11 g, fat 10 g, carbohydrates 49 g, fibre 15 g, ash 7 g (Ca 1.6 g, Fe 44 mg, K 1.7 g, Mg 270 mg, Na 15 mg, P 200 mg). The energy value is about 1280 kJ/100 g. The fresh herb yields 0.1–0.2% essential-oil, the dried herb 0.1–6%. The flowers contain more oil than the leaves. The major constituent of the essential oil is carvacrol.

The seed of marjoram and oregano is very light; the 1000-seed weight for both is about 0.2 g.

Adulterations and substitutes There are many plants which have a similar scent or flavour to marjoram and oregano and which can be found as adulteration or as substitute. In commerce more than 60 plant species (belonging to 17 genera in 6 families) are offered as oregano. The most important ones are: *Lippia graveolens* Kunth (*Verbenaceae*; Mexican oregano; so similar to true oregano that the commercial herb trade does not distinguish between these); *Origanum dictamnus* L. (Crete dittany); *O. onites* L. (Turkish oregano); *O. syriacum* L., and *Thymus capitatus* (L.) Hoffm. & Link (*Labiatae*; Spanish oregano). *Plectranthus amboinicus* (Loureiro) Sprengel is known as oregano in the Philippines, but is used as a medicinal plant.

Description Subshrubs or perennial herbs, variously hairy to glabrous, often glaucous, glandu-



Origanum vulgare L. – 1, habit; 2, flowering branch; 3, bract and calyx; 4, corolla, stamens and pistil; 5, nutlet.

lar. Stems usually several and square, ascending or erect, branched. Leaves opposite, simple, subsessile to petiolate, glandular. Inflorescence a verticillaster, aggregated in loose to dense spikes which are again arranged into paniculate or corymbiform units; bracts always distinct from the leaves in shape, size and often also in texture and colour, usually imbricate; flowers 2 to several per verticillaster, bisexual or female; calyx usually tubular, regularly 5-toothed or 1–2-lipped; corolla usually 2-lipped, upper lip 2-lobed, lower lip 3-lobed; stamens 4 in 2 pairs (didynamous), the lower 2 longest; style as long as or longer than corolla, 2-lobed at apex. Fruit composed of 4 separate, ovoid, brown nutlets, each one 1–1.5 mm × 0.5 mm.

- *O. majorana*. Subshrub, up to 0.8 m tall with strong roots and hairy, brown stem. Leaves up to 30 pairs per stem; petiole 0–15 mm long; blade roundish to ovate, 3–35 mm × 2–30 mm, margin entire, whitish to greyish, tomentellous, glandular (up to 1500 glands per cm^2), veins not raised. Spike subglobose, ovoid or quadrigonous-cylindrical, 3–20 mm × 3 mm, whitish or greyish, tomentellous, often 3 or 5 closely together at a branch; bracts (2–)6(–30) pairs per spike, ovate, obovate or rhomboid, 2–4 mm × 1–3 mm, whitish or greyish, tomentellous; calyx tubular, 2–3.5 mm long, tomentellous; corolla 3–7 mm long, white to yellowish, the 2 lobes of upper lip 0.2 mm long, the 3 lobes of lower lip subequal, 0.5–2 mm long; stamens protruding, upper pair up to 4 mm, lower pair up to 5 mm long; style up to 9 mm long.
- *O. vulgare*. Woody perennial up to 1 m tall. Stem ascending, rooting at the base, purplish-brown, pilose to glabrous, branches up to 25 cm long. Leaves up to 45 pairs per stem; petiole up to 2 cm long; blade ovate to roundish, 6–40 mm × 5–30 mm, hairy to glabrous, glandular (100–2000 glands per cm^2), margin entire or remotely serrulate. Spike 3–35 mm × 2–8 mm; bracts 2–25 pairs per spike, subovate, 2–11 mm × 1–7 mm, hairy to glabrous, purplish to greenish; calyx tubular, 2.5–4.5 mm long, teeth 0.5–1 mm long, hairy to glabrous; corolla 3–11 mm long, purple, pink or white, hairy outside; lobes of upper lip 0.2–0.7 mm long; lobes of lower lip unequal, 0.5–1.7 mm long; upper pair of stamens up to 4.5 mm, lower pair up to 5.5 mm long; style up to 13 mm long.

Growth and development In Europe, marjoram and oregano seed sown in spring reaches full flowering stage in about 2–3 months. After pollination and fertilization, seed ripens in about 1 month. Under unfavourable water conditions, hardly any normal seed develops. In Europe the growing period for marjoram and oregano is from March to November. Under favourable climatic conditions both species can be grown as a perennial crop with a lifespan of 3–4 years; often, however, both species are grown as annuals. Oregano has been reported to be affected by daylength. Plants exposed to photoperiods of 12 h or 16 h were significantly taller, had more nodes, larger leaf area, and higher shoot and root dry weight than those exposed to 8 h. Floral differentiation occurred only at photoperiods of 12 and 16 h, with a faster rate of differentiation at longer daylengths, suggesting that oregano is a long-day plant.

In oregano uptake of water and the nutrients N, P and K is highest during seed formation and lowest during flowering. The dry weight of leaves and inflorescences peaks at seed formation. The essential-oil content is highest at the initiation of flowering and decreases when seeds start to develop.

In oregano gynodioecy may occur. It is estimated that in Europe up to 50% of the plants in some populations have functionally female flowers.

Other botanical information The genus *Origanum* comprises 38 species, mainly occurring in the Mediterranean region, and most species have a very limited distribution area. In addition to the species there are also 17 known hybrids.

Cultivated plants of *O. majorana* often behave as annual or biennial herbs with a less compact habit, longer branches, a less dense indumentum with larger leaves and longer petioles than wild ones.

O. vulgare with its wide distribution, is a very variable species, bearing a heavy load of different species and subclassification names in the literature, mainly based on differences in indumentum, number of glands on leaves, bracts and calyx and in size and colour of bracts and flowers. None of the subclassifications is satisfactory because *O. vulgare* is one complex species with numerous intermediate forms between distinguishable extremes. The most widely accepted subclassification distinguishes 6 subspecies:

- subsp. *glandulosum* (Desf.) Ietswaart: plant hirsute; leaves not glaucous; inflorescences very wide; leaves, bracts and calyces conspicuously glandular punctate; bracts 1.5–6 mm × 1–3 mm, shorter than calyx; distributed in Tunesia and northern Algeria.
- subsp. *gracile* (Koch) Ietswaart: plant pilosellous or glabrescent; branches and spikes slender;

leaves glaucous; leaves and calyces conspicuously glandular punctate; bracts 1.5–6 mm × 1–3 mm; distributed in eastern Turkey, northern Iraq, Iran, Afghanistan and southern central Russia.

- subsp. *hirtum* (Link) Ietswaart (in the literature often mentioned *O. heracleoticum* auct., non L.): plant hirsute; leaves not glaucous; inflorescences compact; leaves, bracts and calyces conspicuously glandular punctate; bracts 1.5–6 mm × 1–3 mm, as long as or longer than calyx; distributed over the eastern Mediterranean area; this taxon is known as 'Greek oregano' and is considered to be the best quality oregano (called 'rigani' in Greece).
- subsp. *virens* (Hoffm. & Link) Ietswaart: leaves and calyces inconspicuously glandular punctate; inflorescence compact; bracts 3.5–11 mm × 2–7 mm, glabrescent, yellow-green; flowers white; distributed in the western part of the overall species area, Azores, Canary Islands, Madeira, Portugal, Spain and western North Africa.
- subsp. *viride* (Boissier) Hayek (synonym: *O. heracleoticum* L.): leaves and calyces inconspicuously glandular punctate; inflorescence not compact; bracts 2–8 mm × 1–4 mm, pilosellous, green; flowers white; distributed widely, from Corse to eastern China.
- subsp. *vulgare*: leaves and calyces inconspicuously glandular punctate; bracts 2–11 mm × 1–7 mm, purple; flowers pink; distributed all over the northern part of the area, from Britain and Scandinavia through Europe to Asia and Taiwan; it has also naturalized in North America.

O. vulgare is also widely cultivated as ornamental; cultivar 'Aureum' has golden-yellow leaves and 'Humile' is a dwarf form up to 20 cm tall.

There are hardly any officially registered marjoram and oregano cultivars. Commercial unofficial cultivars are numerous and are a source of endless confusion. An internationally accepted official cultivar registration authority is badly needed. There are 3 official cultivars of marjoram in Germany: 'Francia' (developed from Hungarian material), 'Miraz' (from Poland) and 'Marcelka' (from Czech Republic).

Some other well-known but minor *Origanum* species are:

- *O. dictamnus* L., only known from Crete (Greece) where it grows wild and cultivated, is the very famous medicinal herb mentioned by most classic Greek authors as having the property to stop bleeding and to cure stomach-ache. The herb can easily be recognized from its woolly hairs, which are branched. It is also used as culinary herb.
- *O. onites* L., occurring in southern Greece and many Greek islands, western and southern Turkey and on Sicily (Italy) is the 'pot marjoram', cultivated in France and on Cyprus as a culinary herb.
- *O. syriacum* L., occurring in the eastern part of the Mediterranean, is the 'hyssop' of the bible, used as a culinary herb and medicinally.

Ecology Marjoram and oregano are sun-loving plants. Being temperate and subtropical in origin, they can survive cold weather conditions. Oregano, however, is more hardy than marjoram. In its natural habitat marjoram often grows on dry, rocky, limestone soil, at altitudes of 100–1500 m, oregano on limestone soil up to 4000 m altitude. Marjoram prefers rich light soils, with a pH of 5.8–7.2, oregano prefers light dry soils with a pH of 4.5–8.7. For both crops the mean water requirement during the growing period is 500–1000 mm, and average temperature should not be lower than 15°C, although plants may survive much worse conditions. In the tropics both crops grow best at altitudes of 1000–2000 m. In the Philippines oregano is cultivated in Silang, Cavite, which is at 600 m altitude with an average annual temperature of 23–25°C.

Propagation and planting Marjoram and oregano are mainly propagated by seed. Seed dormancy sometimes occurs. If sown in germination boxes, seedlings emerge in 14–21 days. Both crops can be planted directly in the field, preferably at distances of 50–60 cm × 20 cm. In the Philippines seeds are sown very densely: in rows 40 cm apart and about 25 plants per m of row. Alternatively, the plants are initially grown in the greenhouse and transplanted to the field when having 10–15 leaves. Oregano can also be propagated by stem cuttings and by division of plant clusters.

Rapid multiplication of oregano can be achieved through regeneration of plants from cotyledonary callus optimally induced on Gamborgs' medium. Subsequent shoot induction and root initiation can be achieved on the same medium.

In vitro production of active compounds The production of volatile oil has been reported in undifferentiated callus culture of oregano; the amount obtained, however, was minute and only the chemical component carvacrol was identified to be present in the oil.

Husbandry Weed control is very important for both species and weeding is needed about 3 times per growing season. Normally *Origanum* is grown

in dry climatic conditions and survives under natural rainfall. Higher yields, however, are only obtained if the crop is irrigated during dry periods. Oregano and marjoram respond well to fertilizer application. For marjoram, herbage yield was highest at 60 kg/ha N. Fertilizing oregano with 100 kg/ha N immediately before planting and after harvest was found to increase dry herbage and oil yield. Essential-oil yield was not affected by N. Application of composted cow manure has also been shown to increase herbage and essential-oil yields in both crops.
In Germany, marjoram is cultivated as an annual in a crop rotation before wheat and barley and after legumes or potatoes.

Diseases and pests In general, marjoram and oregano do not suffer from serious diseases or pests. Marjoram may suffer from *Alternaria* fungi at the seedling stage, and on oregano a rust disease of little importance caused by *Puccinia menthae* has been observed.

Harvesting For essential-oil production *Origanum* is preferably harvested in full bloom, for herb production at the beginning of flowering. In practice, material for the fresh-herb market is harvested at any time throughout the growing season after the plant has established. In small commercial plantings in the Philippines there are two harvests per month.
For large-scale production of dried herb and extraction of essential oil, the first harvest of leaves and tender tops of both marjoram and oregano occurs just as flowering commences. The first harvest may occur 3–5 months from field planting. Plants are cut 5–7 cm above the soil. Depending on cultivation methods and growing conditions, there can be 2–4 harvests per year.

Yield Yield figures greatly depend on method of cultivation (annual or perennial, plant density). In a 2-year cycle the yield of dried leaves of marjoram varies from 1.4–3.4 t/ha for the first year and 2.8–5.2 t/ha for the second year of cultivation. Calculated annual yield of essential oil averages 73 l/ha. In oregano, yield of dried leaves may range from 2.6–3.2 t/ha and 3.8–5.0 t/ha for the first and second year of cultivation, respectively. Calculated annual yield of essential oil varies from 158–316 l/ha.
In Italy, total dried product yield of a 4-year *Origanum* crop is estimated at 20 t/ha. There are two harvests per year (June and October). The oil content of the leaves in the October harvest is very low.

Handling after harvest Post-harvest handling depends on the desired state of the final product: fresh or dried. The herb should be free from soil particles, weeds and other dirt.
Fresh herbs are bundled together, packed and kept at low temperatures until sold. The quality of both herbs can be maintained for some time when stored at 10°C. To prevent weight loss and to retain turgidity, fresh oregano is placed in polybags or styrofoam boxes or it is put with its basal stems in water that is changed daily.
Oregano and marjoram are dried using rack dryers placed in a well-ventilated room. The racks are made of wire mesh built to convenient sizes and stacked with adequate space between them to allow free air flow. To speed up drying and to obtain a better quality material, a heat source is provided, with the temperature maintained at 29–43°C. When the herb is dry, leaves and small stems are separated from the more woody portion by flailing. The dried product is then stored in polypropylene sacks.

Genetic resources In most countries where *Origanum* occurs naturally, at least some germplasm is conserved. Major collections are available in France (Conservatoire des Plantes Médicinales, Aromatiques et Industrielles, Milly-La-Foret, 95 accessions), Germany (Institute for Plant Genetics and Crop Plant Research, Gatersleben, 21 accessions), Italy (Institute of Agronomy, University of Palermo, 214 accessions) and Turkey (Izmir Plant Genetic Resources Department, Aegean Agricultural Research Institute, 119 accessions). The increasing interest worldwide for *Origanum* material since the 1980s, resulted in over-harvesting from the wild in several countries (e.g. Greece, Morocco, Turkey and Albania) and hence there is a serious threat of genetic erosion of *Origanum* species. In 1994 the Oregano Genetic Resources Network was established by IPGRI.

Breeding Breeding programmes are ongoing in most Mediterranean countries, e.g. in France, Israel and Greece, for marjoram also in Germany. Breeding efforts are promising because both species show a wide variability. Main targets are: stable cultivars with higher herb and oil yield, drought resistance, better quality of the herb and the oil. The often occurring male sterility can be exploited to make artificial crossings.

Prospects Worldwide interest in marjoram and oregano is increasing. In South-East Asia these culinary herbs are also becoming more popular. A good example is the use and cultivation of oregano in the Philippines. The demand, however, is not yet great enough to warrant large-scale commercial production. More research is needed to investigate the feasibility of cultivation and of creating a market for marjoram and oregano in other countries of South-East Asia.

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Oxalis L.

Sp. pl.: 433 (1753); Gen. pl., ed. 5: 198 (1754).
OXALIDACEAE
x = unknown; $2n$ = 12, 24 (*O. barrelieri*); $2n$ = 14, 22, 28 (*O. corymbosa*); $2n$ = 24, 26, 46 (*O. latifolia*)

Major species and synonyms
- *Oxalis barrelieri* L., Sp. pl., ed. 2: 624 (1763), synonyms: *O. sepium* A. St. Hil. (1825), *O. sepium* A. St. Hil. var. *picta* Progel (1877);
- *Oxalis corymbosa* DC., Prodr. 1: 696 (1824), synonyms: *O. martiana* Zucc. (1825), *O. violacea* auct., non L. (1753); *O. debilis* Kunth var. *corymbosa* (DC.) Lourteig (1980);
- *Oxalis latifolia* Kunth, Nov. gen. sp. 5: 184, t. 467 (1822), synonym: *O. intermedia* A. Rich. (1841).

Vernacular names General: Oxalis, sorrel, shamrock (En). Oxalis, oxalide (Fr). Indonesia: calingcing (Sundanese).
- *O. barrelieri*: Indonesia: belimbing tanah (Indonesian), calingcing (Sundanese).
- *O. corymbosa*: Pink wood-sorrel (En). Indonesia: kembang gelas (Indonesian), calingcing beureum (Sundanese), asam puja (West Sumatra). Vietnam: chua me d[aas]t hoa d[or].
- *O. latifolia*: Purple garden oxalis, fishtail oxalis (En). Indonesia: calingcing (Sundanese).

Origin and geographic distribution *Oxalis* is a cosmopolitan genus of more than 800 species, but major centres of diversity are in South America and South Africa.
- *O. barrelieri* is native to tropical South America, but has naturalized in many areas. It was first observed in Java in 1888. In South-East Asia it is common in Indonesia (Sumatra, Bangka, Java, Irian Jaya), Peninsular Malaysia, and Papua New Guinea.
- *O. corymbosa* is native to tropical South America, but has naturalized in many areas and is a common pot-plant. It was introduced into Java from Sydney before 1848. In South-East Asia it is common but only occasionally cultivated in Indonesia (Java, West Sumatra), Peninsular Malaysia and the Philippines (Luzon).
- *O. latifolia* is native to Central and tropical South America. It has naturalized in many areas. In South-East Asia it occurs in Indonesia (Java), where it was already abundant before 1924.

Uses In Indonesia, the leaves of *Oxalis* are used in salads, in particular for their sour or slightly acid taste. They are sometimes used as a substitute for tamarind. When consumed in large quantities, they are toxic.
Oxalis contains many ornamental plants. Among the 'culinary herb' species it is especially *O. corymbosa* which has ornamental value; it is a common pot-plant in e.g. California. Some cultivars are marketed, such as 'Aureo-reticulata' with yellow-veined leaves. There are also double-flowered forms. Medicinal use of *O. corymbosa* has been reported from Zaire (febrifuge and antimalaria) and India.
It is important to realize, however, that *Oxalis*, es-

pecially the ones with underground bulbils, are potentially troublesome weeds difficult to eradicate.

Production and international trade As culinary herbs *Oxalis* spp. are only used locally and have no importance on the market in South-East Asia.

Properties Many *Oxalis* spp. accumulate large amounts of oxalic acid in water-soluble form. Excess consumption should be avoided.

Adulterations and substitutes It seems that *Oxalis* is used mainly when the many other sources of 'asam' (sour leaves, sour fruits) are not readily at hand.

Description Annual or perennial herbs or subshrubs, some stemless with rhizomes, bulbs and tuberous roots. Leaves alternate, apparently cauline, subopposite or pseudoverticillate, digitately or pinnately 3(–4)-foliolate; stipules, when present, adnate to the base of the petiole. Inflorescence axillary, cymose to umbellate or flowers solitary; bracts small, bracteoles 2; pedicel articulate; calyx 5-partite; petals 5, connate near the middle; stamens 10, connate at base, 5 outer ones opposite the petals and shorter than the 5 inner ones opposite the sepals; pistil heterostylous, carpels 1–15-ovuled, styles 5, stigmas capitate. Fruit a capsule, loculicidally dehiscent, each carpel with 1–15 seeds. Seed with crustaceous testa, longitudinally zig-zag ribbed, transversely striate or sculptured, densely verrucate, the external integument fleshy, arilliform, breaking elastically and ejecting the ripe seed.

- *O. barrelieri*. Erect, branched herb or shrub, up to 1.5 m tall, pubescent, without bulbs or rhizomes. Leaves subopposite, pinnately 3-foliolate, without stipules; petiole 2–9 cm long, canaliculate, ascendent; petiolule fleshy, about 1 mm long; leaflet elliptical to oblong, 1–5.5 cm × 0.5–2.5 cm, terminal one largest, base cuneate to emarginate, margin ciliate (especially at base), apex obtuse to rounded, discolorous, glaucous above. Inflorescence cymose, up to 11(–30)-flowered; peduncle up to 6.5 cm long, bifid with branches up to 3 cm long, pubescent; bracts opposite the pedicels, pilose; pedicel up to 3 mm long with appressed bracteoles; sepals ovate-lanceolate, 2–4 mm × 0.5–1.5 mm, light green, sometimes reddish veined; petals obovate-lanceolate, 6–9 mm × 2–2.5 mm, pink but lower half greenish with yellow spots, rolling inwards after anthesis; outer stamens up to 2 mm long, inner ones up to 3 mm long bearing a dorsal tooth; pistil 3.5–4 mm long, carpels 3–4-ovuled, styles 1–1.5 mm long, pubescent. Capsule ovoid, 5–10 mm × 3–5 mm, 5-angular, base and apex 5-lobed, glabrous. Seeds usually 3 per carpel, flattened-ovoid, about 1.5–2 mm × 1 mm, 8-ribbed in zigzag, deeply transversely striate, brownish.
- *O. corymbosa*. Stemless herb, 10–45 cm tall, arising from an underground bulb with fibrous roots but sometimes with an obconical, up to 4 cm long and often rather thick, white taproot; bulb globose, ovoid or cylindrical, up to 1–2 cm long, 3 cm in diameter, composed of numerous densely clustered bulbils each covered by a number of 3-veined, brown, acuminate, ovate to oblong scales up to 2 cm × 0.6 cm. Leaves digitately 3-foliolate; petiole up to 30 cm long, sparsely to densely hairy; petiolules fleshy, up to 1 mm long, pilose; leaflets more or less equal, suborbicular-cordate to broadly obcordate, up to 4.5 cm × 6 cm, incision at apex up to 20% of the length, usually subglabrous above and appressed hairy beneath, with punctiform minute, translucid, orange or violaceous oxalate 'crystals' scattered all over the surface, more densely along the mar-

Oxalis corymbosa DC. – 1, habit flowering plant; 2, leaf; 3, scale of bulbil; 4, flower (top view), 5, flower (side view).

gins. Inflorescence a bifid or twice bifid cyme with unequal branches, asymmetrical or umbelliform, 3–15-flowered; peduncle up to 45 cm long, similar to the petiole; bracts and bracteoles small with linear calli near the middle; pedicel up to 2.5 cm long, articulate near the base; sepals linear to elliptical, 3.5–7 mm × 1–2 mm, at apex with 2 orange calli (dots or stripes); petals spatulate-oblong-lanceolate, 2–3 times the size of the sepals, pinkish, salmon or red-violet; outer stamens 2–4 mm long, inner ones 5–6 mm long; pistil 7.5 mm long, carpels 2–12-ovuled, styles of different lengths, 1–2 mm long, stigma subcapitate, bilobed. Capsule cylindrical, up to 17 mm long, glabrous, carpels 3–10-seeded, but fruiting is rare. Seed flattened ovoid, 12-ribbed in zig-zag with 12 transversal striae, brownish.

- *O. latifolia*. Stemless herb, 10–30 cm tall, arising from a bulbous base with often a whitish, thick, vertical taproot about 5 cm long and fibrous branches; bulb ovoid to globose, up to 5 cm × 2 cm, with many brown, elliptical, 3-many-veined scales up to 5 cm × 2 cm, inner scales smallest and fleshy; from the base of the bulb arise numerous, more or less erect stolons 1–7 cm long, each ending in an ovoid bulbil about 1 cm long. Leaves digitately 3-foliolate; petiole up to 20 cm long, subglabrous; petiolules fleshy, about 1 mm long, pilose; leaflets subequal, broadly obtriangular, 1–7.5 cm × 2–8.5 cm, shallowly but broadly notched and often with 2 orange calli in the notch, margin finely ciliate. Inflorescence an umbelliform cyme, up to 30 cm long, loosely 5–20-flowered; peduncle 10–25 cm long; bracts and bracteoles small; pedicel filiform, up to 2 cm long; sepals linear-elliptical to oblong, 3–6 mm × 0.5–3 mm, indistinctly 3–5-veined, with 2 orange apical calli about 1 mm long; petals narrowly obtriangular, 10–20 mm × 3–8 mm, truncate, red-purplish with greenish base; stamens puberulous, outer ones about 3 mm long, inner ones 4 mm long and bearing a small tooth near the middle; pistil up to 5.5 mm long, carpels 4–8-ovuled, styles about 1 mm long (only short ones), stigmas bifid. Capsule cylindrical, 4–8.5 mm long, glabrous, carpels 4–8-seeded but fruiting is rare. Seed flattened ellipsoidal, 1 mm long, 8–9-ribbed in zig-zag with 12–13 transversal striae, brownish.

Growth and development Three main phases in the growth of *O. latifolia* raised from bulbs can be distinguished. The establishment phase (weeks 1–5) is characterized by slow gain in dry weight in absolute terms, but a high relative growth rate (RGR). During the reproductive phase (weeks 6–12) stolons grow off the parental bulb and initiate bulbils at the apices; some primary bulbils support secondary bulbils. The RGR, net assimilation rate (NAR) and leaf area index (LAI) decrease. They decrease further during the senescence phase (week 13 and onwards).

The seed-bearing *Oxalis* such as *O. barrelieri* have a peculiar ejaculative aril originally enveloping the entire seed which at maturity is shot some distance away. The non-fruiting species such as *O. corymbosa* and *O. latifolia* perpetuate tenaciously through their bulbils. *O. latifolia* is apparently functionally heterostylous; it occurs in the short-styled form only with probable loss of the mid- and long-styled forms. It has never been observed with fruit in South-East Asia. *O. corymbosa* occurring in short-styled and mid-styled forms but with probable loss of the long-styled form, does not fruit easily either.

Other botanical information In South-East Asia 8 *Oxalis* species occur, 3 native (*O. acetosella* L. subsp. *griffithii* (Edgew. & Hook.f.) Hara, *O. corniculata* L., *O. magellanica* Forst.f.) and 5 introduced (*O. barrelieri*, *O. corymbosa*, *O. fruticosa* Raddi, *O. latifolia* and *O. tetraphylla* Cav.). Apart from the 3 species treated here as culinary herbs, *O. corniculata* is similarly used (Indonesia: 'daun asam kecil') but has greater importance as medicinal plant, whereas the others have some importance as ornamental plants.

The 3 *Oxalis* species dealt with here can easily be distinguished: *O. barrelieri* has a stem but no bulbs and bulbils and the leaves are pinnately 3-foliolate; *O. corymbosa* and *O. latifolia* are stemless with underground bulbs and bulbils and the leaves are digitately 3-foliolate; in *O. corymbosa* the bulbils are clustered and without stolons, in *O. latifolia* the bulbils appear at the end of stolons arising from the bulb.

Ecology *Oxalis* is primarily found in anthropogenic habitats: in gardens, along roads, in hedges, fields, village groves, estates, along rivers, and in grassy locations with shade. *O. barrelieri* occurs from sea-level up to 1500 m altitude, *O. corymbosa* between 400–1500 m, and *O. latifolia* between 1100–1800 m.

In weed control studies, it has been observed that *O. corymbosa* grows best under heavy shade (50%); however, bulb or bulbil production is not affected by shade. Alfisols are preferred above Entisols, Inceptisols and Ultisols. Growth and reproduction are negatively affected at moisture conditions below field capacity. Acid soils are preferred and growth slows down with increasing pH.

Agronomy *O. barrelieri* is propagated by seed, whereas *O. corymbosa* and *O. latifolia* are reproduced successfully by bulbils. Planting depth (1–25 cm) hardly affects the sprouting percentage of *O. corymbosa* bulbs, but increasing depth delays emergence and decreases number of leaves and number of daughter bulbs. Bulbs weigh between 0.1–2.5 g, sprouting being highest in the weight range of 0.2–2.0 g. Since *Oxalis* herbs are easily collected from the wild, they are rarely cultivated.

O. corymbosa and *O. latifolia* are sometimes affected by orange rust caused by *Puccinia oxalidis*, resulting in many lesions on the leaves. Both species have been reported as a host for root-knot nematodes (*Meloidogyne arenaria* in particular), whereas *O. corymbosa* is also affected by *Meloidogyne javanica*.

Genetic resources and breeding The *Oxalis* herbs are widespread, and their occurrence in anthropogenic habitats makes them unlikely candidates for genetic erosion. There is even much effort to eradicate them as noxious weeds. There are no known breeding programmes.

Prospects Since there is little information on *Oxalis*, it is difficult to judge its future importance as culinary herb. Because of restricted use it is best marketed to the consumer in small quantities, e.g. as living plants in small pots as is practised for parsley, leaf celery (celery herb) and chives in the western world.

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R.C.K. Chung & S.S. Budi Rahayu

Pandanus amaryllifolius Roxb.

Fl. ind. 3: 743 (1832).

PANDANACEAE

$2n = 60, 70$

Synonyms *Pandanus latifolius* Hassk. (1842), *P. hasskarlii* Merrill (1917), *P. odorus* Ridley (1925).

Vernacular names Fragrant pandan, fragrant screwpine (En). Indonesia: pandan wangi (general), pandan rampe (Sundanese), pondak (Moluccas). Malaysia: pandan wangi. Papua New Guinea: karuka. Philippines: pandan, pandan mabango. Cambodia: taëy. Laos: të:y ho:m, të:y ba:nz. Thailand: toei-hom, panae-wo-nging. Vietnam: d[uws]a th[ow]m.

Origin and geographic distribution Fragrant pandan is an ancient cultigen which has never been found wild. It might originate from the Moluccas (Indonesia), from where the only flowering specimen is known. It is widespread in Sri Lanka, Thailand, Vietnam, Malaysia, Indonesia (including Irian Jaya), and the Philippines, and is probably cultivated in many other countries, having been brought in by South-East Asian migrants.

Uses *P. amaryllifolius* is the only pandan with scented leaves. Throughout South-East Asia, they are used fresh in cooking to impart flavour and colour (chlorophyll) to rice, sweets, jellies and many other food products; the leaves are removed from the food before consumption. Leaves of *P. amaryllifolius* are widely used to flavour ordinary rice, as a substitute for expensive aromatic rice cultivars. Fried chicken wrapped in pandan leaves is a delicacy. Juice is pressed from the leaves for flavouring and colouring cakes. Freshly chopped leaves are mixed with the petals of various flowers to make potpourris. Leaves can be woven into small baskets. Fragrant pandan has definite potential as an ornamental plant, in the garden as well as for interior decoration.

P. amaryllifolius has a number of local medicinal and ceremonial uses. For instance, after soaking the leaves in coconut oil, the oil is employed as an embrocation for rheumatic troubles. Infusions of the leaves are used internally and externally as a sedative against restlessness. In Thailand it is a traditional medicine to treat diabetes. Powdered pandan leaves may be used against *Callosobruchus chinensis* infestation of mung-bean seeds.

Production and international trade No production figures are available for fragrant pandan. It is commonly grown for home consumption, and is regularly offered on local markets.

Properties It has been speculated that the scent in fragrant pandan leaves is not an essential oil, but a volatile product of oxidative degradation of a yellow carotenoid pigment.

The leaves, however, yield a very small amount of essential oil (several ppm only), consisting for 6–42% of sesquiterpene hydrocarbons, and 6% linalool as the only monoterpene. The oil also contains about 10% of the aromatic compound 2-acetyl-1-pyrroline, which is the compound responsible for the pandan-like aroma of the well-known Thai aromatic rice cultivar Khao Dawk Mali 105, and which is absent in non-aromatic rice cultivars. The essential oil has insect-repellent activity, for instance against the ordinary cockroach *Periplaneta americana*.

Three piperidine alkaloids (pandamarilactone-1, pandamarilactone-32, pandamarilactone-31) have been isolated and identified from the leaves of fragrant pandan. They all have a C-9-N-C-9 skeleton and could be derived biogenetically from 4-hydroxy-4-methylglutamic acid.

The application as antidiabetic drug seems linked to 4-hydroxybenzoic acid, which has been isolated from *P. amaryllifolius* roots. It shows hypoglycaemic effects in normal rats (oral administration of 5 mg/kg), and increases serum insulin levels and liver glycogen content.

Description *P. amaryllifolius* has two distinct growth forms.

- Small growth form: Perpetuated sucker shoots. Stem slender, 1–1.6 m tall, 2–5 cm in diameter, decumbent and ascending, emitting aerial roots throughout its length. Leaves oblong, 25–75 cm × 2–5 cm, rather pale green, somewhat thin and flaccid, more or less glaucous and keeled beneath, the apex with rather distinct twin lateral pleats, the margins entire, unarmed except a few minute prickles less than 1 mm long near the apex. Flowers and fruits unknown.
- Large growth form: Eventually producing an erect stem, 2–4.5 m tall, 15 cm in diameter, unbranched or sparsely branched, bearing large aerial prop roots. Leaves oblong, 150–220 cm × 7–9 cm, apex acute, rather dark green above, glaucous and keeled beneath, the twin lateral pleats above somewhat prominent, margins entire, unarmed except near leaf apex with small antrorse prickles about 1 mm long and very rarely with 1–3 small stout prickles near the base. Female inflorescence unknown. Male inflorescence (evidently exceedingly rare), probably pendent, up to 60 cm long, the spathes 90 cm long, white or the lower ones with green foliaceous tips, bearing several oblong spikes to 35 cm long or more, several cm wide; upper ones much shorter, about 9–10 cm long, 2 cm wide, composed of many crowded staminal phalanges; staminal phalange with column 4–9 mm × 1.5–2.5 mm, compressed to flat, containing 3–6 stamens with very short filaments, 0.5–1.5 mm × 0.4–0.6 mm and oblong anthers, 2.5 mm long.

Pandanus amaryllifolius Roxb. – habit.

Growth and development The small growth form of fragrant pandan is perpetuated by continued harvesting of the leaves. When abandoned or allowed to develop without hindrance, it grows very slowly but eventually will enter into the 'large' growth phase and develop a stout trunk. The odour of the leaves remains the same in both growth forms. Flowering never occurs in the small form, and is very rare in the large form.

Other botanical information 'Large' fragrant pandan and 'small' fragrant pandan were long considered two distinct species, but the two forms are merely growth phases of one and the same species, *P. amaryllifolius*. However, the rarity of flowering, pistillate flowering in particular, has hindered positioning of the species in the genus, and its relatives and ancestry are much in doubt. Based on the available information, *P. amaryllifolius* probably belongs to the subgenus *Kurzia* Stone, Sect. *Jeanneretia* (Gaudich.) Stone.

In spite of the relatively high number of somatic chromosomes in the whole genus *Pandanus* Parkinson ($x = 30$), there is no evidence of a possible polyploid origin.

Ecology Apart from the continuous harvesting of fragrant pandan, there are some indications that ever-wet climatic conditions are less favourable for the development of the large growth form, and thus assist in the perpetuation of the small growth form. Fragrant pandan tolerates shade very well.

Propagation and planting Fragrant pandan is propagated by suckers or by stem cuttings. Suckers removed from the leaf axils can be planted straight away or rooted first in a sandy medium. Stem cuttings should be inserted obliquely in the planting medium.

Husbandry Fragrant pandan is not usually grown in regularly spaced stands. Domestic plantings tend to consist of a few plants mixed with other species. A typical Indo-Malay home garden may have perhaps a dozen small plants of *P. amaryllifolius* for kitchen use, a few clumps of *P. kaida* Kurz for fibres, and a single decorative plant of one of the variegated pandans.

Harvesting Harvesting of fragrant pandan may start about 6 months after planting and may continue for several years. Individual leaves are cut, leaving the top with 3–4 leaves intact.

Yield Information on yield of fragrant pandan is scanty. A one-ha plot in the Philippines, with fragrant pandan under pepper and some fruit trees, was harvested twice a week, yielding 60 kg of fresh leaves per harvest, or 6 t/ha per year.

Handling after harvest Fragrant pandan is usually used and marketed fresh. Flavour extraction with ethanol and the use of dextrin 2% as the filler substance has given good results.

Genetic resources and breeding There are no known substantial germplasm collections or breeding programmes.

Prospects Fragrant pandan has only been of marginal interest to agricultural institutions; even information on yield levels is lacking. Although it is a minor crop grown for domestic use, ingenuity in developing new uses for pandan flavouring and colouring could enhance its value. Flavour powder and colouring tablets are potential new applications expected to improve quality, durability and ease of handling.

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F.M. Setyowati & J.S. Siemonsma

Perilla frutescens (L.) Britton

Mem. Torrey Bot. Club 5: 277 (1894).

LABIATAE

$2n = 28$–40

Synonyms *Ocimum frutescens* L. (1753), *Perilla ocymoides (ocimoides)* L. (1764), *P. nankinensis* (Lour.) J. Decaisne (1852).

Vernacular names Perilla, perilla mint, Chinese basil (En). Pérille, pérille de Nankin (Fr). Indonesia: daun shiso (derived from Japanese). Laos: nga: chieng, nga: chi:n. Thailand: nga-khimon, nga-mon. Vietnam: t[is]a t[oo], t[uwr] t[oo].

Origin and geographic distribution Perilla is native to the mountainous areas of India and China, and is cultivated widely in China, India, Indo-China, Japan, Korea, and on a small scale in other parts of South-East Asia, e.g. by hill-tribes in northern Thailand. It naturalized in the United States and the Ukraine as an annual weed of waste places, pastures and roadsides. Perilla is gradually becoming better known in Europe, and its cultivation is being tried out in many locations, even as far north as Finland.

Uses The leaves, inflorescences, fruits, seeds, and seedlings (sprouts) are used as a flavouring or as a garnish in a number of foods, particularly in Japanese, Korean and Vietnamese cooking. Its customary addition to raw seafood is believed to prevent food poisoning. Perilla serves as a side dish with rice and as an important ingredient in noodles, baked fish, fried foods, cakes and beverages. The leaves can be easily dried for off-season use. The purple-leaved forms, which contain large amounts of anthocyanins, are used for colouring pickled fruits and vegetables. These forms are also very decorative ornamental plants.

Essential oil distilled from the foliage is used as a flavouring agent and as a source of commercially important compounds for the preparation of perfumes and sweetening agents.

The seed contains 29–52% fatty oil. It can be used in cooking and is employed as a drying oil in paints, varnishes, linoleum, printing ink and lacquers and as a waterproof coating on cloth. The seed meal can be used as a ruminant feed.

In folk medicine, perilla is considered diaphoretic, anodyne, sedative, diuretic, anti-inflammatory and as a remedy for cough. Perilla extracts show much promise as an anti-inflammatory and antiallergic reagent.

Production and international trade No statistics are available on the world production of perilla. Production in China must be considerable, particularly for medicinal purposes. Taiwan has a small production of perilla vegetable for export to Japan. In 1995, Japan had some 1030 ha under perilla. South Korea is probably the largest producer of perilla seed, averaging 28 000–37 000 t from 37 000–50 000 ha during the period 1990–1993. Annual world production of perilla essential oil in the 1990s has been estimated at 1500 kg valued at US$ 1.8 million.

Properties Dried perilla leaves and flowering tops contain 0.3–1.3% essential oil. Several chemotypes of perilla exist but the type containing mainly perillaldehyde is most commonly used as a culinary herb. Analysis of a typical essential oil of this chemotype may indicate as chemical composition: perillaldehyde 74%, limonene 13%, β-caryophyllene 4%, linalool 3%, benzaldehyde 2% and less than 1% of sabinene, β-pinene, pseudolimonene, terpinolene, pulegone, perillyl alcohol, isoeugeniol, α-caryophyllene. A monograph on the physiological properties of perilla oil has been published by the Research Institute for Fragrance Materials (RIFM).

The leaf essential oil from one of the other perilla chemotypes has been shown to consist largely of perillaketone, a potent pulmonary edemagenic agent for laboratory animals, cattle and possibly humans. This form of perilla is normally avoided by cattle, but poisoning may be caused by hay containing it.

Another chemotype contains myristicin, which is hallucinogenic. Yet another type has the ketone rosefuran, one of the character impact components of rose oil, as its major component. This suggests it would be feasible to use perilla essential oil as a substitute for rose oil in perfumery. Perilla essential oil has also been used as a source of perillaldehyde for the preparation of perillartine which is 2000 times sweeter than sugar and has been used to flavour tobacco, but is rarely used nowadays because of its poor solubility in water, its bitterness and its flavour of menthol and liquorice.

Perillaldehyde has been reported to exhibit antimicrobial activity.

The deep purple leaves and seeds have been shown to contain 5 anthocyanins, 2 flavones and 9 flavone glycosides, of which shisonin and 7-caffeoylglucosides of apigenin and luteolin are the most important ones in the leaves. A large number of caffeic acid derivatives are also present in the leaves. The seeds contain apigenin and luteolin in a 1:1 ratio.

The seed oil is similar to linseed oil in odour and taste but has a superior drying quality. It is one of the richest vegetable sources of α-linolenic acid, which has anti-hypertensive and anti-thrombosis effects, anti-allergic activity, and inhibitory effects in carcinogenesis.

The weight of 1000 seeds is 1–2 g.

Description Erect, aromatic, annual herb, 0.3–2 m tall, green or purplish. Stem square with obtuse angles, 0.5–1.5 cm in diameter, often profusely branched, finely pilose to densely villous and glandular dotted. Leaves simple, decussately opposite, gradually decreasing in size from bottom to top of the plant, finely pilose to densely villous; petiole 0–7 cm long, absent or very small in upper-

Perilla frutescens (L.) Britton – 1, flowering branch; 2, flower; 3, fruiting calyx; 4, nutlet.

most leaves; blade broadly ovate to circular, 2–13 cm × 1.5–10 cm, base rounded to cuneate, margin finely to coarsely serrate, sometimes wavy, apex short acuminate to mucronate. Inflorescence terminal or axillary, racemose or paniculate, 2–20 cm long, consisting of 2-flowered verticillate cymes, densely villous; peduncle 1–1.5 cm long; bracts linear-lanceolate to subcircular, 3–6 mm × 0.5–4 mm, red-brown glandular; pedicel about 1.5 mm long; calyx campanulate, 2-lipped, about 3 mm long, 10-veined, erect, glandular hairy, lower lip with 2 lanceolate teeth, longer than the 3-toothed upper lip; in fruit the calyx is enlarged up to 11 mm long and becomes spreading or pendulous; corolla campanulate, 2-lipped, 3–4.5 mm long, white to purple-red, lower lip 3-lobed, upper lip 2-lobed; stamens 4, erect, subequal; pistil with deeply 4-lobed ovary and 1 style ending in 2 stigmatic lobes. Fruit composed of 4 subglobose nutlets 1–2 mm in diameter, grey-brown to black-brown, with netted surface, enclosed within the persistent calyx.

Growth and development Germination of perilla seed takes 5–15 days. Initially the plant grows slowly. Harvesting of leaves can start about 3 months after germination. Undisturbed plants start flowering about 4 months after sowing. Seeds are mature about 6 weeks after flowering.
In the United States, where perilla has become an introduced weed, it germinates in spring when there is no longer any night frost. During summer the plants remain about 15 cm tall until flowering in August, when the stem elongates to about 1 m. Frosts kill the plant in November.

Other botanical information Perilla is a very variable species and the variability has been expressed in numerous species, variety, form and cultivar names. At the moment perilla is considered as a single complex species which is subdivided into varieties and cultivars, mainly based on size and colour of the leaves, incision-type of the leaf-margin, size and hairiness of the calyx in fruit, and size and colour of the nutlet. Cultivars include 'Atropurpurea', 'Crispa' and 'Curled'.
Based on the chemical constituents of the essential oil in the leaves, 6 genetically stable chemotypes of perilla have been identified:
- PA type: perillaldehyde and L-limonene are the 2 major components;
- EK type: elsholtziaketone is the major component and naginataketone a minor component;
- PK type: the major component is perillaketone with a small amount of isoegomaketone and perillene;
- PP type: consists mainly of phenylpropanoids (myristicin, dillapiol and elemicin) with few or no monoterpenoids;
- C type: trans-citral is the major component, with small amounts of perillene, perillaketone and isoegomaketone;
- PL type: perillene is the major component, with trans-citral, perillaketone and isoegomaketone as minor components.

The PA type is preferred for use as a spicy herb or crude drug because of the agreeable scent of perillaldehyde. In contrast, EK and PK possess the disagreeable odour of terpene ketone, while PP is odourless. PK and PP are both unfit for human use because of the presence of large amounts of perillaketone in PK which has been shown to be toxic to animals, while myristicin in PP is hallucinogenic.

Ecology The reported ecological range of perilla is considerable. In its range the mean annual rainfall varies between (500–)1000–2000 mm and the mean annual temperature from (6–)12 to 18°C. The optimal temperature for germination and growth is about 20°C, but higher temperatures are easily tolerated. Temperatures should not fall below 10°C. In the tropics perilla is found at higher elevations. It needs sunny or partially sunny conditions. For abundant vegetative growth, the plants should be exposed to warm conditions and long daylengths and provided with adequate moisture; for flower production perilla requires short-day conditions. It is tolerant of a soil pH of 5–7.5, and thrives in sandy soils rich in organic matter.

Perilla is a short-day plant and has been a favourite experimental subject for the elucidation of the mechanism of flowering in higher plants, particularly the concept of a transmissible flowering stimulus. It has a critical daylength of about 14 hours and the minimal number of short days for the induction of flowering ranges from 6–9. The dark period should have a temperature of 22–27°C for optimum induction. For abundant flowering and hence abundant production of seeds, perilla should be exposed to short days for 3–4 weeks, starting after the fourth leaf-pair stage. N-stress can also induce flowering, even under continuous lighting.

Propagation and planting Perilla is commercially propagated by seed. Seeds developing in autumn remain dormant until spring. Gibberellin is sometimes used to break dormancy. Seeds lose their viability in less than a year at room temperature, but viability can be extended if they are stored at low temperatures and low humidity. Seeds are either sown directly in the field or initially raised in a nursery until they have developed 5–6 leaves at which time they are ready for transplanting. Prior to sowing, fertilizer is applied and incorporated into the soil. For the production of leaves, seeds are sown in rows 40 cm apart in raised beds and thinned to 12 cm apart (200 000 plants/ha). When flower heads are desired, perilla is planted in rows 90–120 cm apart with the spacing within rows depending on the cultivar and time of planting: spacing is narrower for early-flowering types and under short-daylength conditions.

To produce perilla sprouts for consumption, seeds are broadcast on raised beds worked up to a fine tilth. Seeds are then just covered with sieved soil or sand and the bed watered and covered with straw. The cover is removed as soon as the sprouts emerge.

In vitro production of active compounds The volatile compounds of callus tissue of perilla have been reported to consist mainly of rosmarinic acid (about 50% of the phenolic extractives), caffeoylglucose (20–30%) and caffeic acid. In addition to these components, intact plants contain large amounts of flavones, apigenins, luteolins and anthocyanin. Callus culture can thus serve as a simpler method for the isolation of caffeic and rosmarinic acids which are useful as antiphlogistic agents and for other remedies.

The economic production of safe food colourants, antioxidants, and free radical scavengers from cell culture of perilla anthocyanins seems to be within reach.

Husbandry Perilla benefits from application of 10 t/ha of compost. A basal dressing per ha of 40 kg N, 30 kg P_2O_5 and 20 kg K_2O is recommended. A top dressing of 70 kg/ha urea and 50 kg/ha KCl is advisable after harvesting tops. When grown on field scale, perilla is often mulched with black polythene sheet to conserve moisture and prevent weed growth. In Japan perilla is commonly grown under polythene cover or in glasshouses with artificial heating and lighting and controlled irrigation. Deep-flow hydroponic culture of perilla has been reported from Korea.

Diseases and pests Diseases known to attack perilla include downy mildew, rust, bacterial wilt and damping off. Cutworm, mites, aphids, leaf folders, browsing caterpillars and whiteflies are among the reported insect pests.

Harvesting Perilla sprouts are harvested when the cotyledons are expanded and the first true leaves have formed (7–20 days after sowing depending on the season).

Harvesting of vegetative tops or leaves can start when plants are 30–40 cm tall, about 2–3 months after sowing or transplanting. Harvesting continues as often as needed, usually until flowering starts. Mechanical harvesting of leaves has been reported from Taiwan, using tea-leaf harvesters. As flowering progresses, the level of aldehydes in fresh perilla herb is reported to increase and the level of esters to decrease.

Perilla inflorescences are collected by simply cutting the stalks, usually when these bear 5–6 opened flowers. When perilla is grown as a seed crop, leaves are often picked as a by-product.

Yield Yields of fresh perilla leaves may reach 20–30 t/ha, or 2–3 t/ha dry weight. Thus, about 20 kg/ha of perilla essential oil may be obtained. Seed yield has been reported to average 770 kg/ha in commercial production in Korea. However, high-yielding cultivars can easily reach 1.1–1.2 t/ha. The commercial extraction rate of seed oil is about 40%.

Handling after harvest Harvested perilla leaves are tied together with a rubber band into bundles of 10. Inflorescence stalks are trimmed to a final length of 8–10 cm and sprouts are washed before they are packaged and sold in the market. For extraction of essential oil, the leaves and flowering tops are hung in bundles in a well-ventilated room and allowed to dry for about 2 weeks prior to distillation.

Genetic resources Institutions maintaining germplasm collections of perilla include the National Institute of Agrobiological Resources at Tsukuba (Japan), the NBPGR Regional Station at Shillong (India), and the Crop Experiment Station, Rural Development Administration at Suwon (Korea). A small collection is maintained at the North Central Regional Plant Introduction Station in Ames (United States).

Breeding Perilla is predominantly self-pollinating. The chemical composition of the various chemotypes of perilla is controlled by single genes following Mendelian inheritance: a series of multiple alleles (G_1, G_2, g) and an independent pair of alleles (H, h). G_1 and G_2 have been found to be essential in the initiation of monoterpenoid biosynthesis in perilla. G_1 is responsible for the development of the EK type and is dominant over G_2 that produces the PK type, while the homozygous (gg) plants produce the PP type. With G_1 or G_2, plants homozygous for the dominant allele H (G-HH) produce the PA type while those heterozygous for H (G-Hh) contain large quantities of L-limonene, an intermediate product in the synthesis of perillaldehyde. The PL type is produced in the presence of the polymeric genes Fr_1 and Fr_2 which are involved in the conversion of citral into perillene, while the C type, which controls the production of large quantities of citral, is homozygous recessive for the two genes, $fr_1\ fr_1\ fr_2\ fr_2$.
Non-shattering cultivars should be bred for commercial seed production.

Prospects Perilla as an oil-seed crop and spice is particularly important to some countries in Asia, e.g. Japan, Korea, China and Vietnam. There is a limited market in Europe and the United States catering to the taste of Asian immigrants. Uses of perilla other than those traditionally known, e.g. as animal feed additive, artificial sweetener and a source of rosefuran have not been fully explored. Production of the red pigment shisonin from perilla may fill the need for the future demand for natural food colouring. In all these endeavours, cultivation of the PA type fit for human use should be considered. There is a definite potential for South-East Asian countries to be players in the market for novel uses of perilla.

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C.C. de Guzman & J.S.Siemonsma

Persicaria odorata (Lour.) Soják

Preslia (Prague) 46: 154 (1974).
POLYGONACEAE
$2n$ = unknown

Synonyms *Polygonum odoratum* Lour. (1790).

Vernacular names Rau ram, Vietnamese coriander (En). Renouée odorante (Fr). Cambodia: chi krassang tomhom. Laos: phăk ph'è:w. Thailand: chanchom (Nakhon Ratchasima), phakphai (northern), homchan (Ayutthaya). Vietnam: rau r[aw]m.

Origin and geographic distribution Rau ram is native to and is cultivated in Indo-China. Since the 1960s its cultivation has spread with Vietnamese migrants, mainly to Australia, the Philippines and the United States.

Uses The leaves of rau ram are used to flavour many Vietnamese dishes. The fresh leaves are eaten in salads and also with incubated duck eggs, while fresh or cooked leaves are used in various fish, shellfish (mussels, clams, oysters), turtle and frog dishes. It imparts a flavour reminiscent of lemon and coriander leaves with a slight radish-like pungent aftertaste. The flavour is destroyed by prolonged cooking.

A few shoots of rau ram and water dropwort (*Oenanthe javanica* (Blume) DC.) are often added when preparing cabbage preserved in brine (like sauerkraut). Although relished by the Vietnamese, the flavour of rau ram is not universally admired, though it is liked by some people who do not appreciate the taste of coriander leaves.

Medicinally the leaves are used as a diuretic, stomachic, febrifuge and anti-aphrodisiac. Externally the crushed leaves are applied against fever, vomiting, ringworm and phagedaena. Juice prepared from the crushed leaves is taken as an antidote against poisonous snake bite, and the bite is covered with the residue of the leaves. In Vietnam pregnant women avoid the use of rau ram, since fresh leaves seem to have abortifacient properties.

Properties The nutritional value of rau ram is unknown. The leaves contain a yellowish essential oil, consisting mainly of alkane aldehydes. Drimane sesquiterpenoids, which are under investigation for their antifungal and anticarcinogenic properties, are present in some *Persicaria* and *Polygonum* species, but have not been found in *P. odorata*.

Adulterations and substitutes Besides coriander leaves, leaves of *Eryngium foetidum* L., known as sawtooth coriander or 'Mexican coriander', are used as a substitute.

Description Short-lived perennial, fragrant herb, somewhat glandular in all parts. Stem ascending, 30–35 cm tall, 2–3 mm in diameter, red, grooved; base trailing and forming roots at all nodes, much thicker than upright part. Leaves alternate; ocrea membranous, short, up to a quarter of the length of the internode, loosely enveloping the stem, parallel veined, each vein culminating at apex in a long silky hair, with some glandular dots in horizontal lines; petiole attached to basal part of ocrea; blade entire, lanceolate to ovate-lanceolate, base attenuate, apex acuminate or obtuse, green, marked with red, margins and veins, especially the midrib, with appressed, fairly long hairs. Inflorescence an axillary, long, many-flowered, narrow spike, single or in pairs or in a small cluster; bracts long and funnel-shaped, with long hairs on margins; flowers hermaphrodite; perianth pentamerous, white to purplish-pink, persistent in fruit; stamens 8; styles 3. Fruit triangular, 1.5 mm long, acuminate at both ends, smooth and shiny.

Growth and development Rau ram is a tender perennial. In Vietnam and the Philippines flowering is profuse and starts in the first year. In Vietnam flowering occurs in August–September

Persicaria odorata (Lour.) Soják – habit non-flowering shoot.

and fruiting in September–October. In the United States rau ram flowers only occasionally and only after vernalization. Harvesting can continue when plants are flowering. Under greenhouse conditions in the United States leaves can be harvested year-round.

Other botanical information In popular horticultural handbooks confusion between *Persicaria odorata* and *P. hydropiper* (L.) Spach (synonym: *Polygonum hydropiper* L.) is common. The synonym *Polygonum odoratum* is occasionally confused with *Polygonatum odoratum* (Mill.) Druce (*Liliaceae*).

Ecology Rau ram requires warm and humid growing conditions. Light frost is probably tolerated. It grows best under partial shade, but full sunlight is tolerated if ample moisture is available. In Vietnam it can be grown and harvested year-round, but it grows best in spring. In cold and dry winters in northern Vietnam it may wither away. Fertile soils with adequate soil moisture are essential for optimal production. Under drier conditions, the stem base becomes woody and the leaves turn yellowish.

Propagation and planting Rau ram is usually and easily propagated by stem cuttings with 4–6 internodes (8–10 cm long) taken from the top of mature stems. These are planted obliquely 5–6 cm apart with a row spacing of 10–15 cm in raised beds of light, well-manured soil and are watered well. Under warm and humid conditions cuttings start rooting after 3–5 days and growing after about a week. They are planted out in the field at a spacing of about 20 cm × 20 cm. In lowland Vietnam cuttings are sometimes planted directly in well-prepared and manured muddy rice fields.
Seed is difficult to obtain in the United States and Australia.

Husbandry Rau ram can be rejuvenated by cutting back the stems.

Diseases and pests Occasional damage to rau ram from diseases and pests is reported from Vietnam, but the causal agents are not known. In the United States fungal diseases and slugs sometimes affect rau ram. Providing more sunlight can reduce damage. Caterpillars are the main problem in the Philippines.

Harvesting The first harvest of rau ram is taken when plants are nearly 2 months old; subsequent harvests are every 12–15 days in Vietnam, and every 3–4 weeks in the United States. In home gardens leaves are picked when required. In commercial plantings whole tops are harvested.

Yield Under very intensive cultivation in small market gardens yields of fresh tops of rau ram may reach 1.3 t/ha per harvest or about 15 t/ha per year.

Handling after harvest Leaves of rau ram should be kept cool and moist to maintain their fresh appearance.

Genetic resources and breeding It is unlikely that germplasm collections of rau ram are being maintained and there are no breeding programmes.

Prospects Migration of Vietnamese people has greatly increased interest in Vietnamese cuisine in many countries, which will be a strong incentive to increase production of rau ram. As people become more familiar with its flavour, rau ram may become an alternative for coriander leaves, as many who do not like coriander find the taste of rau ram more acceptable.

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L.P.A. Oyen & Dzuong Duc Huyen

Petroselinum crispum (Miller) Nyman ex A.W. Hill

Hand-list herb. pl. Kew, ed. 3: 122 (1925).
UMBELLIFERAE
$2n = 22$

Synonyms *Petroselinum vulgare* J. Hill (1756), *P. hortense* Hoffm. (1814), *P. sativum* Hoffm. (1814).

Vernacular names Parsley (En). Persil (Fr). Indonesia: peterseli (general), patraseli (Javanese), potrasoli (Sundanese). Cambodia: vannsuy baraing. Thailand: phakchi-farang (Bangkok). Vietnam: rau m[uf]i, m[uf]i t[aa]y.

Origin and geographic distribution Parsley probably originated in the western Mediterranean. It occurs naturally or naturalized in most Mediterranean (including northern Africa) countries, and in many temperate countries. Parsley is an old crop, which was already well known in classical Greece and Rome. It is widely grown for its leaves in most Mediterranean countries, Europe and North America. In the tropics, including South-East Asia, it is cultivated on a small scale at higher elevations. Forms with a thickened, edible taproot are of recent origin and were probably developed around 1500 AD in northern Germany. Their cultivation is concentrated in north-western and eastern Europe and among North Americans originating from that area.

Uses Both dried and fresh parsley have numerous uses. The fresh leaves of curly-leaved cultivars are commonly used for garnishing and seasoning, while those of flat-leaved cultivars are mainly used to flavour dishes, playing a role in Western cooking similar to that of coriander leaves in Asia. The leaves are also eaten as 'lalab' with rice or in mixed vegetables, and are sometimes fried in butter or oil. Dried leaves of parsley, known as parsley flakes, are used to flavour soups, meat and fish dishes, vegetables and salads. They can be made into a tasty tea and are an ingredient of some types of savoury biscuits. Parsley tea is reported to have carminative and diuretic properties and aids in digestion. The taproot of turnip-rooted cultivars is eaten as an aromatic vegetable, their leaves are used like those of flat-leaved cultivars.

Essential oils from the fruits and the herb are used as a seasoning agent in all kinds of food products, especially meats, sausages and sauces. The maximum permitted level of parsley leaf oil is about 1.5% in processed vegetables, and of parsley oleoresin about 0.05% in condiments. The oil from the fruits is occasionally used in perfumery. In the United States the regulatory status 'generally recognized as safe' has been accorded to parsley (GRAS 2835), parsley leaf oil (GRAS 2836) and parsley oleoresin (GRAS 2837) (no status known for parsley fruit oil).

Parsley has diuretic, carminative, emmenagogue and antipyretic properties, and is effectively used to control hypertension. Fruits taken in large quantities may induce abortion. Casualties due to its use still occur and for this reason the fruit has been removed from the German pharmacopoeia. Parsley fruits are still incorporated in products against halitosis. Applying the leaves to the breasts several times a day is said to effectively suppress secretion of milk. Bruised leaves are used as a poultice for sore eyes and can be applied to insect bites and stings. The fruits are used to get rid of lice and skin parasites; the juice from the leaves is used as an insecticide.

Production and international trade No statistics are available on world production and trade in parsley, but data on selected markets reveal its importance. Parsley is the most widely used fresh herb in the major European countries, but a large part of the demand is met by domestic growers. In the United Kingdom it accounts for over half the area planted with culinary herbs (300 ha out of 558 ha in 1986), contributing nearly two-thirds of the total production of culinary herbs (900 t out of 1420 t). The total market for dried parsley in France, Germany and the United Kingdom is estimated at 3050–3250 t. In the United States, over 10 000 t of parsley is consumed annually in 23 major cities. Parsley is also a popular herb in South-East Asia. In the Philippines, for example, it is the most popular culinary herb for the fresh herb market: monthly sales in Metro Manila are about 1.2 t.

World production of the essential oils distilled from parsley is estimated to amount to 8.3 t of parsley seed oil, valued at US$ 1.16 million, and 4.0 t of parsley herb oil, valued at US$ 560 000.

Properties Dried parsley contains per 100 g: water 9.0 g, protein 22.4 g, fat 4.4 g, carbohydrates 41.4, fibre 10.3 g, ash 12.5 g (Ca 1.5 g, Fe 98 mg, Mg 249 mg, P 351 mg, K 3.8 g, Na 452 mg, Zn 4 mg), ascorbic acid 122 mg, thiamine 0.172 mg, riboflavin 1.23 mg, niacin 7.93 mg, vitamin B_6 1.00 mg, vitamin A 23 340 IU. The energy value is about 1155 kJ/100 g. Fresh parsley loses 80–90% of its weight on drying.

Two types of essential oil can be steam-distilled from parsley: fruit oil (commercially called seed oil) and herb oil. Fully ripe fruits give the highest yield of oil, ranging from 1.5–7.0%. It is, however, the parsley herb oil, obtained from the flowering tops, which truly represents the odour and flavour of the fresh herb. On a commercial scale parsley herb oil is steam-distilled from the entire shoot plus immature fruits (the latter contain 0.25% oil), since very little oil is derived from the leaves and stems (about 0.06%). Parsley herb oil is a pale-yellow to greenish-yellow liquid with an odour described as unusual, warm-spicy, very leafy, yet like the fresh herb. The flavour is warm, but slightly burning and bitter. It is used exclusively in the food industry. The composition of parsley herb oil varies with its origin.

The odour of parsley fruit oil is described as warm-woody, spicy and somewhat sweet-herbaceous, but not directly reminiscent of the fresh herb. The flavour is rich and deep, aromatic and warm-spicy, but rather bitter. In perfumery it is used to impart a special note to a variety of perfumes, but its main use is in the food industry, to flavour meat sauces, seasonings, canned food and pickles. It has also been used to flavour tobacco.

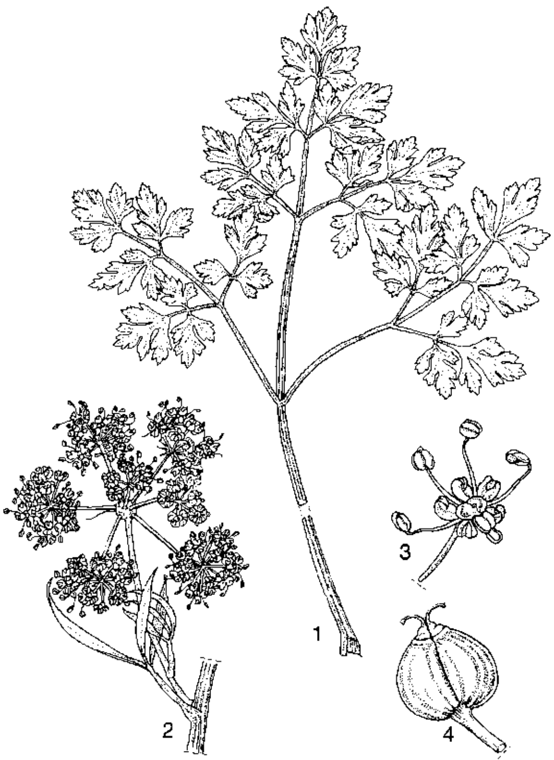
The aerial parts of parsley are reported to contain furanocoumarins (mainly bergapten) and glucosides (derivatives of glucose and apiose with apigenin and luteolin as aglucon parts).

The essential-oil constituent apiol has been used to treat kidney ailments and menstrual problems.

It is also an abortifacient, but large doses may cause paralysis and death. Apiol in minute doses helps cure epileptic fits. Some people get dermatitis from working regularly with parsley.
A monograph on the physiological properties of parsley leaf oil has been published by the Research Institute for Fragrance Materials (RIFM).
The 1000-seed weight is about 1.5 g.

Adulterations and substitutes The essential oil from the parsley herb is sometimes adulterated with that from the fruit. Adulteration can be detected by changes in the optical rotation from dextro for herb oil to laevo for fruit oil.

Description Erect, copiously branched, biennial to perennial herb, 30–100 cm tall, aromatic in all parts, glabrous. Root system slender, fibrous, taproot up to 1 m long, sometimes thickened, with a radical rosette of leaves when young. Stem terete, sulcate, hollow. Leaves alternate, 1–3-pinnately compound, dark green, glossy, flat or curled, sheathing at base; petiole longest in lower leaves; pinnae long stalked, leaflets obovate-cuneate to finely linear, divided into acute segments, higher leaves gradually less divided, topmost one consisting of a few acute segments only. Inflorescence a terminal or axillary compound umbel; bracts 1–3-foliolate, rather short; peduncle up to 12 cm long; primary rays 5–20, 1–5 cm long; bracteoles 3–8-foliolate; secondary rays (pedicels) 3–15, 2–5 mm long; flowers small, yellow-green, bisexual; calyx obscure; corolla consisting of 5 petals, each one suborbicular to obovate, up to 1 mm × 0.5 mm, subemarginate with an inflexed apical lobe; stamens 5; pistil with inferior, 2-carpelled ovary, each carpel with a thickened stylopodium, a style and a small globose stigma. Fruit a schizocarp, ovoid, 2–3 mm long, at maturity splitting into 2 mericarps, each one with 5 narrow ribs.



Petroselinum crispum (Miller) Nyman ex A.W. Hill – 1, leaf; 2, umbel; 3, flower; 4, fruit.

Growth and development Parsley is a biennial or short-lived perennial herb which is commercially mostly grown as an annual. During the first year, only a rosette of leaves is formed; after induction by low temperatures (below 10°C) an inflorescence is formed. Early planting in temperate areas may lead to flowering in the first year. Daylength seems to have no influence on flowering. Germination and early growth are slow.

Other botanical information Parsley was named *Apium petroselinum* by Linnaeus in 1753, *Petroselinum vulgare* by J. Hill in 1756 and *Apium crispum* by Miller in 1768. In *Petroselinum* the epithet *petroselinum* cannot be used. According to the botanical code, *vulgare* is not eligible because Hill did not accept the binary system of nomenclature in the publication where he published his name. The next epithet is '*crispum*' of Miller. In 1925 A.W. Hill published the correct name using the combination *P. crispum* as indicated by Nyman (1879), who, however, did not publish this name correctly.
P. crispum is an old, worldwide cultivated crop showing great variation. The variability in habit, size, leaf form and root thickness is also expressed in the numerous botanical names, classifications and subclassifications. Within *P. crispum* 3 main types can be recognized, best classified as cultivar groups:
- cv. group Curly-leaved Parsley (also referred to as var. *crispum*). Curly-leaved parsley has compact branches with curled leaf blades and is used to flavour food products, but especially as a garnish, and in the preparation of Arab salad dishes. Cultivars commonly grown are 'Afro', 'Perfection', 'Banquet', 'Forest Green', 'Decorator', 'Moss Curled', 'Deep Green', 'Improved Market Gardener' and 'Dark Moss Colored'.
- cv. group Flat-leaved Parsley (including var. *la-*

tifolium Airy-Shaw, var. *filicinum* Bailey with fern-like leaves, and var. *neapolitanum* Danert or Italian parsley). Flat-leaved parsley has more open branches with flat leaf-blades. It is stronger flavoured than the curly-leaved type and is mainly used in flavouring sauces, soups and stews. Cultivars of this type are 'Plain' and 'Plain Italian Dark Green'.
- cv. group Turnip-rooted Parsley (also referred to as var. *tuberosum* (Bernh.) Mart. Crov. or Hamburg or Dutch parsley, var. *radicosum* Alefeld). Turnip-rooted parsley possesses long fern-like leaves and is more robust. It is cultivated for its thickened aromatic edible root. Its leaves may be used to flavour dishes. Some well-known cultivars are 'Early Sugar', 'Fakir' and 'Hamburg Thick Rooted'.

The fresh herb essential oil content of these cultivar groups differs: 0.07–0.15% for Curly-leaved Parsley, 0.04% for Flat-leaved Parsley, and 0.05% for Turnip-rooted Parsley.

Ecology Parsley tolerates temperatures of 3°C to over 24°C, but grows best between 7–16°C. Even in areas with a fairly cold winter, e.g. the warmer parts of Canada, it can be left in the ground until the second season if seed is required. In the tropics it is generally grown above 600 m altitude, its growth rate being reduced at lower altitudes. It is cultivated in Malaysia at 2000 m and in the Philippines at 600 m altitude. Adequate moisture supply is most important during germination and early growth; for a good crop a precipitation of at least 500 mm is needed. Parsley thrives in well-drained fertile loams high in organic matter, with pH ranging from 4.9–8.2.

Propagation and planting Parsley is propagated by seed, which can be sown directly in the field. Curly-leaved Parsley and Flat-leaved Parsley can also be sown first in a nursery and then transplanted. Seeds germinate very slowly, but the process can be enhanced by soaking the seeds in warm water overnight. Briefly freezing the seed also helps to break seed dormancy. Sowing rates range from 7–12 kg/ha when grown for the fresh market, higher seed rates of 20–25 kg/ha are used for plants grown for industrial purposes, but 40–60 kg/ha for direct sowing has also been reported. Seed may be sown in double rows, 30–60 cm apart on raised beds, and the seedlings thinned to 10–15 cm apart. Seedlings grown in the nursery can be transplanted when they have 6 leaves or are 5–8 cm tall. In intensive cultivation in Western countries sowing in peat blocks is common.

Husbandry Weeding in parsley, although difficult because of the close spacing, should be done by hoeing, cultivation or mulching. Mulching will produce a cleaner product, since it prevents soil from splashing on the foliage during the rainy season. Both pre-emergence and post-emergence herbicides have been registered for parsley production in several countries, e.g. glyphosate and chlorbromuron. Fertilizer can be broadcast before planting and N side-dressed after germination and after the first leaf harvest, to maintain a continuous production of leaves. Turnip-rooted parsley requires more fertilizer than the leaf types. In the Philippines, chicken manure and rice hulls (1:1) are incorporated into garden plots prior to transplanting. The usual production period from sowing to last harvest is 4–6 months.

Diseases and pests Parsley is rarely severely attacked by diseases and pests. The most common diseases are septoria leaf spot (*Septoria apiicola*), damping-off (*Pythium* spp.), aster yellows, bacterial soft rot, blight, stem rot (white mould), Texas root rot, heart rot and several viruses. Septoria leaf spot is disseminated by seed or rain splash and can be prevented by using clean seed and mulching. Aster yellows can be prevented by controlling leafhoppers. Heart rot can be prevented by Ca application and careful watering.

Important pests of parsley are carrot fly (*Psila rosae*), aphids transmitting carrot mottle dwarf virus, several caterpillars, plant bugs and nematodes.

Harvesting Harvesting of parsley may start 75 days after sowing or when the plants are about 20 cm tall. In temperate regions, three cuts can be made a year. Parsley is harvested manually by grasping the stalks of the outer leaves, cutting them off with a knife and tying them together to maintain bunch integrity. New leaves develop continuously from the centre of the plant for later harvests. Single-harvesting systems are gaining popularity. Plants are then harvested by slicing off the top of the taproot; this facilitates bunching. Parsley grown for industrial use is harvested mechanically; roots of turnip-rooted parsley are mostly harvested manually by digging.

Yield Yields of parsley are generally 10–20(–60) t/ha of fresh herb or 2–3(–5) t/ha of dried herb. There is little difference in yield between single and multiple harvesting systems, but the quality of the product is generally better with frequent harvests. Height of cutting and amount of N fertilizer applied for regrowth also influence the yield and quality. Turnip-rooted parsley may yield up to 28 t/ha fresh roots.

Handling after harvest For the modern fresh-herb market, parsley is washed and packed on ice in styrofoam boxes to maintain crispness and fresh appearance. For the production of parsley flakes, fresh leaves are dried rapidly under controlled conditions of temperature and humidity to retain the essential oil and the bright green leaf colour. For commercial purposes, dried parsley should be free from yellow or discoloured leaves, and have a moisture content not exceeding 4.5%. Dried parsley can be packed either in polythene-lined corrugated fibre cases or well-sealed metal containers. They should be stored under cool, dry conditions. Steam distillation of the shoot and the mature fruits yields the commercial parsley herb oil and fruit oil, respectively.

Genetic resources There is little danger of genetic erosion in parsley as it is a popular herb grown almost throughout the world. Several germplasm collections are being maintained, e.g. at the Research Centre for Agrobotany, Tápiószele, Hungary (about 170 accessions, 1990), the N.I. Vavilov Institute of Plant Industry, St. Petersburg, Russian Federation (about 100 accessions, 1990) and the North Central Regional Plant Introduction Station, Ames, United States (176 accessions, 1997).

Breeding Important characters in breeding of parsley cultivars are a dark green colour, fineness and leaf form (curliness), regrowing capacity and yield. Hybridization of parsley and celery (*Apium graveolens* L.) has given promising results.

Prospects Parsley is used extensively as a fresh herb in innumerable dishes in many countries throughout the world, including South-East Asia. Due to the absence of major problems in crop protection, it has high potential for large-scale planting also in tropical areas.

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I.B. Ipor & L.P.A. Oyen

Pimenta dioica (L.) Merrill

Contrib. Gray Herb. 165: 37 (1947).

MYRTACEAE

$2n = 22$

Synonyms *Myrtus pimenta* L. (1753), *M. dioica* L. (1759), *Pimenta officinalis* Lindley (1821).

Vernacular names Pimento, Jamaica pepper (En). Allspice (Am). Piment des anglais, toute-épice (Fr).

Origin and geographic distribution The exact origin of pimento is not known but it is indigenous to the West Indies (Jamaica, Cuba) and Central America (southern Mexico, Guatemala, Honduras). Its use as a spice in the Caribbean Islands was discovered by Spanish explorers in the 16th Century. Most pimento is now cultivated or collected from the wild in the region of its natural distribution, most abundantly in Jamaica, and in surrounding areas where it also has been introduced, e.g. Haiti, Costa Rica, Grenada, Barbados, Trinidad, Puerto Rico, Brazil. Elsewhere in the tropics, e.g. in India, Sri Lanka, Fiji, Malaysia (Pinang), Singapore and Indonesia (Java, Sumatra), cultivation of pimento has been tried but never became successful.

Uses Pimento, being the dried green-mature fruit, is mainly used as a flavouring and curing agent in processed meats and bakery products, and as a flavouring ingredient for domestic culinary purposes. It is said to combine the flavours of cinnamon, clove and nutmeg, hence the name allspice. It is an important component of pimento dram, a Jamaican drink made with ripe fruits and rum, and of liqueurs like Benedictine and Chartreuse. Whole fruits are used in meat broth, gravies and pickling liquids. In desserts, fruit cakes, pies, relishes, sausages and preserves, ground fruits are preferred. Essential oil and oleoresin obtained from pimento fruits are used in meat products, to flavour other fruits and as a scenting agent in the manufacture of soap and men's perfumes. The maximum permitted level of pimento berry oil in food products is about 0.025%. Essential oil from the leaves is used as a flavouring agent in meat products and confectionery. In the United States the regulatory status 'generally recognized as safe' has been accorded to pimento (GRAS 2017), pimento berry oil (GRAS 2018), pimento oleoresin (GRAS 2019) and pimento leaf oil (GRAS 2901).

The powdered fruit is used in traditional medicine to treat flatulence, dyspepsia, diarrhoea and as a remedy for corns, neuralgia and rheumatism. A fruit decoction is reported to cure colds, menorrhagia and stomach-ache. Pimento possesses antioxidant, bactericidal, fungicidal, carminative, stimulant and purgative properties. Young woody shoots of pimento are popularly made into walking sticks and umbrella handles.

Production and international trade Jamaica is the largest producer and exporter of pimento, accounting for 70% of the world exports; this Jamaican pimento is considered the best quality. The remaining 30% of lesser quality is shared by Honduras, Guatemala, Mexico, Brazil, the Leeward Islands and Belize. The annual world trade of pimento averages 3000–4000 t valued at US$ 5–7 million. The major importing countries are the United States, Germany, United Kingdom, Sweden, Finland and Canada. The end-uses of the total pimento production can roughly be divided as follows: domestic use 5–10%, food industry 65–70%, pimento berry oil 20–25%, and oleoresin 1–2%. The average annual pimento leaf oil production is 30–60 t and is mainly exported to the United States and the United Kingdom.

Properties Per 100 g ground pimento contains approximately: water 8.5 g, protein 6.1 g, fat 8.7 g, carbohydrates 50.5 g, fibre 21.6 g, ash 4.6 g (Ca 661 mg, Fe 7 mg, Mg 135 mg, P 113 mg, K 1.0 g, Na 77 mg, Zn 1 mg), ascorbic acid 39.2 mg, thiamine 0.10 mg, riboflavin 0.06 mg, niacin 2.9 mg, vitamin A 540 IU, phytosterols 61 mg. The energy value is about 1100 kJ/100 g.

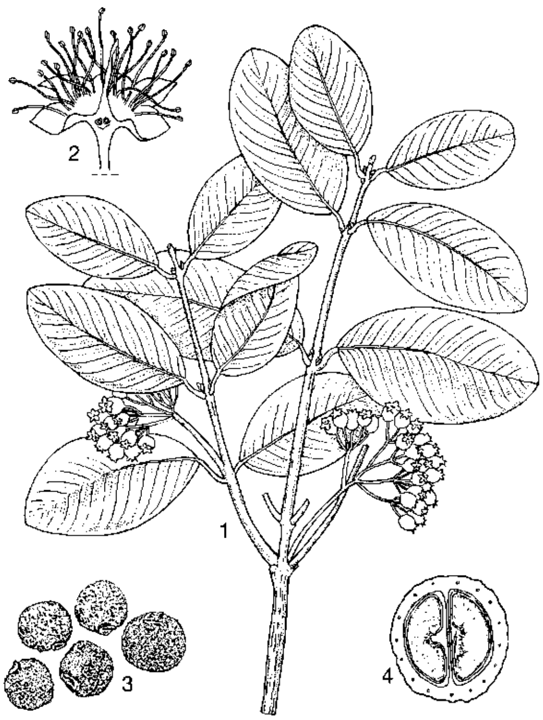
The characteristic scent of pimento is attributed to the presence of a yellow to brownish essential oil (3.3–4.5%, known as pimento berry oil) found mainly in the pericarp. The oil is warm-spicy with a peculiar fresh and sweet top note. Some 50 constituents of the oil have been identified, the major ones being: eugenol 50–80%, methyl eugenol 3–28%, myrcene 1–9%, β-caryophyllene 4–6%, 1,8-cineole 1–3% and humulene 1–2%. Essential oil from Jamaica pimento is considered to be of the highest quality, having the highest eugenol content.

Dried pimento leaves yield 0.7–2.9%, and fresh leaves 0.3–1.3% of a brownish-yellow essential oil (pimento leaf oil). Its major component is also eugenol, but the concentration is somewhat higher (65–96%) than in the berry oil, and its taste is quite different. Pimento oleoresin is a brownish to dark green oily liquid, obtained by solvent extraction of the crushed spice. Its quality and strength are more consistent than the essential oil and its application presents a smaller risk of bacterial contamination. Eugenol is toxic in large amounts and can cause contact dermatitis, whereas the spice itself is also a skin irritant.

Monographs on the physiological properties of pimento berry oil and pimento leaf oil have been published by the Research Institute for Fragrance Materials (RIFM).

Adulteration and substitutes Ground pimento is sometimes adulterated with clove stems and starchy products. A mixture of pimento leaf oil and clove stem and leaf oils can serve as a relatively inexpensive substitute for the berry oil. Pimento berry oil is sometimes adulterated with eugenol from cheaper sources.

Description Small dioecious evergreen tree, 7–10(–15) m tall, profusely branched, young shoots four-angled; bark smooth and shiny, pale silvery brown, shedding in long strips; wood hard, close-grained, heavy, strong, durable, pink. Leaves borne in clusters at the end of branches, opposite, simple, thinly coriaceous, punctate with pellucid glands, aromatic when crushed; petiole 1–1.5 cm long; blade elliptical to elliptical-oblong, 6–15 cm × 3–6 cm, base tapering, margin entire, apex rounded, above dark green, beneath pale green, venation pinnate. Inflorescence axillary, compound, paniculate, repeatedly branched, 5–15 cm long, composed of many-flowered cymes. Flowers structurally bisexual but functionally male or female, 8–10 mm in diameter, white, aromatic; pedicel about 1 cm long, pale green, pubescent; calyx tubular, tube shortly prolonged above the ovary, lobes 4, rounded, 1.5–2 mm long, creamy-white, wide-spreading at anthesis, persistent in fruit; petals 4, reflexed, rounded, 3–4 mm long, white, falling early; stamens free, numerous, 80–100 in functionally male trees, 40–50 in functionally fe-



Pimenta dioica (L.) Merrill – 1, fruiting branch; 2, section through flower; 3, dried unripe fruits; 4, section through fruit.

male ones, about 5 mm long, filaments white, slender, anthers cream-coloured, basifixed, bilocular, dehiscing by longitudinal slits; ovary inferior, 2-celled, usually with one ovule in each cell, style about 5 mm long, white, pubescent, stigma yellow. Fruit a subglobose berry, 4–6 mm in diameter, green when unripe, turning glossy purple to black on ripening, with sweet pulpy flesh; dried unripe fruits are dark brown, rough. Seeds usually 2, with spirally coiled embryo.

Growth and development The leaves of pimento are shed at intervals of 2–2.5 years. Pimento grown from seed flowers at the age of 7–8 years, trees from grafted material at 3 years. In Jamaica the main flowering period is from March–June. The functionally male trees shed copious pollen which is mainly transported by bees and wind. Pollen of functionally female trees is usually sterile, so some male trees are always necessary in a plantation. Full bearing for seedling trees may be attained in 15–25 years, depending on the care given to the plantation. Fruiting may continue for 100 years or more. Seeds are dispersed by birds.

Other botanical information Because pimento is functionally dioecious, there are male and female trees. Fruiting trees are functionally female; non-fruiting or barren trees are functionally male. Both tree types are so similar in appearance that they cannot be identified before flowering. In Jamaica and other production areas several cultivars have been developed but collection of the spice from wild stands is still very important.

Pimento is entirely different from 'pimiento', a form of red *Capsicum* pepper, although it is usually classified with this group in the import statistics of most countries. The fruits of pimento were initially mistaken by the early Spanish explorers for the fruits of pepper (*Piper nigrum* L.) because of their similarity in shape and flavour. They named the fruits 'pimienta' (pepper) which was later corrupted and anglicized into 'pimento'.

Ecology The natural habitat of pimento in Jamaica is limestone forest. Optimum average annual rainfall is 1500–1600 mm, but a range of 1000–2500 mm annual rainfall is acceptable, with only a few months with less than 100 mm rain. Mean annual temperatures range from 18–24°C, with a minimum of 15°C and a maximum of 32°C. Pimento grows best on well-drained loamy limestone soils with pH of 6.3–8.0, from sea-level up to 1000 m altitude, but it does best below 300 m.

Propagation and planting Pimento is propagated either by seed or vegetatively by bud or approach grafting. Although more cumbersome, approach grafting has been reported to give 95% success as compared with only 30% for budding. Seed should be selected from fresh ripe fruits collected from healthy, regularly bearing trees and sown immediately in seedbeds or boxes to obtain a high germination rate. Seed cannot be stored since it quickly loses viability. Seedbeds should be well-watered before sowing and mulched with dried leaves or straw, paper or damp sacks to promote germination. All coverings must be removed at the initiation of germination, which may begin 9–10 days after sowing and continues irregularly over an extended period. At the 2-leaf stage, seedlings are potted into reasonably large containers, maintained in humid, shady conditions and are ready for field transplanting when 9–10 months old, being about 25–40 cm tall. Planting holes are dug 60 cm wide and deep and filled with a mixture of topsoil, farmyard manure and compost. Three seedlings are planted in each hole in a triangle 30–45 cm apart. Once flowering begins, the best female tree is retained and the other two removed. To ensure adequate pollination, one male tree should be retained for every 10 female trees. For grafted plants, only one plant is planted per hole, provided its sex is known. Final spacing between trees should be about 6 m × 6 m. A much closer spacing together with regular trimming to promote small bushy growth is used if leaf oil rather than berries is desired. Intercropping with banana and other crops is sometimes practised during the first 5 years.

Husbandry Pimento benefits from regular weeding and mulching, and young trees should be protected from grazing stock. Complete NPK fertilizer, e.g. 15-15-15, 12-10-18 or 10-10-20 may be applied annually at the rate of 0.9 kg/tree in 2 applications, increasing up to 2.5 kg for trees older than 10 years. Trees cultivated for leaf production benefit from regular nitrogen applications.

Diseases and pests The most serious disease of pimento is leaf rust caused by *Puccinia psidii*. Favoured by wet weather and low temperatures, it causes severe defoliation of young leaves and may eventually lead to the death of the plant. It may be controlled by spraying with commercial fungicides. Another important disease is dieback, fireblight or canker caused by *Ceratocystis fimbriata*. The symptoms include formation of bark canker, dark streaking of the wood and drying out of the leaves. Judicious pruning and cutting of infected branches are some ways to control the spread of the disease.
Pimento is not seriously attacked by insect pests but among those reported to cause some damage are scale insects, whitefly, red-banded thrips, bagworm caterpillars, fiddler beetles, several borers, black ants and termites.

Harvesting Fully mature but still green fruits of pimento are harvested 3–4 months after flowering. In Jamaica, harvesting normally occurs from July to September. In Central America and Mexico harvesting is from June to August and mostly from wild sources. In Jamaica, harvesting is done on contract by families. Small fruiting branches are broken off from the trees and fruits are picked individually. If not done carefully, this often severely damages the trees, which take 3–4 years to recover; it also facilitates disease attacks. Leaves from the broken branches are collected separately and used for distillation of oil.

Yield Mean annual yields of 1–2.5 kg green pimento per tree have been reported for young trees, but average yields up to 25 kg are possible. Average yields are low because pimento usually has a good crop only once in 3 years. About 52–62 kg of pimento spice can be obtained from 100 kg of fresh green fruits. Mean annual yield for trees of all ages is 1.1 kg dried pimento per tree. Annual leaf yield averages 10–30 t/ha.

Handling after harvest Before drying, fresh green fruits of pimento may undergo 'fermentation' or 'sweating' for up to 5 days as done in Jamaica or are simply blanched for 10 minutes in boiling water as practised in Central America and Mexico. These techniques are believed to speed up drying and give a brighter colour to the dried fruits. The fruits are subsequently dried either in the sun or with artificial dryers. They should be regularly turned to obtain uniform colour and to reduce the moisture content to 12%. Sun-drying may take 5–10 days, depending on weather conditions. Well-dried fruits should be brownish-black and rattle when a handful is shaken.
If essential oil is desired, the fruits are crushed and distilled immediately using direct steam for about 10 hours. The crushed spice also yields an oleoresin when a variety of organic solvents is used. The essential oil from the leaves is obtained by steam distillation.

Genetic resources and breeding The Ministry of Agriculture in Jamaica maintains germplasm collections and has breeding programmes for pimento. Vegetative propagation can be used to develop high-yielding cultivars, but breeding work is still in its initial stage. Other breeding objectives are high essential-oil content, modified tree shape with low branching, and disease resistance.

Prospects World demand for pimento is relatively static and future plans for expansion of production should be considered with caution. Research and development efforts should focus on novel uses of pimento, coupled with new marketing strategies to promote the spice.

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D. Sulistiarini

Pimpinella anisum L.

Sp. pl.: 264 (1753).
UMBELLIFERAE
$2n = 18, 20$

Synonyms *Apium anisum* (L.) Crantz (1767), *Anisum vulgare* Gaertner (1788), *A. officinarum* Moench (1794).

Vernacular names Anise, aniseed, sweet cumin (En). Anis vert, boucage, pimpinelle (Fr). Indonesia: jinten manis. Malaysia: jintan manis. Philippines: anis.

Origin and geographic distribution Anise probably originated in the eastern Mediterranean region. It is known to have been used by the ancient Egyptians about 1500 BC; the Greeks and Romans also used it. Later on it was brought to India via Persia. Anise fruits, which are known in the spice trade as 'seeds', found their way to China (Canton) in 1200 AD through a shipment from Java; the fruits had not been produced in Java but had come from much farther west. Anise is cultivated nowadays in a wide range of countries, especially in southern Europe (in particular Spain and Italy), the former Soviet Union, Bulgaria, Romania, Turkey, Iran, northern Africa, India, China, Japan, Chili, Argentina and Mexico, and is often naturalized. Anise fruits are used in South-East Asia, but the crop does not grow satisfactorily in tropical lowlands. Only very occasionally is anise grown in South-East Asia.

Uses Anise fruits, either whole or ground, are used as a spice. They flavour curries, sweets, confectionery and baked goods, and are an ingredient of various alcoholic drinks or beverages, e.g. anisette of France, 'raki' of Turkey, 'aguardiente' of Latin America and 'anisado' of the Philippines. The leaves are used for flavouring and garnishing. In the Netherlands sugar-coated anise seeds are given to guests visiting a new-born baby.

The fruits yield an essential oil, which is increasingly replacing the fruits. The odour is not only attractive to humans, as is evidenced by its use as a lure for fox hounds and as a bait for mice, rats and fish. The oil is also applied in perfumery, soaps and other toilet articles, as a sensitizer for bleaching colours in photography and as an insecticide against small insects. The residue left after essential oil distillation may serve as cattle feed. In the United States the regulatory status 'generally recognized as safe' has been accorded to anise (GRAS 2093) and anise oil (GRAS 2094).

Anise fruits are considered stomachic, carminative, diaphoretic, diuretic, antispasmodic, antiseptic, stimulative and galactagogue. In Malaysia, anise fruits are an ingredient of compound medicines against stomach-ache or colic, for instance together with leaves of *Blumea balsamifera* (L.) DC. or *Cajanus cajan* (L.) Millsp. They are also used in Malaysia in a tonic taken after childbirth, and, together with *Phyllanthus* leaves, they have been recommended against gonorrhoea. In Thailand, anise is considered antipyretic, and it is a remedy against morning sickness.

The essential oil is applied as a carminative, stimulant, mild spasmolytic, weak antibacterial and expectorant, e.g. in cough mixtures and lozenges. In Germany, a mean daily dose of 3 g seed or 0.3 g essential oil is allowed as a bronchial expectorant and a gastro-intestinal spasmolytic, and preparations with 5–10% essential oil are prescribed as a respiratory inhalant. The oil is also used in veterinary medicine against lice and mites.

Production and international trade On the international market, anise is classified as one of the 'spice seeds'. Since it is lumped together with the other spices in this category, specific production and trade statistics are not available. In 1976–1980, estimated world trade of all spice seeds ranged from 44 000–53 000 t annually, valued at US$ 35–65 million.

In the 1980s, the annual production of anise oil was estimated at 40–50 t. The main exporting countries were the former Soviet Union, Spain and Poland, whereas France was the main importer.

Properties Anise fruits contain per 100 g edible portion: water 9 g, protein 18 g, fat 16 g, carbohydrates 35 g, fibre 15 g, ash 7 g (Ca 646 mg, Fe 37 mg, Mg 170 mg, P 440 mg, K 1441 mg, Na 16 mg, Zn 5 mg). The energy value is about 1400 kJ/100 g. The lipid fraction comprises about 10 g mono-unsaturated and 3 g poly-unsaturated fatty acids.

The essential oil of anise, derived from the fruits, is a colourless or pale yellow, strongly refractive substance, liquid at temperatures above 20°C, with the characteristic odour and sweet taste of the fruit. Anise oil is traditionally used with liquorice (*Glycyrrhiza glabra* L.) in liquorice candy. As a result, the flavour of anise is often confused with that of liquorice and erroneously described as liquorice-like.

The oil yield varies with the method of extraction:

1.9–3.1% for hydrodistillation, 2.3% for hydrodiffusion and 4.3–5.1% for CO_2 extraction. The essential oil consists primarily of phenols and derivatives 90–95%, hydrocarbons 2–5%, and less than 1% each of alcohols, carbonyls, acids and esters. The oil contains 80–95% (E)-anethole which is the character-impact compound, and up to 5% methyl chavicol (estragole). (Z)-anethole, which has toxic properties, is also found, but usually at concentrations below 0.2%. Also present are oxidation products of the anetholes, including anisic alcohol, anisaldehyde, anisic acid, anethole epoxide, p-methoxyphenylacetone and p-methoxypropiophenone. The presence of the oxidation products may be an indication of oil deterioration. Anise is reported to contain coumarins, flavonoid glycosides, β-amyrin, sitosterol and myristicin.

Anise oil can cause skin irritation and induce nausea, seizures and pulmonary oedema. Anethole has been reported as a cause of dermatitis. Long-term studies have shown that anethole is not carcinogenic. Methyl chavicol (estragole) is a hepatic carcinogen in mice. The reputed oestrogenic activity of anise, e.g. increasing milk secretion and promoting menstruation, is probably due to polymers of anethole, such as dianethole and photanetholes. Anise essential oil and anethole show antifungal activity. The essential oil also possesses antiviral activity against potato virus X (PVX), tobacco mosaic virus (TMV) and tobacco ringspot virus (TRSV). The spice and the essential oil have both antibacterial and antioxidant activity. Anethole, anisaldehyde and myristicin exhibit mild insecticidal properties.

A monograph on the physiological properties of anise oil has been published by the Research Institute for Fragrance Materials (RIFM).

The weight of 1000 seeds is 1–4 g.

Adulterations and substitutes Anise fruits are adulterated with exhausted fruits (after distillation), dust and other similar-looking fruits and seeds. Ground anise is adulterated with ground fennel (*Foeniculum vulgare* Miller).

The oil from *P. anisum* is used interchangeably in the United States with that of star anise (*Illicium verum* Hook.f.), both under the name 'anise oil'. Although this has become accepted practice, it has also been stated that the former is superior to the latter, which has a harsher odour. Synthetic anethole isolated from sulphate terpentine, and oil of fennel are occasionally added as adulterants.

Description Aromatic, erect, annual herb, (10–)15–50(–90) cm tall, with stem grooved and finely patently pubescent. Leaves alternate, entire to pinnately compound; petiole 4–10 cm long in lower leaves, gradually shorter to absent in uppermost leaves, always sheathing at base; blade of lower leaves orbicular-reniform, dentately lobed; blade of middle leaves pinnate or 3-foliolate with incised leaflets; blade of uppermost leaves 3-partite, subsessile. Inflorescence a terminal and leaf opposed, compound umbel; peduncle 2.5–7 cm long; involucre of bracts absent or short, 1–2-foliolate; primary rays 4–15, 0.5–2.5 cm long, hairy; secondary rays (pedicels) 7–13, 1–5 mm long, flowers bisexual; calyx indistinct; corolla with 5 obovate-cordate petals, 1–1.5 mm long, margin ciliate, apex inflexed; stamens 5, filaments longer than petals, inflexed at apex; pistil with inferior, bilocular, 2-carpelled ovary, styles 2, each with swollen stylopodium at base and globular stigma at top. Fruit a schizocarp, ovoid, 3–5 mm long, short hairy, at maturity splitting into 2 mericarps; mericarp 5-ribbed, with numerous oil ducts, containing a single seed; fruit wall connate with seed testa.

Pimpinella anisum L. – 1, habit flowering plant; 2, flower; 3, fruit; 4, mericarp; 5, cross-section through fruit.

Growth and development In anise the time from sowing to seed ripening is 4–5 months. Germination normally takes 17–25 days. Initial growth is slow: 35–40 days from germination to stem emergence. Flowering normally starts 65–75 days after germination, whereas the duration of flowering and seed development is 20–25 days. Experiments done in Turkey with several provenances, however, showed that the time from sowing to flowering varies, depending on sowing date. The range was from 88–102 days (plants sown in March) to 175–200 days (plants sown in November), indicating that anise requires a long photoperiod for flowering. The ripening of seeds is uneven. Anise is cross-pollinated by insects.

Other botanical information The herb *P. anisum*, anise (family: *Umbelliferae*), should not be confused with the Chinese star anise tree, *Illicium verum* Hook.f. or the Japanese star anise, *I. anisatum* L. (family of both: *Illiciaceae*).

Certain cultivars of fennel (*Foeniculum vulgare* Miller) are confusingly called 'anise' or 'sweet anise' because of their anise taste.

The genus *Pimpinella* L. comprises about 150 herbaceous species, most of them native in Eurasia and northern Africa. In Malesia 4 species are known, of which *P. pruatjan* Molkenb. has aromatic roots.

Ecology Anise can be grown in temperate and subtropical climates, but does not grow well under tropical lowland conditions. It requires a frost-free growing season of about 120 days. It grows under conditions ranging from 1000–2000 mm average annual rainfall and mean annual temperatures of (6–)12–18(–24)°C. Moisture requirements are highest in the period from stem emergence to flowering. Temperature and rainfall should be rather uniform, because anise is unfavourably affected by sudden changes in both. Anise can be grown in a wide range of soils, from sandy to clayey loams with a pH of 5–8, but it thrives on well-drained, moderate to heavy loams with adequate water-holding capacity. Sandy soils and heavy clay soils are unsuitable.

Propagation and planting Anise is propagated by seed, which is drilled in rows or broadcast. Direct sowing is recommended, because seedlings are harmed by transplanting. Germination is facilitated by soaking the seed overnight in water before sowing. Seeds remain viable for 1–3 years. Prior to sowing, the soil is often ploughed and harrowed to obtain a fine seedbed. When anise is grown in rows, seeds are sown 1–3 cm deep, 15–90 cm between rows and 2.5–15 cm apart in the row. In experiments in Pakistan, rows 40 cm apart gave higher seed yields per ha than rows 20 or 30 cm apart or than broadcasting. The higher yield was attributed to more vigorous vegetative growth and more umbels. At 30 days from sowing or when seedlings are 5–8 cm tall, they are thinned to 10–30 cm between plants. Seed rates range from 6–15 kg/ha. The crop is sown in October–November in northern India, and in March–April in Europe.

With respect to in vitro propagation, multiple shoot formation has been achieved from callus cultures derived from shoot apices, root and stem explants, and seeds. Somatic embryogenesis has been observed in callus cultures derived from shoot apices, root explants and seeds. Plantlets have also been directly regenerated from shoot apices.

In vitro production of active compounds At present, the use of cell cultures is only of importance for the elucidation of biochemical pathways and not for the economic production of essential oil or anethole. The amount of essential oil in both callus culture (3–4 mg/100 g fresh weight) and suspension culture (1–2 mg/100 g fresh weight) is 1000 times less than that of anise fruits. Anethole and myristicin have been detected in undifferentiated cultures, but the amounts are variable, and sometimes neither are found; however, epoxy-pseudoisoeugenol-2-methylbutyrate (EPB) and β-bisabolene are always found. Leaf-differentiating callus cultures have been found to accumulate high amounts of EPB, some anethole and pseudoisoeugenol-2-methylbutyrate, whereas root organ cultures accumulate EPB, but no anethole and only traces of pseudoisoeugenol-2-methylbutyrate.

Husbandry Because of the slow germination and initial development, weed control is of major importance in anise growing, especially when the crop is broadcast. The presence of weeds at harvest time is likely to reduce product quality.

Adequate nutrient supply is also essential. The crop uptake needed to produce 100 kg of fruits is 3.5 kg N, 1.5 kg P_2O_5 and 4 kg K_2O; most of this is taken up in the period from stem emergence to flowering. Anise can be staked as plants mature, to support the tops heavy with fruits.

Diseases and pests Anise is sensitive to bacterial attack. In India, fruit-bearing anise may be severely infected with *Trichothecium roseum*, a fungus producing toxins which, if ingested over a prolonged period, may cause neurological disorders in humans.

Harvesting Anise fruits are ready for harvest when they turn greyish-green. The uneven ripening of the fruits, which starts on the main stem and continues later on the side branches, leads to a dilemma: early harvesting will yield immature fruits of low quality, but late harvesting results in shattering of the fruits. Thus, two harvests may be desirable, though this is more expensive in terms of labour costs. In practice, anise is harvested when 80–90% of the fruits turn greyish-green or when the fruits in the main umbel are completely ripe.

Harvesting is done by pulling the plants or cutting off the tops. Large areas are combine harvested, but garden plots are harvested by hand.

Yield Average yields of anise fruits range from 0.7–1.5 t/ha. Yield of anise oil is about 15 kg/ha.

Handling after harvest Harvested and bundled tops of anise are stacked up to 2 m high in the field with the fruiting heads toward the centre and left there for 4–5 days for further drying and fruit ripening. The moisture content of the fruits should have fallen to 10–12% before they are threshed, cleaned and stored in jute bags lined with polythene in a cool, dry place. Storage is difficult, because the essential-oil content decreases rapidly. It is therefore recommended to store fruits in airtight containers in a cool and dark place.

For the extraction of anise oil, fruits should be crushed first and distilled immediately to reduce oil loss due to evaporation.

Genetic resources and breeding Small germplasm collections are available in most countries where anise is grown. Some larger collections are at the Plant Genetic Resources Department of the Aegean Agricultural Research Institute in Menemen, Izmir, Turkey (85 accessions), at the Gene Bank of the Institute for Plant Genetics and Crop Plant Research in Gatersleben, Germany (20 accessions) and at the Institute of Plant Introduction and Genetic Resources 'K. Malkov', Sadovo, Bulgaria (10 accessions). There are no known breeding programmes. However, several cultivars are available.

Prospects It might be feasible to crop adapted anise cultivars in highland areas of South-East Asia for import substitution and perhaps export. If anise truly requires long photoperiods for flowering, the prospects for growing anise in South-East Asia are limited, however.

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L.B. Cardenas & C.C. de Guzman

Piper L.

Sp. pl.: 28 (1753); Gen. pl., ed. 5: 18 (1754).

PIPERACEAE

x = 12, 13, 14, 16; $2n$ = 24 (*P. cubeba*); $2n$ = 24, 44, 48, 52, 96 (*P. longum*); most New World species are diploids; Old World species polyploids

Major species and synonyms

- *Piper cubeba* L.f., Suppl. pl.: 90 (1782), synonym: *Cubeba officinalis* Raf. (1838).
- *Piper longum* L., Sp. pl.: 29 (1753), synonyms: *P. latifolium* Hunter (1809), *Chavica roxburghii* Miq. (1844).
- *Piper nigrum* L. – see separate article.
- *Piper retrofractum* Vahl, Enum. 1: 314 (1804), synonyms: *P. chaba* Hunter (1809), *Chavica retrofracta* (Vahl) Miq. (1844), *Piper officinarum* (Miq.) C. DC. (1869).

Vernacular names General: Pepper (En). Poivre (Fr). Indonesia: lada, uceng-ucengan.

- *P. cubeba*: cubeb, tailed pepper (En). Poivre cubèbe, poivre à queue (Fr). Indonesia: kemukus (Javanese), rinu (Sundanese), pamukusu (Sulawesi). Malaysia: kemukus, lada berekur, chabai ekur. Vietnam: ti[ee]u th[aas]t.
- *P. longum*: Indian long pepper (En). Poivre long (Fr). Malaysia: chabai. Cambodia: môrech ansai.

Laos: 'i:x lô:z. Thailand: phrik-hang (central). Vietnam: ti[ee]u l[oo]t, tat ph[aws]t, t[aws]t b[aj]t.

- *P. retrofractum*: Javanese long pepper (En). Poivre long de Java (Fr). Indonesia: cabe jawa (general), lada panjang (Sumatra), cabia (Sulawesi). Malaysia: chabai jawa, bakek, kedawak. Philippines: litlit (Tagalog), amaras (Iloko), boyo-boyo (Tagbanua). Laos: sali: pi:. Thailand: dipli (general), dipli-chuak (peninsular). Vietnam: ti[ee]u d[ooj]i.

Origin and geographic distribution *Piper* comprises about 1200 species, distributed pantropically but with most of them occurring in the neotropics. Over 400 species have been recorded for the Malesian region. Most pepper spices originated from South and South-East Asia. *P. cubeba* is a native of Indonesia (Java, Sumatra, Kalimantan) and is also cultivated in Java, less commonly in Singapore and Peninsular Malaysia and rarely elsewhere. *P. longum* grows wild at the foot of the Himalayas in north-eastern India. It is widely cultivated in India and Sri Lanka but only occasionally elsewhere, including South-East Asia. *P. retrofractum* occurs wild from Thailand, Indo-China, Malaysia and the Philippines to the Moluccas, and occurs semi-wild in the Ryukyu Islands. It is also cultivated in northern Peninsular Malaysia and Java.

Uses Pepper, in particular the dried fruit of *P. nigrum*, is one of the oldest spices and is certainly the most important spice in the world. It has extensive culinary uses and is medicinally renowned for its stimulating action on the digestive organs. The other peppers dealt with here are of much less importance worldwide than *P. nigrum*. Locally in South and South-East Asia, however, their role is important, sometimes more as medicinal plants than as a spice.

The dried, unripe stalked fruits of *P. cubeba* were used as a spice in Europe from the Middle Ages onwards, but later their medicinal use became dominant. Cubebs are applied as stimulants to the genito-urinary mucous membrane. They are also applied to the bronchial mucous membrane, for example to treat bronchitis and coughs. They are an ingredient in many mixtures given as tonics against indigestion, are a popular aphrodisiac in Java, and are used as a diuretic, antiseptic and as a medicine against gonorrhoea, amoebic dysentery and rheumatism. In the United States the regulatory status 'generally recognized as safe' has been accorded to cubebs (GRAS 2338) and cubeb oil (GRAS 2339). The oil is used as a flavour component in major food products, including alcoholic and non-alcoholic beverages. The maximum permitted level for cubeb oil in food products is about 0.004%. The maximum level for use as a fragrance component in soaps, detergents, creams and alcoholic perfumery is 0.8%.

P. longum is probably the first known pepper in the Mediterranean region; in Rome at the time of Pliny it was twice as expensive as black pepper and more highly esteemed. The whole spikes, which consist of minute fruits embedded in a fleshy rachis, are used as a spice. In Indo-China and many areas of India the medicinal application of fruits and sliced, dried rootstock and stem parts is more important than the use as a spice. *P. longum* is said to be effective against coughs, asthma, dyspepsia and paralyses, and it has laxative and carminative properties. It is believed that the older the product the better it works. In China the powdered root is given to pregnant women to speed up delivery.

P. retrofractum resembles *P. longum* and is used similarly. The spice is the dried, unripe infructescence, which is an ingredient of pickles, preserves and curries. It is applied medicinally as a tonic and against a variety of digestive and intestinal disorders. A tincture is used in childbirth to bring about the expulsion of the placenta. It is applied against haemorrhoids, irritation of the skin and many other complaints. In Indonesia a leaf extract is used as a mouthwash and to alleviate toothache. In the Philippines the root is chewed or a decoction is used as a cure for colic. In Malesia the roots of wild peppers are used to prepare poisons.

Production and international trade Compared with *P. nigrum*, the production and trade of other *Piper* spp. are negligible. Local production and trade are important, but there are no recent statistics. At the end of the 19th and in the early 20th Century *P. cubeba* fruits were exported from Indonesia to Europe and the United States and sometimes fetched high prices. Exports were about 270 t in 1925 and were 135 t on average per annum until 1940. Later in the 20th Century only local trade and some trade via Singapore to India remained. *P. cubeba* is predominantly a smallholder's crop. *P. longum* is only of importance in India, with modest export to other Asian countries. *P. retrofractum* is exported from Indonesia to Peninsular Malaysia, Singapore, China and in small amounts to Europe and the United States, but outside the Far East it is practically a forgotten spice. In the 1920s annual export from Java amounted to 200–250 t.

Properties *P. cubeba* spice has an aromatic odour but the taste is somewhat bitter and acrid. Cubebs contain cubecic acid (1%), the colourless, crystalline cubebin and about 10–20% essential oil (cubeb oil). Cubeb oil can be obtained by steam distillation of the unripe, dried, crushed fruits. The oil is pale greenish-yellow to bluish-yellow or sometimes colourless, somewhat viscous with a very dry-woody but warm-camphoraceous, spicy-peppery odour. The oil consists mainly of sesquiterpenes (cadinene, dipentene), sesquiterpene alcohols and minor amounts of monoterpenes and is useful in soap perfumes and in woody-peppery perfume bases. Cubeb oleoresin is used for flavouring. It can be obtained by extracting crushed fruits with a hydrocarbon solvent or with ethyl alcohol. The oleoresin has a warm-spicy, peppery odour and taste, but is not very pungent. It is used in spice blends, e.g. for pickles and meat sauces, and to flavour tobacco. Its main constituent is cubeb oil. A monograph on the physiological properties of cubeb oil has been published by the Research Institute for Fragrance Materials (RIFM).

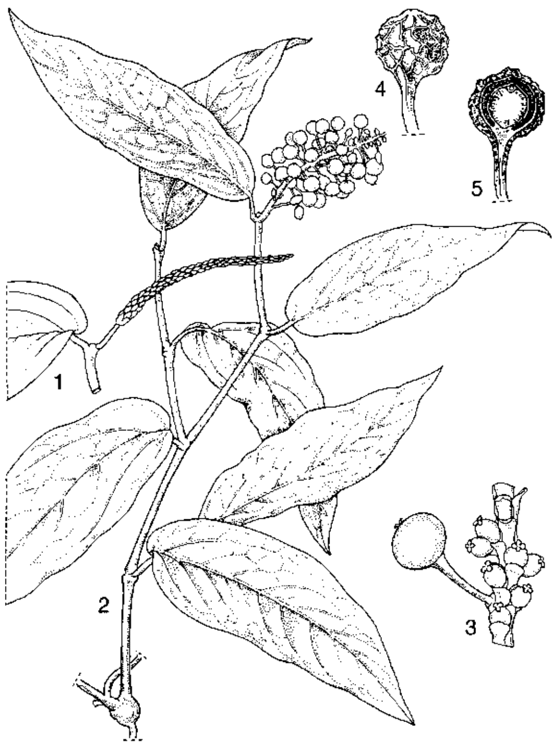
P. longum infructescences contain 4–6% piperine and 0.9–1.5% cadinene. The essential oil distilled from the spikes has an odour reminiscent of ginger, is used as a food flavouring with a milder taste than pepper oil but is hardly traded outside India.

P. retrofractum spice has an agreeable aromatic taste but is more pungent than black pepper and Indian long pepper. It contains piperine, resin, fibrous material 10–15%, starch 44–49%, ash 8%, fixed oil and essential oil. The yield of essential oil after distillation is about 1%; it has an odour of ginger, is viscid and light green but is not traded.

Adulterations and substitutes Genuine cubebs can be distinguished from other pepper fruits by their stalked fruits which are very distinctive and by the seed inside the fruit which is only basally attached to the fruit wall. Cubeb can be distinguished from other products by sprinkling cubeb powder onto 80% sulphuric acid: a characteristic crimson colour appears, owing to the presence of about 1% cubecic acid. In the past, when cubebs fetched high prices, they were adulterated with fruits of other pepper species: *P. baccatum* Blume, *P. caninum* Blume, *P. crassipes* Korth., *P. guineense* Schum. & Thonn., *P. mollissimum* Blume, *P. nigrum*, and even with fruits of the non-pepper species: *Bridelia tomentosa* Blume (*Euphorbiaceae*), *Lindera* spp. (*Lauraceae*), *Litsea cubeba* (Lour.) Pers. (*Lauraceae*), *Pericampylus glaucus* (Lamk) Merrill (*Menispermaceae*), *Rhamnus* spp. (*Rhamnaceae*), *Xylopia frutescens* Gaertner (*Annonaceae*) and *Zanthoxylum rhetsa* (Roxb.) DC. (*Rutaceae*).

Description Herbs, shrubs or slender trees, occasionally scandent, usually terrestrial. Stems thickened at the nodes, often hollow. A single prophyll is usually present at the shoot apex. Leaves alternate, entire, symmetrical or asymmetrical, sometimes deeply lobed at the base, usually palmately 3- or more-veined, petiolate. Indumentum present or absent, hairs simple or multicellular, minute pellucid glands often present. Inflorescence spicate, solitary, leaf-opposed, pedunculate; flowers without sepals and petals, subtended by triangular to semilunar bracts, often crowded on a fleshy rachis; stamens 2–6, anthers 2-thecous, filaments short to exserted; ovary unilocular with single basal ovule, style present or absent. Fruit a berry or drupaceous, often fleshy, globose, ellipsoidal to obovoid.

– *P. cubeba*: Perennial, woody, dioecious climber, 5–15 m long. Twigs glabrous. Leaves firmly cori-



Piper cubeba L.f. – 1, male spike; 2, fruiting branch; 3, detail of the infructescence; 4, dried fruit; 5, cross-section dried fruit.

aceous, subglabrous, lower surface with numerous small sunken glands; petiole 0.5–2 cm long; blade ovate to oblong, 8–15 cm × 2–9 cm, base cordate to rounded, apex tapering to acuminate. Spike 3–10 cm long, female ones shortest and often curved, peduncle up to 2 cm long; male flower with oblong-obovate bract of up to 2 mm × 1 mm and 3(–5) stamens; female flower with oblong bract up to 5 mm × 8 mm, stigmas 3–5. Berry on 3–15 mm long stipe, globose, 6–8 mm in diameter, red-yellow, drying to black. Seed globose.

- *P. longum*: Perennial, dioecious herb with woody rootstock and slender prostrate or ascending shoots. Leaves thinly membranous, not glossy, gland-dotted; petiole up to 1.2 cm long, longest in lower leaves, upper leaves almost sessile and amplexicaul; blade ovate, 4–7 cm × 2–3 cm, cordate at base, acute or acuminate at apex. Fertile branches erect, 30–60 cm tall, bearing erect inflorescences; peduncle 1–2 cm long; bracts peltate, orbicular; male spike 3–6 cm × 1.5–2 mm, flowers crowded, each with 2 stamens; female spike 1.4–3 cm × 3–8 mm, flowers crowded, each with 3–4 stigmas. Berries concrescent, forming a thin, fleshy, slender, cylindrical infructescence.
- *P. retrofractum*: Perennial, soft woody, dioecious herb, creeping or climbing with adhesive roots, up to 10 m long. Leaves glabrous, firmly coriaceous, with many sunken gland dots beneath; petiole 0.5–3 cm long; blade ovate to oblong, 8–20 cm × 3–13 cm, base cordate, obtuse or cuneate, apex tapering or acuminate. Spikes erect or patent; peduncle 1–2 cm long; bracts broadly ovate, 1–2 mm long; male spike 2.5–8.5 cm long, stamens 2(–3), very short; female spike 2–3 cm long, stigmas 2–3, short, persistent. Infructescence cylindrical, about 2–4 cm × 4–8 mm on a stalk 1 cm long; berries connate and adnate to stalk of bract, broadly rounded, hard and pungent when green, becoming soft and sweet and finally bright red-brown when fully mature, often covered with a grey dust. Seed globose, 2–2.5 mm in diameter, white and mealy inside.

Growth and development Rooted cuttings of *P. cubeba* can reach a length of about 80 cm in the first year. *P. cubeba* starts flowering and fruiting the first year after planting, but full productivity is reached after about 3 years when planted below 300 m altitude and after about 4 years when planted at higher altitudes. Plants can remain productive for 50–60 years. In India *P. longum* flowers and fruits in and toward the end of the rainy season. In Indo-China infructescences mature in January. Its economic lifetime is about 3–5 years, after which the crop is rejuvenated. *P. retrofractum* is a vigorous climber, but if not pruned regularly when cultivated, it rarely flowers. When plants are kept at a height of about 5 m, flowering and fruiting are year-round.

Other botanical information The taxonomy of *Piper* is highly confusing and needs to be revised. A revision would possibly combine species with fused or partly fused ovaries and fruits into a separate genus (e.g. in *Chavica* Miq.).

Several cultivars of *P. cubeba* are distinguished in Indonesia, but their identity is obscure and their nomenclature not regulated. The cultivars with the vernacular names 'rinu katuncur' and 'rinu cengke' are considered as true cubeb cultivars; 'rinu badak', 'rinu carulang', 'rinu pedes' and 'rinu tembaga' are said to be false cubebs.

The infructescences of *P. longum* and *P. retrofractum* are markedly distinct from *P. nigrum*. In the latter the infructescence bears a number of distinct berries and the spice is the dried berry. In the former two the numerous tiny fruits fuse to form a cylindrical spike-like cone which, when dried, constitutes the long pepper spice.

In the literature *P. sarmentosum* Roxb. ex Hunter is sometimes considered as identical with *P. longum*. However, *P. sarmentosum* is a distinct species, widely distributed in South-East Asia and rarely used as a minor spice, while *P. longum* hardly occurs in Malesia.

Numerous *Piper* species are occasionally used as a spice, or more often medicinally. Those not dealt with in this volume or referred to other volumes of the Prosea handbook are mentioned below:

- *P. baccatum* Blume. A vigorous climbing pepper of Java, Borneo and the Philippines. (Indonesia: bodeh (Javanese), rinu, rinu manuk (Sundanese). Philippines: sambanganai). The vines can reach 30 m length; leaves circular-ovate, 8–18 cm × 3–12 cm; spikes drooping, unisexual, thin; fruit a stalked, globose berry. The juice of the plant is drunk as a cough remedy and the shredded leaves are used as a poultice for the neck. Fruits are very spicy and are used in tonics and have been used to adulterate cubebs.
- *P. decumanum* L. Occurring in the Philippines, Sulawesi, Moluccas and New Guinea. (Philippines: baragit (Bagobo), buyog (Manobo), malapagba (Bukidnon)). It is a glabrous, dioecious climber; leaf blade ovate, 40 cm × 18 cm, length/breadth ratio 2/1; male inflorescences as long as leaves, female ones longer, stigma 2-lipped to 3-

fid; infructescence up to 60 cm long; fruit cylindrical, 3 mm × 1.5 mm. The fruits are used medicinally.

- *P. febrifugum* C. DC. Occurring in Peninsular Malaysia ('akar sangkap'). It is a large-leaved hairy climber with long spikes. A decoction of the leaves is used against fever.
- *P. fragile* Benth. Occurring in the Philippines, Moluccas, New Guinea and Solomon Islands. (Philippines: litlit-anito (Tagalog)). It is a dioecious climber, glabrous; leaf blade ovate, 8 cm × 6 cm, length/breadth ratio 4/3; inflorescence shorter than leaves, female ones very short; male flowers 2 stamens, female flowers with 4-fid stigma; fruit globose, 3 mm in diameter. The fruits are used medicinally.
- *P. guineense* Schum. & Thonn. (synonym: *P. clusii* DC.). Guinea pepper, black West African pepper, Ashanti pepper. It grows in tropical West and Central Africa and the fruits are used as a condiment and as a substitute for cubebs (African cubeb).
- *P. longifolium* Ruiz & Pavón. A species from tropical America used medicinally.
- *P. medium* Jacq. A species from tropical America where it is used to make a drink.
- *P. pinnatum* Lour. Occurring in Indo-China. Parts of the plant are put in washing water to impart a pleasant smell to clothes.
- *P. ribesioides* Wallich. Occurring from Burma (Myanmar) to Peninsular Malaysia (lada rimba, akar kalong ular, dunlok) and Sumatra. Crushed leaves are used for poulticing in cases of swellings. The fruit is also used as an adulterant of cubebs.
- *P. saigonense* C. DC. A wild and cultivated pepper of Vietnam (Saigon pepper (En), poivre de Saigon (Fr), lolo (Vietnamese). Its fruits are used as a spice, just like black pepper. It is possibly identical to *P. nigrum*.
- *P. stylosum* Miq. Occurring in Malaysia (kadok hutan), Sumatra and Borneo. The leaves are used as a vegetable. The roots are used medicinally.
- *P. subbullatum* K. Schum. & Lauterb. (synonym: *P. torricellense* Lauterb.). Occurring in the Philippines, New Guinea, Bismarck Archipelago, Solomon Islands, Vanuatu. A dioecious shrub to soft wooded tree; leaf blade asymmetrically broad ovate, up to 28 cm × 21 cm; inflorescence up to 40 cm long, female ones shortest; male flowers 2-staminate; female flowers sessile with 3-fid stigmas; fruit obconical. The fruits are used medicinally. *P. subbullatum* is possibly the ancestor of *P. methysticum* Forster f., the well-known kava plant of the South Pacific.

The following species are not related to *Piper* but contain the term pepper in their vernacular names:

- African pepper (Guinea pepper, negro pepper): fruit of *Xylopia aethiopica* A. Rich. (*Annonaceae*);
- Capsicum peppers (cayenne pepper, chili pepper, red pepper, green pepper, sweet pepper): fruits of *Capsicum* spp. (*Solanaceae*);
- Jamaica pepper (allspice, pimento): fruits of *Pimenta dioica* (L.) Merrill (*Myrtaceae*);
- Melegueta pepper: seeds of *Aframomum melegueta* (Roscoe) K. Schum. (*Zingiberaceae*);
- Pepper tree (American pepper): fruits of *Schinus molle* L. (*Anacardiaceae*);
- Wild Chinese pepper: fruit of *Zanthoxylum armatum* DC. (syn. *Z. alatum* Roxb.) (*Rutaceae*).

Ecology *Piper* species mostly grow in moist habitats, frequently in cleared or disturbed forest areas. They are often opportunist colonizers, growing along roadsides, forest tracks or streams, wherever more light penetrates. In Java, *P. cubeba* occurs abundantly at the edges of mangrove forest and is grown from sea-level up to 700 m altitude, preferably shaded. *P. longum* prefers drier conditions and most areas in South-East Asia are not suitable for its cultivation. *P. retrofractum* preferably grows in deciduous forest on poor soils, up to 600 m altitude, but also along beaches.

Propagation and planting In Indonesia, particularly in Central Java, *P. cubeba* is propagated by cuttings, preferably taken from basal shoots. Potted cuttings are kept under shade and are planted out against a support tree as soon as they have rooted. Popular support trees are shade trees in coffee and cocoa plantations, like silk tree (*Albizia chinensis* (Osbeck) Merrill) and kapok (*Ceiba pentandra* (L.) Gaertner). Propagation by seed is also possible but usually less successful. In general the cultivation of *P. cubeba* is like *P. nigrum*, but the plants are weaker and more difficult to grow. *P. longum* is propagated by stem cuttings or shoots planted in a rich, well-drained soil. When the rainy season starts the cuttings are transplanted to the field, at 1.5 m spacing, often in mixed cropping systems. In Java, cultivated *P. retrofractum* is propagated by cuttings.

Husbandry After planting, *P. cubeba* is regularly weeded. The young basal shoots are removed and the plants are trained up support trees. Once they reach 1.5 m height (after about 1 year) they receive no further care. Ultimately 1 male plant is retained to pollinate about 9 female plants in the vicinity. In India, *P. longum* does not require much attention as soon as the crop is established. After harvest, the aboveground parts usually wither and the rootstock is protected against the sun in the dry season by mulching. In Java, *P. retrofractum* is mainly collected from the wild. When planted, it is given artificial support or is trained up support trees such as *Erythrina* spp., *Dolichandrone spathacea* (L.f.) K. Schumann, *Borassus flabellifer* L., or *Moringa oleifera* Lamk; it is pruned regularly to promote flowering and fruiting. In East Java, *P. retrofractum* is also alley-cropped. Support trees are planted along both sides of field plots, with a spacing of 8–15 m between rows and 1.5–2 m in the row. TSP fertilizer is applied one month after planting the pepper cuttings. Earthing up is done twice and weeding is done 4–5 times a year. The support trees are first pruned when *P. retrofractum* has climbed into them; they are pruned again if their foliage becomes too dense.

Diseases and pests The major diseases and pests of *P. nigrum* may also attack other *Piper* species. The major disease is foot-rot caused by the soilborne fungus *Phytophthora palmivora*. Slow wilt, called 'yellow disease', is associated with *Radopholus* nematodes.

Harvesting The fruiting spikes of *P. cubeba* are collected when the fruits have turned yellow; the fruits are then stripped from the rachis and dried in the sun to turn blackish. Earlier harvesting of green fruits results in too much shrivelling and brownish fruits. Harvesting should be done with care because bruised fruits turn into non-marketable light grey fruits after drying. In India fruiting spikes and parts of the rootstock of *P. longum* are harvested at the end of the rainy season and dried in the sun. The best time to harvest *P. retrofractum* is when the spikes are still green but turning slightly reddish at the top. Harvested spikes should be quickly dried in the sun or artificially, because they easily start rotting. Boiling Java long pepper and then spraying it with ash may shorten the drying time to 2 days, otherwise it takes 5 days or longer to dry.

Yield Annual yield of dried fruits per full-grown plant of *P. cubeba* is about 0.5 kg. *P. longum* yields from 250 kg/ha in the first year to 1250 kg/ha in the 3rd. Yields then decrease, so after 4–5 years the crop is renewed.

Handling after harvest Harvested *P. cubeba* fruits are dried in the sun until they have lost 2/3 of their weight and have become as hard as glass. Dried fruits are hygroscopic and should be stored dry and airtight. *P. longum* and *P. retrofractum* spikes are also dried after harvesting and sold as whole fruiting spikes.

Genetic resources and breeding Germplasm collections are available in Indonesia, Malaysia (Sarawak), India and Brazil. Breeding in *Piper* is primarily directed towards obtaining foot-rot resistant cultivars in *P. nigrum*, not towards improving other species.

Prospects *P. cubeba, P. longum* and *P. retrofractum* are forgotten spices outside South and South-East Asia. They deserve more research attention because their products are still of interest, and the world market for natural flavourings and medicines is growing steadily. They are suitable as a smallholder's crop, but basic agronomic information is still lacking and should be obtained first by applied research.

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Piper nigrum L.

Sp. pl.: 28 (1753).
PIPERACEAE
$2n$ = 52 (occasionally other numbers have been reported, including $2n$ = 48, 104, 128)

Synonyms *Piper aromaticum* Lamk (1791).

Vernacular names Pepper, black pepper (En). Poivre (Fr). Indonesia: lada, merica. Malaysia: lada. Papua New Guinea: daka. Philippines: paminta, paminta-liso (Cebuano), pamienta (Ilocano). Burma (Myanmar): ngayok-kaung. Cambodia: mréch. Laos: ph'ik no:yz, ph'ik th'ai. Thailand: phrik-thai (central), phrik-noi (northern). Vietnam: ti[ee]u, h[oof] ti[ee]u.

Origin and geographic distribution Pepper is native to the Western Ghats of Kerala State, India, where it still occurs wild in the mountains. Pepper reached South-East Asia as early as 100 BC, brought by Hindu colonists migrating from India to Indonesia and other countries. In about 1930, Japanese immigrants who had travelled through South-East Asia introduced the plant into Para State of northern Brazil, where it became a major crop.
In India, Indonesia and Malaysia, there is a long-established tradition of commercial cultivation by smallholders. The main areas of production in Indonesia are Lampung, Bangka and East and West Kalimantan, together accounting for 95% of the crop. Early in the 19th Century, pepper also spread to Sarawak, where nowadays 95% of the Malaysian crop is produced. In the 1990s Sri Lanka and China overtook Malaysia in pepper production, while Thailand and Vietnam also became important producers.

Uses Black and white pepper are the two main dried commodities growers prepare from the fruits of *P. nigrum*. The use of the dried product as a food flavouring was already known in classical Rome and Europe was an important importer of pepper as early as the 12th Century. About 80% of the pepper consumption is now concentrated in the industrially developed countries, where it is mainly used for domestic culinary purposes and for flavouring and preserving processed foods. There is a remarkable lack of tradition in the consumption of both types of pepper in Indonesia, Malaysia and adjacent countries of South-East Asia. In recent decades, its classic use as a spice in food flavouring and preservation has increased gradually in these countries because of expanding tourism and industrial development. However, most of the production is still exported. In India and Sri Lanka, domestic consumption for food flavouring is common tradition. Pepper oil and pepper oleoresin, extractable from peppercorns, are mainly used in the production of convenience foods. Of secondary importance is the use of preserved immature green pepper or fresh green pepper fruits. In the United States the regulatory status 'generally recognized as safe' has been accorded to black pepper (GRAS 2844), black pepper oil (GRAS 2845) and black pepper oleoresin (GRAS 2846). The same applies to white pepper (GRAS 2850), white pepper oil (GRAS 2851) and white pepper oleoresin (GRAS 2852). The maximum permitted level of the oils in food products is about 0.04%.

Production and international trade No distinction is made between black and white pepper in trade statistics. Between 1985 and 1997, annual world production of pepper fluctuated from 140 000–280 000 t. Production peaked in 1990. The area planted worldwide in 1997 was about 365 000 ha, with 200 000 ha in India, 75 000 ha in Indonesia, 26 000 ha in Sri Lanka, 12 000 ha in Brazil, 12 000 ha in China and 10 000 ha in Malaysia. World production in 1997 amounted to 215 000 t, with 62 000 t from India, 50 000 t from Indonesia, 17 000 t from Sri Lanka, 22 000 t from Brazil, 14 000 t from China and 12 000 t from Malaysia. By 1997 the acreage and production had reportedly increased to 3600 ha and 12 000(!) t in Thailand, and to 7500 ha and 11 000 t in Vietnam.
Annual world exports during 1988–1993 ranged from 172 000–242 000 t. The major exporters were India, Singapore, Indonesia, Brazil and Malaysia. Singapore serves mainly as an entrepôt. The value of world exports from 1988 to 1993 ranged from US$ 270–569 million per year. The highest revenue was in 1988, the year with the lowest export in terms of tonnage. The major importers were the United States, Germany, France, the Netherlands, Japan and the United Kingdom. Imports ranged from 174 000–216 000 t valued at US$ 273–658 million.

Properties Dried peppercorns (black pepper) contain per 100 g edible portion: water 9.5–12.0 g, protein 10.9–12.7 g, starch 25.8–44.8 g, fibre 9.7–17.2 g, and ash 3.4–6.0 g. White pepper contains per 100 g edible portion: water 9.5–13.7 g, protein 10.7–12.4 g, starch 53.9–60.4 g, fibre 3.5–4.5 g, and ash 1.0–2.8 g. With the energy value averaging 1300 kJ/100 g and a very small daily intake, the nutritional value is negligible.
Flavour and pungency differ for black and white

pepper, and tend to vary with region and cultivar. Pepper is highly popular for its piquant flavour and pungency and distinctive aroma. Piperine, $C_{17}H_{19}O_3N$, is the chief pungent principle, its content varying from 4.9–7.7% in black pepper and 5.5–5.9% in white pepper. Essential oil is also an important constituent of pepper, being responsible for the characteristic odour. In commercial cultivars its content ranges from 1.0–1.8% in black pepper to 0.5–0.9% in white pepper. About 90% of the essential oil consists of monoterpene and sesquiterpene hydrocarbons.

A monograph on the physiological properties of black pepper oil has been published by the Research Institute for Fragrance Materials (RIFM). The weight of 100 peppercorns is (3–)4.5(–8) g.

Adulterations and substitutes Common adulterants of whole or ground pepper are pepper of lower quality and various foreign matter. Synthetic compounds or isolates of volatiles from cheaper sources are used to adulterate pepper essential oil.

Description A perennial woody climber, up to 10 m long or more. In cultivation, mature plants grown on supports may also appear as bushy columns, 3–4 m tall and 1.25 m in diameter. Root system with 5–20 main roots, 4 m or more deep, and with feeder roots in the upper 60 cm of soil, which form an extensive dense mat. Orthotropic stems climbing and remaining vegetative, adhering to supports with short adventitious roots present at the nodes, internodes 5–12 cm long and 4–6 cm in diameter. Plagiotropic branches generative, without adventitious roots, internodes 4–6 cm long and 1–1.5 cm in diameter, producing higher-order branches as well as inflorescences. Leaves alternate, simple, glabrous, coriaceous, petiolate; petiole 2–5 cm long; blade ovate, 8–20 cm × 4–12 cm, entire, oblique to rounded at base, tip acuminate, shiny dark green above, pale and densely glandular-dotted beneath with 5–7 veins. Inflorescence a spike, appearing opposite the leaves on plagiotropic branches, 3–15 cm long with 50–150 flowers; flowers unisexual or bisexual (cultivars usually have up to 90% bisexual flowers), without perianth, stamens 2–4, stigma with 3–5 lobes. Fruit a globose drupe, 4–6 mm in diameter, sessile, with pulpy mesocarp, red when mature. Seed globose, 3–4 mm in diameter.

Piper nigrum L. – 1, twig with young inflorescence; 2, fruiting branch.

Growth and development Ripe shade-dried seed of pepper without mesocarp germinates in 2–3 weeks, but commercial propagation is only by cuttings. The vegetative development of planted cuttings proceeds with the formation of several orthotropic shoots from axillary buds; only during active growth may primary lateral branches develop on the nodes. A few early spikes may appear on the lateral branches. Continuous branching gives rise to the bushy habit, and when vigorous growth is stimulated, regular growth of orthotrophic stems and development of plagiotropic branches allows large numbers of spikes to be formed at the onset of the rains.

In South-East Asia, flowering starts in July in the Philippines, and September in Sarawak, followed by Bangka and Lampung; it usually extends over about three months. Spikes show protogynous development from base to tip. Geitonogamy (autogamous pollination that results from the transfer of pollen between different flowers on the same individual) is believed to be the common mode of pollination. Self-pollination by wind is rare. High relative humidity may extend stigma receptivity from 8–13 days and thus promote self-pollination. Heavy rains, storms and long sunny days may reduce fertilization, while light intermittent rain and showery conditions may increase fruit set. After fertilization, the ovary develops into a mature

fruit in 8–9 months. Fruit development is accelerated by well-distributed rainfall and the presence of balanced minerals, especially potassium and magnesium. Pepper plants can produce abundantly for up to 30 years.
If stolons or suckers are used for planting, spike formation will be retarded by 2 years, because the formation of lateral branches on the orthotropic stem is delayed.

Other botanical information In the wild, *P. nigrum* is mostly dioecious and morphologically rather variable. *P. nigrum* cultivars are usually bisexual. In its country of origin, India, there are more than 75 cultivars. Some well-known Indian pepper cultivars are: 'Balamcotta' (leaves large, light green; fruit yield regular and high); 'Kalluvalli' (leaves narrower, dark green; drought and wilt resistant; bearing regular); 'Cheria Kaniakadan' (leaves small, elliptical; wilt-resistant; regular and heavy bearer; unsuccessful in Sarawak, where it was unisexual). In Indonesia, more than 5 cultivars of pepper are commercially produced. The major cultivars in Lampung are 'Kerenci', 'Belantung' and 'Jambi'. On Bangka, the cultivars 'Lampung' (broad leaf) and 'Bangka' are popular. Differences are mainly in leaf shape and size, internode length, branching habit and flowering and fruiting ability. In Malaysia (Sarawak) the dense-branching high-yielding cultivar 'Kuching' is most popular. It has large leaves and is very susceptible to foot-rot. 'Sarikei' is a smaller-leaved cultivar. In Cambodia 'Phnom-Pon' is a large-leaved cultivar, 'Kamchay' a small-leaved one.

Ecology The most suitable climate for pepper is per-humid tropical, with a well-distributed annual rainfall of 2000–4000 mm associated with a mean air temperature of 25–30°C and a relative humidity of 65–95%. In Sarawak, annual rainfall may exceed 4000 mm in a non-seasonal climate, whereas on Bangka an average of 2500 mm is usual. In Lampung, the crop grows well in the north with over 3000 mm annual rainfall and in the south-east with sometimes less than 2000 mm. A drier period of 2–3 months, with a monthly rainfall of 60–80 mm, is not usually harmful. The crop thrives below 500 m altitude on the equator, but may grow at altitudes as high as 1500 m.
Pepper grows well on soils ranging from heavy clay to light sandy clays. Soils should be deep, well-drained but with ample water-holding capacity to avoid water stress during marked dry periods. Mineral limitations are common, except on virgin soils. In brown-red latosols, N, P and Mg are often limiting. In physically suitable red-yellow podzols, deficiencies of most major and minor elements are not exceptional, with too high acidity and excess Al at pH below 5. The most favourable soil types are deep, well-drained, brown-red latosols or andosols, but the crop can grow well on deep sandy clay red-yellow podzols if carefully managed and amply provided with mineral nutrients and organic matter.

Propagation and planting Most cultivars of pepper are propagated by cuttings. Early in the wet season, usually pre-topped 5–7 cm long pieces of terminal orthotropic shoots are taken from vigorous plants 12–30 months old. Cuttings can be rooted in a moist medium in a shaded nursery. Ample roots should have appeared after about 2 months. Sometimes cuttings are directly planted in the field. Though easier to root, stolons or runners are less suitable as planting material than terminal orthotropic shoots because they bear fruit late, about 3 years from planting. Micropropagation through shoot-tip culture has also been reported.
Before planting, the land is cleared, tilled and hoed. Hardwood supports 3.60 m high are placed at 2–4 m × 2–4 m. In poor soils, the topsoil is mounded around the base of the supports. In rich soils, planting is usually directly into loosened topsoil.
If trees are used as support, stumps are planted at the required spacing about one year before the rooted cuttings are set in the field. Cuttings are transplanted to the field during a rainy period and usually receive temporary shade. One to two months later, growth becomes vigorous.
In Sarawak, West and East Kalimantan and on Bangka, an intensive system of sole cropping on dead posts and without shade prevails. It is characteristically associated with chemically poor soils, high inputs and high productivity. In Lampung, cultivation of pepper against living *Erythrina* shade trees (up to 10 m tall) predominates and is characterized by fertile soils, low inputs and low productivity. In the Philippines, *Gliricidia* support trees are commonly used. Intercropping is rare in the system using shade, although it occurs in smallholdings in the Philippines. In several countries, pepper is planted as an intercrop in coconut and coffee plantations.

Husbandry In unshaded intensive cropping of pepper, husbandry mainly includes weeding, mounding, topping of stem shoots, pruning for regular shape, manuring and disease and pest control. In Sarawak, clean-weeding is common.

Mounds are maintained to provide ample room for dense rooting. During times of rapid growth, stems are tied to the posts weekly. Pruning aims to maximize the number of fruiting branches. Usually three stems are allowed to climb up the post. When 60–90 cm long, each is pruned back, usually to just below the lowest stem node without lateral branch, leaving 3–4 nodes, each with a fruiting branch. This process is repeated regularly, stimulating secondary and higher-order branching. After 30 months, plants are 2.5 m tall, have a bushy appearance with the maximum number of main branches and a close canopy. The plants may now be considered as full-grown and start flowering fully with the onset of the rains.

During vegetative development, vines on poor soils are supplied with complete fertilizer, usually with a content of 12% N, 5% P_2O_5, 17% K_2O, 2% MgO and a range of minor elements. In the first year each plant receives 0.5 kg in 4 equal applications, in the second year 1 kg also in 4 equal applications. During the generative phase, each vine receives annual dressings of 1.5–2 kg, again divided over 4 applications. In the Philippines, fertilizer is applied only twice a year, at the onset and towards the end of the rainy season.

Intensive cropping in Indonesia is less elaborate than in Sarawak. Clean-weeding is usually done irregularly and manuring practised less precisely. To achieve bushy plants, stem shoots are allowed to grow freely to the top of the post. The stems are then bent down and trained in a circle around the post and their upper nodes are tied to the support. The results are generally less satisfactory than those in Sarawak, although precise application of this system on Bangka gave yields comparable to those in Sarawak. In Lampung, husbandry operations in shaded cropping are limited to irregular weeding and annual pruning of the shade trees.

Diseases and pests The major destructive disease of pepper cultivars in Malaysia and Indonesia is a foot-rot, caused by the soilborne fungus *Phytophthora palmivora* MF 4, which thrives under warm and humid conditions. The disease may infect the leaves and the roots, underground stem and root collar. It usually arises after rains. Leaves, especially the lower ones, are infected through soil-splash, resulting in the formation of black necrotic spots with typical fringed margins. Affected leaves drop within a few days before the infection spreads to the stem. The leaf drop contributes to the build-up of the soil inoculum. Symptoms of rapid, almost uniform wilting of leaves are visible, especially towards the end of the rainy season. They result from blocked water vessels in the stem and increasing water stress. Infected vines die within days or weeks. Rapid spread in gardens is typical; infected gardens may be ruined within weeks up to a few months. No effective control measures, suitable for smallholders, are yet available. Current research aims at grafting susceptible cultivars onto a rootstock of resistant pepper species such as *Piper colubrinum* Link and at breeding for resistance.

A second significant disorder in South-East Asia is the slow wilt 'yellow disease' occurring mainly on Bangka. Symptoms include a slow wilting and associated yellowing and drooping of leaves. The disorder has been identified as a combination of poor mineral nutrition and root invasion by *Radopholus* nematodes. The decline may be well controlled by liberal dressings of complete and balanced mineral nutrients and by liming and mulching.

Other diseases and pests do occur in the region, but can be effectively controlled by simple treatments with suitable fungicides and insecticides.

Harvesting In South-East Asia, pepper harvesting extends from April–June to August–September. This period generally coincides with dry weather and sunshine. To obtain black pepper, entire fruit spikes are picked when the fruits are full-grown and mature but still green (shiny yellowish green). For white pepper, fruit spikes are collected when a few fruits have turned red or yellow. Fruit spikes are harvested by hand, using a tripod ladder. Frequency of harvesting is usually 6–8 times per season (every 2 weeks); in some areas only twice or thrice. Whether black or white pepper is prepared may depend on the expected price of the product.

Yield Assuming uninterrupted optimal conditions for commercial vines and no fatal diseases, unshaded pepper has an economic life of 15–20 years. This lifetime is reduced to 6–10 years by poor husbandry. Mean annual production of fresh fruits per plant varies from (2–)6–12(–18) kg in Sarawak to (0.5–)2–4(–8) kg on Bangka and in Kalimantan.

For shaded vines (as in Lampung, Indonesia, and in the Philippines), the life span may exceed 30 years. Assuming a minimum of agronomic attention, but fertile soil and absence of fatal diseases, mean annual production per plant reaches (4–)12(–20) kg of fresh fruits.

In 1997, average yields of dried peppercorns per ha per year ranged from 0.3 t/ha in India to 0.7 t/ha in Indonesia, 1.2 t/ha in Malaysia, and 1.9

t/ha in Brazil. The statistics for Vietnam and Thailand indicate yields of 1.4 t/ha and 3.3(!) t/ha respectively.

Handling after harvest Freshly picked fruit spikes of pepper are usually taken to the farmhouse for processing. To prepare black pepper, spikes are left in heaps overnight for brief fermentation. Next morning, the mass of spikes and fruits is usually spread out on bamboo mats or concrete floors to dry in the sun, and is raked regularly. Another option is to blanch spikes and dry them on a flat-bed dryer (this reduces the drying time to about 7 hours). The mesocarp shrinks and fruits separate from the rachis during raking. The fruits may also be threshed by treading or using a threshing machine. After 4–5 days, the peppercorns are black and dry, showing their typical crinkled appearance. Moisture content usually ranges between 10–14%. The dried peppercorns are bagged and stored, pending sale.

To prepare white pepper, the fruit spikes are lightly crushed, put in gunny sacks and soaked for 7–10 days, preferably in slow-running water. The mesocarp disintegrates with retting. After soaking, peppercorns are trampled loose from the spike and separated by washing and sieving. The washed peppercorns are dried in the sun for 3–4 days, during which the white to cream colour develops. The dry peppercorns, usually with a moisture content of 10–14%, are then bagged and stored. If stagnant water has been used for processing, the dried peppercorns assume a grey colour and release a musty odour.

The weight ratio white pepper/fresh fruits is about 26% and that of black pepper/fresh fruits 33%. The proportion of the crop processed into white pepper in Sarawak depends on the price differential with black pepper. In Indonesia, Bangka traditionally produces only white pepper and Lampung only black pepper. The Philippines generally produces black pepper.

Black pepper can be further processed into oleoresin and pepper oil. The pepper oleoresin is obtained by extraction with a suitable solvent. The spice equivalent of oleoresin is 1 : (20–25). Pepper oil is derived by steam distillation of ground pepper.

Genetic resources India is the primary gene centre for pepper, whereas the Amazon Region of Brazil is the primary gene centre for many other *Piperaceae*. *Piper* species have also been found in many countries of South-East Asia, South and Central America, and also Africa.

Small germplasm collections are maintained in Sarawak and in Indonesia. In 1981, the Sarawak gene pool included 18 cultivars of *P. nigrum*, 18 identified *Piper* species, and 98 unidentified accessions. The collection is steadily being expanded. In 1985, the Indonesian gene pool included 40 cultivars of *P. nigrum* and 7 *Piper* species. This collection too is being regularly expanded.

Breeding Malaysia and Indonesia have high-yielding pepper cultivars, and breeding for better yield has low priority. All these cultivars are susceptible or highly susceptible to *Phytophthora* foot-rot disease. Development of resistant plant material is urgently required and is receiving high priority. At first some newly bred cultivars showed a certain degree of resistance or tolerance, but they merely slowed down infection and spread of the disease in gardens. Some new promising hybrids were developed, but they did not survive in the field. More recent results of hybridization, however, have shown encouraging prospects in terms of field resistance.

Another approach in plant improvement involves grafting onto well-tested rootstocks that are resistant to foot-rot. However, the grafts failed at about 6 years of age. In Indonesia, improved techniques for bud-grafting of woody stems and the development of a method for herbaceous budding are promising. Viable resistant buddings, combined with integrated disease-control measures, might overcome this major problem in pepper cultivation.

Prospects World demand for pepper is rather inelastic, but is tending to increase at an average rate of 4–5% per year. So, production of pepper offers fairly attractive prospects for smallholders as a source of cash income. However, with the ever-present danger of sudden destruction of plantations by *Phytophthora* foot-rot, farmers in affected areas are tending to turn away from pepper cultivation. Only when supply of pepper falls short of world demand and prices become high may farmers be induced to take the risks of new planting.

The fluctuations in world production combined with an inelastic demand lead to fluctuations in price that are strongly aggravated by speculation by traders. Only when plant material resistant to foot-rot becomes available will development of agronomic methods for higher productivity and lower production costs be expedient. Overproduction might be overcome by judiciously planned reduction of areas with pepper in favour of alternative remunerative crops.

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P.W.F. de Waard & I.S. Anunciado

Rosmarinus officinalis L.

Sp. pl.: 23 (1753).

LABIATAE

$2n = 20, 24$

Synonyms *Rosmarinus angustifolius* Miller (1768), *R. latifolius* Miller (1768), *Salvia rosmarinus* Schleiden (1852).

Vernacular names Rosemary, compass plant (En). Rosmarin, romarin, incensier (Fr). Philippines: dumero (Tagalog), romero (Tagalog, Bicol), rosmiro (Bontoc).

Origin and geographic distribution Rosemary is indigenous to the Mediterranean region, from where it was introduced into all continents. It is occasionally cultivated as an ornamental in the mountainous areas of Java. In the Philippines it is currently grown on a small scale for the fresh-herb market.

Uses The fresh or dried leaves are excellent flavouring agents in vegetables, meat (particularly lamb, veal and roasted chicken), sauces, stews, herbal butters, cream soups, fruit salads, jams, biscuits and bread.

Rosemary oil, distilled from the flowering tops and leaves, is used to season processed foods, but for the most part it is employed in perfumes, in scenting soaps, detergents, household sprays and other related technical products. It finds application in denaturing alcohol and is popular in aromatherapy. In the United States the regulatory status 'generally recognized as safe' has been accorded to rosemary (GRAS 2991), rosemary oil (GRAS 2992) and rosemary oleoresin (GRAS 3001). The maximum permitted level of rosemary oil in food products is about 0.003%. Rosemary oleoresin is used in the food industry as a natural antioxidant, for instance in cooked meat products.

In traditional medicine rosemary is thought to fortify the brain and refresh the memory. Flowering tops and leaves are considered carminative, diaphoretic, diuretic, aperient, emmenagogue, stimulant, stomachic and astringent. Rosemary also serves as a household remedy for headaches, bruises, colds, nervous tension, asthma, baldness and sore throat. In the Philippines, an infusion of the leaves is used as an eyewash for slight catarrhal conjunctivitis, as vapour baths for rheumatism, paralysis and incipient catarrhs, and to bathe women in puerperal state. Rosemary leaves are therapeutically allowed internally for dyspeptic complaints, and externally for rheumatic diseases and circulatory problems.

Rosemary is very popular as an ornamental plant used as a ground cover, hedge or shrub and is even transformed by hobbyists into bonsai or planted in hanging baskets. The leaves and flowers can be carefully dried and sold in elegant sachets and potpourris. For the last 1000 years in Europe, rosemary has been a symbol of happiness, fidelity and love, and a wedding and funeral flower.

Production and international trade Data on world trade of dried rosemary are fragmentary and available only for selected markets. In the 1970s annual consumption of rosemary in the major markets of Europe, the United States and Japan was estimated at 490–710 t. In 1989–1990 import of rosemary in selected countries of Western Europe (France, Germany, United Kingdom, the Netherlands) totalled 970–1020 t. The bulk of this import came from Spain and the rest from Albania, Tunisia and Morocco.

Rosemary oil, which is used in large amounts in the food-processing industry, is produced mainly in Spain, Tunisia and Morocco. Annual world production of the oil is about 375–425 t and is consumed mostly in the United States and the European Union. The value of world production of rosemary oil is estimated at US$ 5 million. From 1992–1995 the biggest user of rosemary oil, the United States, imported annually about 60 t, valued at US$ 0.9 million.

Properties Dried rosemary contains per 100 g edible portion: water 9.3 g, protein 4.9 g, total lipids 15.2 g, carbohydrates 46.5 g, fibre 17.6 g, ash 6.5 g (Ca 1.3 g, Fe 29 mg, Mg 220 mg, P 70 mg, K 955 mg, Na 50 mg, Zn 3.2 mg), ascorbic acid 61.2 mg, thiamine 0.51 mg, niacin 1.0 mg, vitamin A 3128 IU, and phytosterols 58 mg. The energy value is 1387 kJ/100 g.

The dried leaves contain 1–2% volatile oil. Verbenone is the character-impact compound in rosemary; the pungent, camphoraceous odour and burning taste is attributed to borneol; the cooling and minty note to camphor; the fresh aroma to cineole; and the warm, piny scent to α-pinene. The phenols thymol, carvacrol and eugenol also play an important role in the flavouring properties of the oil. A monograph on the physiological properties of rosemary oil has been published by the Research Institute for Fragrance Materials (RIFM).

Rosemary possesses strong antioxidant properties. Carnosic acid, the major phenolic diterpene present in the leaves, has been found to be several times more effective than the commercial food preservatives butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) in controlling oxidation in soya-bean oil. Rosemary also possesses some antibacterial and antifungal properties. Extracts of the plant have been found to inhibit skin tumorigenesis in test animals. The volatile oil of rosemary has been reported to induce hyperglycemia and to inhibit insulin release in test rabbits.

Three types of rosemary oil are sometimes recognized: a camphor type (produced mainly in Spain), a 1,8-cineole type (produced mainly in Morocco) and a verbenone + bornyl acetate type that is a cottage-industry product from Corsica. In herbal medicine rosemary oil is used to treat acute middle ear infections and to stimulate liver and gall bladder. It is said to be very beneficial for dry skin in skin-care products. Verbenone is also an insect pheromone. Synthetic verbenone is used in programmes to control several bark beetle species in pine trees.

Rosemary is an excellent source of nectar for honeybees.

Adulterations and substitutes Rosemary oil has in the past been adulterated with turpentine, oil of pine, certain fractions of camphor oil (i.e. camphor) and eucalyptus oil (i.e. 1,8-cineole).

Description An evergreen, usually erect, bushy shrub up to 2 m tall and wide. Stem indistinctly quadrangular, finely grey pubescent. Leaves opposite, tufted on the branches, sessile to short petiolate; blade linear, 1–5 cm × 1–2 mm, base attenuate, margin entire but revolute, apex obtuse, leathery, dark glossy sea-green and subglabrous above, white-felted tomentose beneath, aromatically fragrant when crushed. Inflorescence race-

Rosmarinus officinalis L. – 1, flowering branch; 2, flower.

mose, axillary, 5–10-flowered, 0.5–2.5 cm long, terminating short lateral branches; pedicel 2–5 mm long; calyx campanulate, 2-lipped, 5–6 mm long, densely stellate tomentose, upper lip small and 3-dentate, lower lip 2-lobed; corolla tubular, 2-lipped, 10–13 mm long, pale blue or blue (seldom white), upper lip erect or recurved, 2-lobed, ovate, about 4 mm long, lower lip 3-lobed, about 7 mm long, with large concave middle lobe; 2 anterior stamens perfect, 7–8 mm long, ascending under the base of the upper lip, 2 posterior stamens reduced to hardly visible staminodes; pistil with deeply 4-partite ovary, style incurved, 1.5 cm long ending into 2 short, unequal branches with stigma. Fruit composed of 4 subglobose to obovoid nutlets, about 2 mm long, glabrous and smooth.

Growth and development Seeds of rosemary are slow to germinate taking about 3–4 weeks before emerging from the soil. To enhance germination the temperature should remain below 18°C. Seedlings are likewise slow to develop, becoming a dense shrub with a diameter of 60 cm and a height of 90 cm only by the end of the second growing season. Flowering is initiated when plants are 2 or more years old. Under favourable growing conditions and optimal cultural management, rosemary can remain productive for up to 30 years.

Other botanical information Rosemary is very variable in habit (erect to creeping), size and colour of leaves and flowers and composition of the essential oil. This variability has led to recognition of 4 species by some; others distinguish 1 species with many varieties and forms. Most appropriate for cultivated plants is to distinguish cultivar groups and cultivars.

Some of the notable cultivars of rosemary are 'Albus' (with white flowers), 'Collingwood Ingram' (0.6–0.9 m tall, spreads to about 1.2 m or more, and can be used as a tall ground cover), 'Tuscan Blue' (with dark blue-violet flowers), 'Lockwood de Forest' and 'Prostratus' (both are low-growing and make excellent ground covers, 'Prostratus' is rich in verbenone).

A frost-resistant rosemary cultivar has recently been selected in Hungary with the following major components of the essential oil: α-pinene 4.1–14.4%, 3-octanone trace–10.0%, β-pinene 5.3–13.7%, 1,8-cineole 21.3–46.4%, camphor 13.0–31.0% and verbenone 2.5–11.1%. Verbenone and 3-octanone were identified as the characteristic chemical features of the new Hungarian selection.

Ecology The ecological amplitude of rosemary is from the temperate humid zone (mean annual temperature of 6–12°C; mean annual rainfall of 1000–2000 mm) to the subtropical semi-arid to humid zones (18–24°C; 500–2000 mm). Its pH tolerance ranges from 4.5–8.3, but preferably 6–7.5. In the Mediterranean region, rosemary thrives on calcareous soils, on dry sunny mountain slopes and near the coast where it is frequently exposed to fog and salt spray (*Rosmarinus* means 'dew of the sea'). Rosemary can survive in areas with mild winters, but not in localities where the temperature frequently falls below -3°C. Once established rosemary roots deeply and is drought-resistant.

Propagation and planting Rosemary is commonly propagated by cuttings, division or by air layering. Seeds are sometimes used, but they are produced only under very favourable growing conditions and often only 10–20% of the seeds germinate. Transplanting to the field is done at a spacing of 45 cm between plants in rows 1.2 m apart. It is also common to produce rosemary in containers in greenhouses.

In vitro production of active compounds Experimental production of rosmarinic acid, a caffeoyl derivative with potent antioxidant properties, has been reported in suspension cultures of rosemary.

Husbandry Rosemary will benefit from balanced fertilizer applications, with K being particularly critical for high essential-oil yield. In cold areas, the crop should be given heavy mulching to prevent winter injury. It should only be moderately watered to prevent root rot.

Growth of rosemary raised in containers strongly depends on the type of growing medium and the fertilizer regime used. The use of peat and perlite as growing medium results in taller plants yielding higher amounts of essential oil compared with those raised in a medium of peat, perlite and soil. Plant fresh weight, however, is not affected. Growth in both media is also satisfactory when plants are provided with an adequate supply of controlled-release or liquid fertilizers.

Diseases and pests Rosemary has been reported to be attacked by *Phytocoris rosmarini* and *Orthotylus ribesi* in Spain and by *Sclerotinia sclerotiorum* in India. It has also been found susceptible to the root-knot nematode *Meloidogyne incognita*.

Harvesting Once established, but before rosemary becomes woody, the terminal shoots (25–30 cm from the tip) are harvested once or twice each season. The shoots are either dried or, if for sale in the fresh-herb market, bundled together in bunches of 8–12, tied with rubber bands. When the essential oil is to be extracted the plants are cut 2–3 years after planting at the onset of flowering, when the oil content is at its maximum.

Yield Yields of fresh leaves of rosemary amount to 3 t/ha, and with a content of 0.1%, essential-oil yield is approximately 3 kg/ha.

Handling after harvest Bunched fresh shoots of rosemary are put in styrofoam containers and delivered as soon as possible to fresh-market outlets. The whole fresh leaves can be frozen, preserving the flavour best. For the dried herb market, the shoots should be dried immediately on screen trays in a dark, sheltered area with good ventilation. The dried leaves are simply stripped by hand from the stems and subsequently stored in closed containers.

Genetic resources Rosemary germplasm collections are available in most Mediterranean countries, e.g. at the Portuguese Germplasm Bank, Braga, Portugal (20 accessions) and at the gene bank of the Institute for Plant Genetics and Crop Plant Research, Gatersleben, Germany (4 accessions).

Breeding In North America it is being attemped to obtain frost-tolerant rosemary cultivars. In some places 'Arp' and 'Hill Hardy', 2 cold-tolerant cultivars, survive severe winters (with protection of mulch) and in others they do not.

Prospects The supply of rosemary is adequate and it is one of the least expensive herbs in the spice trade. Thus, new producers may find it difficult to penetrate the current market.

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C.C. de Guzman

Salvia officinalis L.

Sp. pl.: 23 (1753).
LABIATAE
$2n = 14$

Synonyms *Salvia chromatica* Hoffsgg. (1824), *S. papillosa* Hoffsgg. (1828).

Vernacular names Sage, garden sage, true sage (En). Sauge (Fr). Philippines: salvia (Cebuano).

Origin and geographic distribution Sage is native to the Adriatic belt of the Balkan peninsula (Greece, Albania, former Yugoslavia) and doubtfully native but certainly naturalized in southern France and in Spain. It is widely cultivated in Europe, particularly in the Mediterranean, but it has spread widely and is cultivated in many countries of all continents. In Malaysia, it is grown in the hills in Pinang, in Indonesia in the mountainous regions of Java, and in the Philippines on specialized farms in Luzon at altitudes above 500 m.

Uses Sage has been used since ancient times as a culinary herb, essential-oil plant, medicinal plant and as an ornamental. Sage is best known for its dried leaves, available whole, rubbed or ground, which are used as a spice for flavouring sausages, stuffings, soups and canned vegetables. Fresh leaves are used in herb butters, cheeses, liqueurs, pickles, salads and vinegars, and they make a good dentifrice. Sage combines a nice aroma with a unique bitter and pungent taste.

In the United States the regulatory status 'generally recognized as safe' has been accorded to sage (GRAS 3000), sage oil (GRAS 3001) and sage oleoresin (GRAS 3002). The oil is extensively used in food products, including alcoholic and non-alcoholic beverages. The maximum permitted level in food is about 0.5%. Sage oleoresin is used similarly in flavouring all kinds of food products. The maximum permitted level reported is about 0.014% in meat and meat products. Sage essential oil is also used in perfumery, for deodorants, in pesticidal preparations, and as medicine. Medicinally, sage is used as mild tonic, aromatic bitter, astringent, carminative, antiseptic, antipyretic, and remedy for tumours and cancers. As it contains oestrogenic substances, it is a traditional medicine for female disorders. Sage oil is used for treating rheumatic pains; it is said to cause violent convulsions reminiscent of attacks of epilepsy convulsant. Sage gargle is recommended for bleeding gums, sore throat and tonsillitis. Sage tea is a good tonic. Sage can serve as a source of natural antioxidants.

Production and international trade The Balkan region bordering the Adriatic Sea is the major producing and exporting area of sage and sage oil. The United States, where sage is one of the most popular culinary herbs, is the main importer (Yugoslavian sage, Dalmatian sage).

In the late 1980s, annual imports of sage into selected Western European markets amounted to 1750 t per annum, with Germany accounting for 650 t, United Kingdom for 500 t, France for 450 t, and the Netherlands for 150 t. Major suppliers were Yugoslavia, Turkey, Greece, Albania, Italy, Morocco and Israel. The United States, the biggest user of sage, consumes about 4000 t annually.

Properties The dried ground herb contains per 100 g edible portion: water 6–8 g, protein 10–11 g, fat 13–15 g, carbohydrates 34–42 g, fibre 16–18 g, ash 8 g (Ca 1.7 g, P 91 mg, Fe 28 mg, Mg 428 mg, Na 11 mg, K 1.1 g, Zn 5 mg), vitamin A 5900 IU, thiamine 0.75 mg, riboflavin 0.34 mg, niacin 6 mg, and ascorbic acid 32 mg. The energy value is 1320–1735 kJ/100 g (dried).

The essential oil of sage, to which the plant owes its flavour and character, is produced by steam distillation of freshly harvested leaves. Dry leaves yield up to 2.5% essential oil, depending on the country of origin, growing conditions, and harvesting season. Its colour is pale yellow to almost colourless, its odour strongly aromatic, sickly sweet, camphoraceous, eucalyptus-like. The main components are α-thujone, β-thujone, 1,8-cineole and camphor, but the composition varies widely with the source. The thujones are responsible for the strong characteristic smell of sage. A monograph on the physiological properties of sage oil has been published by the Research Institute for Fragrance Materials (RIFM).

In addition to the essential oil, the leaves contain tannin, fumaric acid, malic acid, ursolic acid, picrosalvin, saponin, pentoses, a wax, and potassium nitrate. Picrosalvin and carnosol are the bitter principles. Nearly 120 mg of picrosalvin can be obtained from 30 kg of sage. Sage, sage oleoresin and sage oil exhibit antioxidant properties due to the presence of a polyhydric phenol. Sage has considerable pesticidal activity.

Sage oleoresin is usually prepared from the Dalmatian type of sage. It is a brownish-green liquid containing a minimum volatile oil content of 25–30 ml per 100 g (1 kg is roughly equivalent to 13.5 kg of ground sage).

Seeds contain 18% protein and a drying oil used as a bonding agent in oil paints. The oil contains 14.2% oleic acid, 29.2% linoleic, 34.7% linolenic and 12% saturated acids.

Adulterations and substitutes The most common adulterant of sage is by its own stems (excluding petioles); these should not exceed 10%. Sage is often augmented with leaves of some other *Salvia* spp., in particular *S. fruticosa* Miller (syn.: *S. triloba* L.f.) (Greek sage). Thujone from cheaper sources is a common adulterant of sage oil. In turn, sage oil is used for adulterating rosemary and lavender oils.

Description Perennial, erect or decumbent subshrub, 40–70 cm tall, rooting at the base, very aromatic with small, sessile, oil globules on most green parts. Stem quadrangular, patent tomentose. Leaves opposite, simple; petiole 0–5 cm long; blade oblong-lanceolate to elliptical, 1–10 cm × 0.25–5 cm, entire, rugose, more or less narrowed at base, margin thickly herbaceous, greenish above, white-pubescent beneath, densely pubescent when young. Inflorescence raceme-like, 10–30 cm long, composed of axillary reduced cymes forming false whorls (verticillasters), rarely

Salvia officinalis L. – 1, flowering branch; 2, flower; 3, section through flower; 4, stamens; 5, calyx; 6, nutlet.

branched; verticillasters remote, sessile, 4–10-flowered; pedicel up to 1 cm long; calyx campanulate, 10–15 mm long, 2-lipped, lower lip 2-dentate, upper lip 3-dentate, glandular punctate; corolla tubular, up to 3.5 cm long, violet-blue, pink or white, inside with a ring of hairs, 2-lipped, lips about equal in length, upper lip erect, lower lip 3-lobed and curved outward; stamens 2, filaments short, glabrous, articulating with a slender connective; connective linear, transverse, both arms subequal, each bearing a fertile, linear anther-cell but upper one larger than lower one; disk equal-sided; pistil with a deeply 4-partite ovary and a shortly 2-fid, glabrous style. Fruit composed of 4 nutlets; nutlet subglobose to trigonous, up to 2.5 mm in diameter, smooth, glabrous, dark brown.

Growth and development In West Java, sage flowers in September. It is self-compatible, but predominantly cross-pollinated by insects. Sage is much frequented by butterflies and bees. Most cultivated *Salvia* species do not set viable nutlets in the tropical lowlands.

Other botanical information *S. officinalis* forms part of a complex of several closely related species, the most important being *S. fruticosa* Miller, *S. lavandulifolia* Vahl and *S. tomentosa* Miller. *S. fruticosa* has simple or, more often, trilobed leaves with 1(–2) pairs of lobes at the base of a larger terminal leaflet, calyx 5–8 mm long, corolla 16–25 mm long. It occurs naturally in the central and eastern Mediterranean region from Sicily to Crete and in Libya, but is also cultivated and sometimes naturalized outside this region (e.g. Canary Islands, Morocco and Algeria). *S. lavandulifolia* has often been considered as a form of *S. officinalis*; its verticillasters bear 6–8 flowers, the calyx is 8–12 mm long and the corolla 20–25 mm; it occurs wild in Spain and southern France, but is also cultivated elsewhere. *S. tomentosa* (synonym: *S. grandiflora* Etlinger) has leaves up to 6.5 cm wide which are rounded to cordate at base, verticillasters bear 4–10 flowers, calyx is 10–15 mm long, corolla up to 35 mm; it occurs wild in the central and southern parts of the Balkan peninsula, but is occasionally also cultivated elsewhere. It yields a commercial essential oil different from sage oil.

Numerous cultivars of *S. officinalis* exist, e.g. 'Albiflora' with white flowers, said to be the best culinary sage; 'Purpurescens' with purple young leaves; 'Rubriflora' with reddish-purple flowers, known to have been cultivated in Europe since the 16th Century.

Salvia L. comprises about 500 species, widely distributed in temperate and subtropical regions, but with few in the tropics. About 20 species occur in South-East Asia; 6 are native or truly naturalized, the others occur only in cultivation (mainly as ornamentals).

Ecology Sage grows best on a rich clay loam with good drainage, in sunny but protected locations. Ample light and high temperatures promote the production of essential oil, so that sage cultivated in Dalmaty (Yugoslavia) yields 2.5% essential oil compared with 1.4% when cultivated in northern Europe. Experiments on photoperiodic response point to most profuse flowering under long-day conditions. Thanks to its woody parts sage is rather hardy.

Propagation and planting Sage is usually grown from seed, but propagation by cuttings, layering or division is also practised. Seeds can be stored for more than 6 years at 5°C in airtight containers. At ambient temperatures (10°/30°C), germination markedly decreases after 2 years of storage. Seeds germinate in about 4 weeks; when strong enough, the seedlings are transplanted. Sage should be planted in rows 0.75–1 m apart, at distances of 35–60 cm in the row. It is often planted in gardens as a border plant. Stable manure or NPK fertilizer should be applied before planting.

Commercial propagation of ornamental cultivars is usually by cuttings. Cuttings normally root in 2–3 weeks at 18–20°C.

Husbandry A fertilizer side-dressing 6–8 weeks after planting is recommended. It is common to divide the clumps biennially, since the plants become straggling if left longer. After about 4 years, sage plants become very woody, and the planting has to be rejuvenated in view of declining yields. However, many sage plants in gardens are 15–20 years old.

Diseases and pests Sage is largely unaffected by diseases and pests. Root-rot caused by *Armillaria mellea* has been observed on dying sage in Greece, downy mildew by *Peronospora lamii* in Florida (United States), and foliar necrosis by *Colletotrichum gloeosporioides* in Argentina.

Eupteryx melissae has been reported as a pest on sage in New Zealand.

Nematodes are the major problem in sage cultivation. *Tylenchorhynchus initans* is a problem in India, and root-knot nematode (*Meloidogyne incognita*) in the United States.

Harvesting The highest essential-oil content occurs in leaves of non-flowering plants. Stems are very poor in essential oil. The harvested crop usually consists of the top 20 cm of growth, cut just before flowering. Inflorescences are sometimes removed if harvesting has to be delayed. The highest grade product is obtained by harvesting only the leaves, and the lowest one by cutting the crop with a mowing machine.

Yield In the first year yields of dried leaves are usually low. In the second and third years, annual yields of 1.2–2(–5) t/ha are possible, declining in the fourth and fifth years. Annual yields (except the first year) of 2.5–5 t/ha are reported from the United States, whereas experimental yields of 12.7 t/ha (yielding 173 kg essential oil) in 2 years have been obtained in Switzerland.

Handling after harvest Fresh leaves should be used or processed as soon as possible, for they lose much of their aroma unless carefully dried. In small-scale production, a warm airy room is best for drying, the plants being either put loosely upon racks or on the floor, or hung from the ceiling and walls. In large-scale production, dehydrators are used with a steady current of warm air. Drying temperatures of 25–30°C are best, both to minimize loss of oil and to ensure good product appearance and low moisture content. After drying, the leaves are separated from the stems, rubbed or ground to a powder, and stored in airtight containers, as the loss of volatile oil continues after drying.

Genetic resources and breeding Most European gene banks have one to several accessions of *S. officinalis*. The largest numbers have been reported from the Plant Germplasm Bank (Braga, Portugal, 40 accessions), the Research and Breeding Institute for Vegetables and Special Plants (Nové Zámky, Slovakia, 16 accessions), the Gene Bank Department, Research Institute for Crop Production (Olomouc-Holice, Czech Republic, 12 accessions) and the Gene Bank, Institute for Plant Genetics and Crop Plant Research (Gatersleben, Germany, 10 accessions). No breeding programmes for *S. officinalis* are known of.

Prospects Sage is an important herb in the flavour and fragrance industry, with interesting secondary uses as medicinal, antimicrobial, insecticidal and ornamental plant. Small-scale cultivation in South-East Asia is taking place, mainly to satisfy the demand of a foreign clientele (international hotels, fast-food chains). Potentially sage may be an interesting crop for the South-East Asian region, and, therefore, deserves more attention.

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U.A. Dasuki

Satureja hortensis L.

Sp. pl.: 568 (1753).
LABIATAE
$2n = 46, 48$

Synonyms *Satureja pachyphylla* K. Koch (1843), *S. laxiflora* K. Koch (1849), *Clinopodium hortense* Kuntze (1891).

Vernacular names Summer savory, annual savory (En). Sarriette annuelle, sarriette, savourée (Fr).

Origin and geographic distribution *Satureja hortensis* is native to the eastern Mediterranean region and widely escaped from cultivation elsewhere. It was probably grown as a condiment in ancient Rome. Since then, it has been planted in Europe, Asia (the former Soviet Union, Afghanistan, India, Sri Lanka), South Africa and the Americas (United States, Argentina). In South-East Asia, it is cultivated in the Philippines on a small scale for the fresh-herb market and similarly in the mountains of Java (Indonesia).

Uses Summer savory, either fresh or dried, is mainly used for flavouring. For the fresh product, all aerial plant parts are used, but for the dried herb, only leaves and flowering tips. The best class of commercial summer savory consists of dried leaves only.

Its main traditional culinary use in Europe is as a flavouring for vegetables, especially beans and peas. In several countries (e.g. Germany, the Netherlands) the vernacular name is the local equivalent of 'bean herb'. Summer savory blends well with other herbs. Alone or in combination with other herbs it is quite widely used to flavour baked products, meat and meat products (e.g. sausages), egg dishes, processed vegetables, salads, soups, gravies and pickles.

Summer savory contains an essential oil with a sharp and bitter flavour. At low concentrations only it is reminiscent of the herb itself. The oil is used in the food industry to flavour processed foods, and in the liqueur and perfume industries. The maximum permitted level in food products is about 0.04%. Sometimes an oleoresin is produced, but in commercially insignificant amounts. In the United States the regulatory status 'generally recognized as safe' has been accorded to summer savory (GRAS 3012), summer savory oil (GRAS 3013) and summer savory oleoresin (GRAS 3014).

Summer savory is used in traditional medicine as a carminative, expectorant, astringent and tonic in the treatment of gastro-intestinal disorders (cramps, nausea, indigestion, diarrhoea), and sore throat, generally in the form of a tea. It has also been used as an aphrodisiac. Fresh summer savory is rubbed on the skin to treat insect bites, e.g. bee stings.

Summer savory has also been planted as a bee-feeding plant.

Production and international trade The main countries producing summer savory include France, Spain, the former Yugoslavia and the United States. Only small quantities are traded internationally and no recent statistics on production and trade are available.

Properties Dried savory has a fragrant, aromatic odour, and a warm, aromatic, slightly sharp and somewhat camphoraceous taste. The odour and taste are sometimes likened to those of thyme (*Thymus vulgaris* L.).

Fresh green herb (leaves and flowering tops), collected at the end of the flowering period, contains per 100 g: moisture 72 g, protein 4.2 g, fat 1.65 g, carbohydrates 11.5 g, fibre 8.6 g and ash 2.1 g. Dried leaves are reported to contain per 100 g edible portion: water 9.0 g, protein 6.7–7.7 g, fat 5.2–5.9 g, carbohydrates 53.4–54.6 g, fibre 15.3 g, ash 8.7–9.6 g (Ca 2132 mg, Fe 38 mg, Mg 377 mg, P 140 mg, K 1051 mg, Na 24 mg, Zn 4 mg), vitamin A (as β-carotene) 5130 IU, niacin 4 mg, and vitamin C 12 mg. The energy value is 1130–1500 kJ/100 g.

The odour and taste of summer savory are due to the presence of 1–2% essential oil in the leaves and flowers. The essential oil is golden yellow with a fresh medicinal-spicy odour reminiscent of sage and thyme, and can be obtained by steam distillation. More than 100 components of the essential oil have been described, but the major components are carvacrol (a monoterpene phenol), γ-terpinene, and p-cymene.

Carvacrol ($C_{10}H_{14}O$) is a colourless to pale yellow liquid, with a pungent, thymol odour, imparting a fresh, slightly sharp, phenolic sensation. Commercial savory oil must contain 20–57% carvacrol, whereas the thymol content should be negligible.

The relative amounts of the volatile compounds in the essential oil is different from those in the ground herb itself, because steam distillation leads to changes in the composition. The main volatile compounds of ground herb are γ-terpinene, p-cymene, α-pinene, α-terpinene and myrcene.

Ground dried leaves and leaf extracts, especially the ethanol extract, of summer savory have shown antioxidant activity in pork meat and sunflower oil respectively, and summer savory has been proposed as a source of natural antioxidants to stabilize lipids and lipid-containing products. An important antioxidant compound in summer savory is rosmarinic acid.

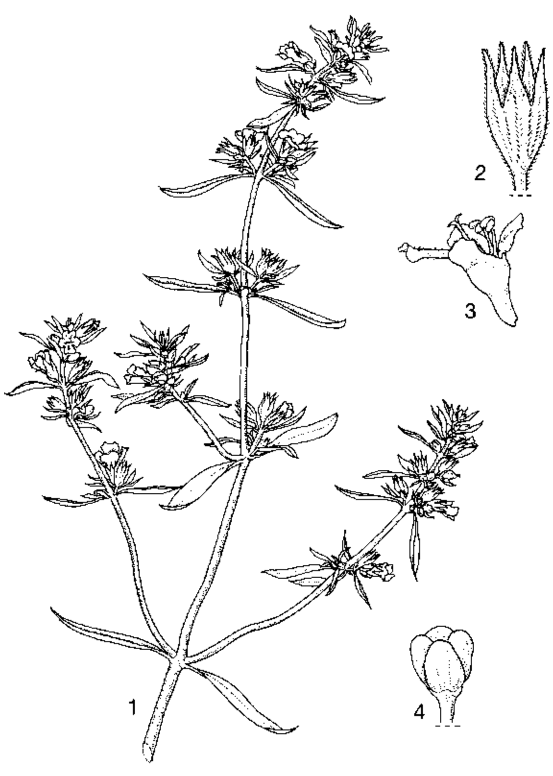
The essential oil has antifungal and antibacterial activity. Carvacrol is responsible for antifungal activity against e.g. *Cladosporium herbarum* and *Penicillium glabrum*. The compounds with the greatest antibacterial activity are carvacrol, 1,8-cineole, p-cymene, eugenol, β-humulene, linalool, β-pinene, α-terpineol and thymol, with the test bacteria *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Salmonella pullorum*, *Staphylococcus aureus*, *Streptococcus faecalis* and *Yersinia enterocolitica*. The essential oil has spasmolytic effects on isolated smooth muscles. A monograph on the physiological properties of summer savory has been published by the Research Institute for Fragrance Materials (RIFM).

The seeds of summer savory contain, on a dry basis, 42% oil and 24% protein. The seed oil is said to be equal or superior to linseed oil as a drying oil, and contains: linolenic acid 60–65%, linoleic acid 18–24%, oleic acid 4–12%, palmitic acid 2–4% and stearic acid 1–3%.

The weight of 1000 seeds is 0.5–0.8 g.

Adulterations and substitutes The perennial winter savory (*S. montana* L.) contains an essential oil which is very similar to that of summer savory, and can be used as a substitute. However, the flavour of winter savory is regarded somewhat inferior to that of summer savory. The chemical composition of oregano (*Origanum vulgare* L.) oil resembles that of savory, but the oil has a coarser character. Thyme (*Thymus vulgaris*) oil is occasionally used as an adulterant of savory oil. Another adulterant of summer savory is *Thymbra spicata* L. (Turkey, Greece).

Description Erect, much branched, very aromatic, annual herb, 10–50 cm tall. Stem obtusely angular to subterete, without furrows, with short hairs. Leaves decussately opposite, subsessile; blade linear to lanceolate or obovate, 1–4 cm × 1–5 mm, base gradually tapering into very short petiole, margin entire, apex obtuse to rather acute, usually subglabrous but densely gland-dotted. Inflorescence consisting of lax to densely congested verticillasters each with 2–20 bisexual flowers; pedicel very short; bracteoles usually longer than calyx, thinly long-ciliate; calyx tubular and 2-lipped, 3–4.5 mm long, 10-veined, glabrous inside, thinly pilose outside, with 5 subequal triangular teeth (longer than the tube) or upper lip 3-dentate and lower lip 2-dentate; corolla tubular and 2-lipped, 4–10 mm long, tube widely funnel-shaped, lower lip 3-fid, upper lip emarginate, light violet to white, in the throat sometimes red-dotted, thinly pubescent outside; stamens 4, curved, inserted in the upper half of the corolla tube under the upper lip, shorter than the corolla; pistil with 4-lobed ovary and a style with 2 equal branches each ending in a small stigma. Fruit composed of 4 nutlets, enclosed within the persistent calyx; nutlet subglobose, about 1 mm long, glabrous, smooth, blackish-brown.



Satureja hortensis L. – 1, flowering and fruiting shoot; 2, calyx; 3, flower, calyx removed (side view); 4, fruit.

Growth and development Germination of summer savory is slow and normally takes 2–3 weeks, but may take longer under unfavourable conditions. Initial development after germination is fast. Flowering starts 75–80 days after germination, and fruits ripen continuously and may shatter. In Europe, the period from germination to ripening of the seeds is about 140–160 days.

Three major development phases can be distinguished in the crop cycle of summer savory: the vegetative phase, the flowering phase, and senescence. The vegetative phase ends when the flower buds appear. The flowering phase may be subdivided into early and full flowering, the latter starting when the first flowers are fully open. The rate of dry matter production increases progressively until the start of the flowering phase, after which the rate remains constant until the maximum biomass is attained and senescence starts. Though the biomass production varies with season, planting date and level of fertilizer application, the relationship between the course of dry matter production and reproductive development remains the same.

Other botanical information Sometimes *Satureja* is erroneously spelled *Satureia*. The genus *Satureja* L. is taxonomically badly known and needs revision; in a wide sense about 200 species are accepted, in a strict sense about 30 species. *S. hortensis* is extremely variable in all its characteristics; subclassifications are numerous, but all differences gradually change from one extreme to the other and cultivated forms are indistinguishable from wild forms. *S. hortensis* is called 'summer savory'; 'winter savory' is *S. montana* L., also originating from the Mediterranean and used for flavouring like summer savory, but considered inferior. Their main differences are: summer savory is a slightly larger annual, with narrow and slightly pubescent leaves and a sweeter, less piquant taste; winter savory is a slightly smaller perennial with narrower and glabrous leaves and a less sweet, more piquant taste.

Ecology Summer savory grows well in most temperate and subtropical climates in full sun on light, rich, well-drained soils. It is native on calcareous soils in the Mediterranean region, and prefers alkaline soils.

Propagation and planting Propagation of summer savory is usually by seed. Information on planting practices is only available from Europe and the United States, where summer savory is sown shallowly in rows or broadcast. Seeds should be sown 0.5–1.5 cm deep at a row distance of 25–30 cm. When mechanically cultivated, rows may be 45–50 cm apart. Too narrow spacings may increase the risk of fungal diseases like grey mould (*Botrytis cinerea*) and mint rust (*Puccinia menthae*). Sowing rates range from 3 to over 10 kg seed per ha. Seeds remain viable for 1–2 years, but can be stored for several years in airtight containers. Adequate soil preparation before planting is very important.

Husbandry Summer savory is sometimes thinned when plants have 4–6 leaves (to 15 cm apart in the United States). The field must be kept free from weeds, either mechanically or chemically. Fertilizer application is usually recommended, with an adequate supply of potassium being particularly important. However, excessive fertilization may lead to lodging in the flowering phase. Per 10 t fresh material of summer savory in Germany 32 kg N, 13 kg P_2O_5, 51 kg K_2O, 7 kg MgO and 35 kg CaO is taken up from the soil. In Scotland, fertilizer application has no influence on the essential-oil concentration and oil composition, but leads to an increased biomass and thus a higher oil yield. In Europe, it is recommended to grow summer savory or other *Labiatae* and to return to the same field only once in 5 years, to prevent the build-up of large populations of disease and pest organisms.

Diseases and pests Mint rust (*Puccinia menthae*), an important disease of mints (*Mentha* spp.), occurs on the leaves and stems of summer savory, but without causing as much damage as in mints. In Europe, *Pythium* fungi cause damping-off of young summer savory, whereas false mildew (*Peronospora* spp.) and grey mould (*Botrytis cinerea*) can be troublesome.
Pests on summer savory in Europe include leaf miners (*Phytomyza horticola*), caterpillars (*Apterona crenulella, Arctia caja*), aphids (*Aphis fabae*), cicadas (*Cicadella atropunctata*) and beetles (*Cassida viridis*).

Harvesting Summer savory should be harvested when flowering. Plants are cut at ground level or above the bottom branches. Under favourable weather conditions a ratoon crop can be obtained.

Yield Yields of summer savory may vary considerably. In Scotland, dry matter yields ranging from 1.4–11.3 t/ha have been found. The oil content was 0.4–0.8% during the vegetative phase, rising to 0.8–1.2% in the early flowering phase to a maximum of 1.4–2.0% at full flowering, and falling sharply to 0.4% during senescence. Maximum oil yield per ha coincided with full flowering, and ranged from 16–60 kg/ha. The oil composition varied between and within seasons, but the carvacrol content of the oil was always according to international standards (20–57%) during the flowering phase. Consequently, harvesting at maximum biomass gave the highest yield of oil of acceptable quality. These dry matter yields are similar to or higher than those for Eastern Europe. However, higher essential-oil concentrations (2–4.7%) and oil yields (60–110 kg/ha) have been obtained in Poland. Experimental yields for Germany are 33–49 t/ha fresh herb, which is equivalent to 5.6–7.5 t/ha dried herb, and fresh yields of leaves and flowering tips, separated from the stems, of 10–22.5 t/ha, equivalent to a dry weight of 1.6–4.1 t/ha.

Handling after harvest The cut herbage of summer savory is usually dried, threshed and cleaned, and then stored in closed containers to maintain the colour and to avoid loss of the essential oil. The harvested material should be dried soon after harvest, to avoid loss of quality. Air-dried summer savory keeps its flavour and odour well, but freeze-dried material loses its odour and flavour rapidly when stored in an atmosphere with oxygen (e.g. glass jars or paper bags). The essential oil is obtained by steam distillation of the whole dried herb.

Genetic resources Germplasm collections are available at several research institutes in Europe, e.g. at the Vavilov Research Institute of Plant Industry, St. Petersburg, Russia (58 accessions) and at the Gene Bank Department of the Research Institute of Crop Production, Olomouc-Holice, Czech Republic (27 accessions).

Breeding Little selection has been done in summer savory. In experiments, inter-plant variability in dry matter production is large, which is com-

monly observed in crops that have undergone little improvement.
As the effects of crop management on the oil content of summer savory seem limited, selection and breeding of improved plant types is important to obtain cultivars with higher oil content. In Poland for instance, a hybrid ('Saturn') of Yugoslavian and Polish material has been bred; it has a high oil yield (4.5% in air-dry herb) and relatively little stem material.

Prospects The present importance of summer savory in South-East Asia is limited. It is only grown on a very limited scale and is not used in traditional food and medicine. Although there may be some scope for production expansion because of the demand from European-style hotels, restaurants, and fast-food chains, this situation will probably remain. Production for international markets is probably not a viable option, because the produce will have to compete with production in temperate and subtropical regions with climates more similar to its natural habitat.

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Dzuong Duc Huyen & M. Brink

Sinapis alba L.

Sp. pl.: 668 (1753).
CRUCIFERAE
$2n = 24$ (genome SS)

Synonyms *Brassica alba* (L.) Rabenhorst (1839), *B. hirta* Moench (1802).

Vernacular names White mustard, yellow mustard (En). Moutarde blanche, moutarde jaune (Fr). Philippines: mustasa. Laos: sômz sien. Vietnam: b[aj]ch gi[ows]i t[uwr].

Origin and geographic distribution *Sinapis alba* originates from the eastern Mediterranean and the Middle East. It is grown for seed worldwide, production being important in Canada, Scandinavia and Hungary.

Uses The use of *S. alba* as a spice and medicine dates back to ancient Middle Eastern, Greek and Indian civilizations. The seed of *S. alba* is one of the main sources of condiment mustard, also named table mustard when produced for domestic purposes. German or Dutch mustard is made by adding vinegar to a coarsely ground mixture of brown mustard (*Brassica juncea* (L.) Czernjaew) or black mustard (*B. nigra* (L.) Koch) seeds (contributing the pungent principle) and white mustard seeds (contributing the hot principle). It has a milder taste than French mustard made from *B. juncea* or *B. nigra* seeds alone. In Europe and northern America, mustard used to be prepared in the home by rolling a special metal ball in a bowl of mustard seed and then mixing vinegar into the resulting crushed seed. Other herbs may be added according to taste and tradition and, for a milder taste, sugar, honey or starchy substances. There are numerous manufacturers' recipes. In cooking, mustard is mainly used to flavour meat dishes and sauces for meat, fish, salads, and snacks. Whole seeds of white mustard are used in the preparation of pickles and sauerkraut and to spice marinades for fish. The regulatory status of white mustard in the United States is 'generally recognized as safe' (GRAS 2761).
The fatty golden-yellow oil pressed from the seed is incorporated in mayonnaise and also used as lubricant and illuminant. The seedlings (mustard sprouts) are eaten raw in salads and sandwiches. Leaves are occasionally used as a potherb. In temperate climates *S. alba* is widely used as a late-sown green manure crop. Some cultivars decrease beet cyst nematode populations in the soil.
The seeds are used as a diaphoretic, diuretic, emetic, expectorant, irritant and stimulant. The seed oil is taken both internally and applied exter-

nally to treat tumours. Tea prepared from the seed is used to cure sore throat and to relieve bronchitis and rheumatism.

Production and international trade In world trade the mustards combined are by far the most important spice in volume, while in value they are second only to black pepper (*Piper nigrum* L.). Seed of *B. juncea* and *S. alba* account for about 40% and 60% respectively of the world mustard trade.

The major consumers of condiment mustard are the United States, Germany, France and the United Kingdom. Production of condiment mustard in Western Europe in 1985 was about 130 000 t, with consumption per head ranging from 0.3 kg (United Kingdom) to 1 kg (France). In 1994 216 000 t were produced in Canada on about 200 000 ha, about half of the mustard crops being white mustard. White-mustard seed fetches about US$ 650 per t. In the United States the annual production is about 6000 t, valued at US$ 1.4 million.

Properties Cruciferous plants are characterized by a range of glucosinolates or mustard-oil glucosides contained in the seeds and other tissues. The enzyme myrosinase also occurs in the tissues but only comes into contact with the glucosinolate when the tissue is damaged. Glucosinolates release volatile or oily isothiocyanates, through the action of myrosinase in the presence of watery substances. The glucosinolate of white mustard, called sinalbin, releases the mildly irritant, oily p-hydroxybenzyl isothiocyanate.

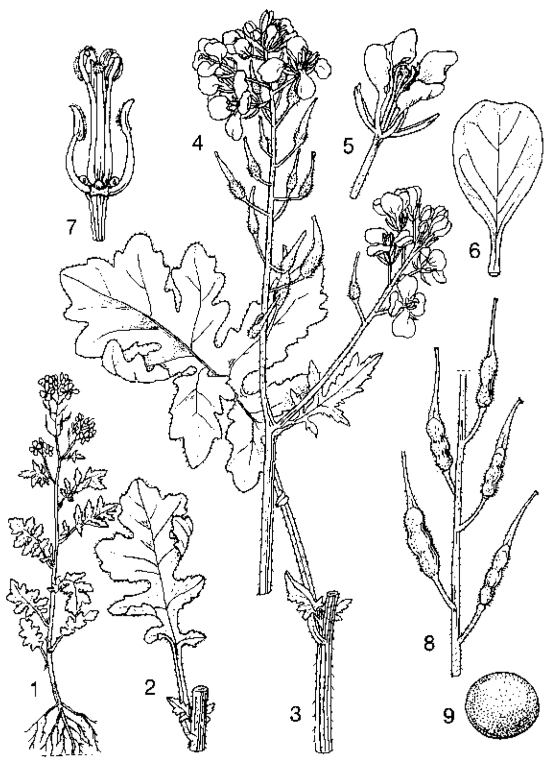
The glucosinolate content of the seed is about 140 μmol/g. Per 100 g edible portion seeds contain: water 5 g, protein 26 g, fat 36 g, carbohydrates 23 g, fibre 5 g, ash 4 g (Ca 0.4 g, P 0.6 g, Fe 21 mg), β-carotene equivalent 0.6 g, thiamine 0.4 mg, riboflavin 0.31 mg, and niacin 7.3 mg. Since the whole seed is used, condiment mustard is in fact quite a complete and nutritious food. The many medicinal properties should therefore not always solely be attributed to the quite overwhelming action of the isothiocyanates.

The oil of white mustard is rich in erucic acid, which is not appreciated in food oils but has several industrial applications.

The 1000-seed weight is 4–8 g.

Adulterations and substitutes Seed of wild mustard or charlock (*Sinapis arvensis* L.) has occasionally been used as an adulterant in poor-quality condiment mustard. Its brittle seed-coat may cause difficulties in milling.

Description Erect annual herb, 30–60(–120) cm tall, mostly sparsely hairy and with a thin tap-



Sinapis alba L. – 1, habit flowering and fruiting plant; 2, part of stem with lower leaf; 3, part of stem with central leaf; 4, flowering and fruiting branch; 5, flower; 6, petal; 7, stamens and pistil; 8, part of infructescence; 9, seed.

root. Stem ribbed, bristly, with hairs pointing downward, usually only branching in upper part. Leaves alternate, variable, central ones often largest; petiole longest in largest leaves; blade elliptical, ovate or obovate in outline, up to 15 cm long, divided deeply or even to the midrib into 1–3 pairs of lobes with irregularly crenate or dentate margins. Inflorescence an axillary or terminal, bractless raceme; flowers bisexual, about 1 cm long, yellow, 4-merous; pedicel 5–7 mm long; sepals 4, narrowly elliptical, 4–5 mm long; petals 4, obovate, up to 10 mm × 4 mm, narrowly clawed at base, bright yellow; stamens 6, outer whorl of 2 shorter, inner whorl of 4 longer ones; pistil slightly shorter than longest stamens, ovary elongated, sessile, style ending in a semi-globose stigma. Fruit a silique, 2–4.5 cm × 3–7 mm, each valve with 3 prominent ribs, lower part setose and seed-bearing with constrictions between the seeds, equalled or exceeded by the flat, mostly slightly curved beak, spreading and not shattering at maturity, containing 4–6 seeds. Seed subglobose, about 2 mm in diameter, pale yellow, minutely pitted. Seedling with epigeal germination.

Growth and development White mustard seed germinates immediately upon sowing, and then grows rapidly. Four stages can be recognized in the development of mustard crops. The seedling stage, lasting 7–10 days in which the aboveground plant consists of a hypocotyl and 2 green cotyledons, is followed by the vegetative stage of 3–4 weeks in which the plant develops a basal rosette of leaves. During the flowering stage the plant bolts, rapidly producing an indeterminate raceme with branch racemes opening 4–5 flowers per day for 3–4 weeks. The final seed-filling stage lasts 4–8 weeks and is terminated by senescence of the pods and plant. Pollination is by insects, e.g. various bee species and pollen beetles such as *Meligethes* spp. Because of the non-shattering nature of the fruit, the chance of white mustard developing into a weed is small.

Other botanical information There is some confusion in the literature about mustards. Botanically, 4 species are involved:

- *Brassica carinata* A. Braun: Abyssinian or Ethiopian mustard, gommenzer, $2n = 34$, BBCC genome. Only known as a cultivated plant from the highlands of Ethiopia and northern Kenya; scarcely used outside those areas.
- *Brassica juncea* (L.) Czernjaew: brown or Indian mustard, $2n = 36$, AABB genome. Is largely replacing *B. nigra* because it allows large-scale mechanical cultivation; in Asia, *B. juncea* has greatest importance as a vegetable and oilseed crop.
- *Brassica nigra*: black mustard, $2n = 16$, BB genome. Because mature fruits shatter their seeds this species is only suitable for hand-harvesting and is rapidly losing importance. It remains, however, one of the 3 basic diploid cultivated *Brassica* species in the famous *Brassica* triangle: *B. nigra* ($2n = 16$, BB genome), *B. oleracea* L. ($2n = 18$, CC genome) and *B. rapa* L. ($2n = 20$, AA genome), from which many *Brassica* crops are derived.
- *Sinapis alba* L.: white mustard, $2n = 24$, SS genome.

Brassica L. and *Sinapis* L. are closely related and difficult to distinguish. Some usually easy recognizable differences are: *Sinapis* has light green leaves, petals with short claws and fruits with bristles; *Brassica* often has grey-green leaves, petals with larger claws and smooth fruits.

Ecology Similar to the closely related *Brassica* crops, white mustard favours moderate temperatures for germination and early growth, and long days and high temperatures for flowering and seed-set. It requires high levels of N and grows best on sandy loamy soils. It does well in the conditions prevailing in the Canadian prairies where most of the commercial seed is produced. It occurs in areas where the annual precipitation ranges from 350–1800 mm, annual temperatures from 5–25°C, and soil pH from (4.5–)5.6–8.2.

Propagation and planting When selecting fields for growing white mustard, those infested with the weeds wild mustard (*Sinapis arvensis* L.), cow cockle (*Saponaria hispanica* (Miller) Rauschert), cleavers (*Galium aparine* L.) and volunteer *Brassica* crops should be avoided, as their seeds may spoil the quality of the mustard seed.

S. alba is propagated by seed. The robust seed will even grow in a poorly prepared seedbed. Seeds may be sown about 1 cm deep in rows 30 cm apart, or broadcast at a rate of about 12 kg/ha.

Husbandry The crop should be weeded until it has established. Nitrogenous fertilizer should also be provided at planting. Soil levels of P and K are usually adequate. White mustard is often grown as a break crop in rotations dominated by cereals, as its production can be fully mechanized, using the same equipment as for cereals.

Diseases and pests The crop is not known to suffer from major diseases, but it attracts a variety of insect pests, including flea beetles (*Phyllotreta* spp.) and aphids (e.g. *Brevicoryne brassicae*). Effective insect pest control can be achieved by using resistant cultivars, appropriate agronomy, crop rotation disinfected seed.

In some years the yeast *Nematospora sinecauda* is an important disease of stored grain. Severe infestation renders the seed unsuitable for human consumption. The yeast infection is initiated by the false cinch bug (*Nysius niger*), but spreads easily in stored grain. As few insects are involved in the initial infection, the only preventive action possible is to control the alternative host flixweed (*Descurainia sophia* (L.) Webb ex Prantl, synonym: *Sisymbrium sophia* L.).

Harvesting The crop is ready for harvesting 70–110 days after sowing, but in Europe long-duration crops that take up to 180 days to mature and give higher yields are grown. Fruit ripening starts at the base of the inflorescences and proceeds upwards. Since fruits do not shatter, the crop can be harvested late. It is usually combine-harvested.

Yield Annual seed yield of *S. alba* is about

500–1500 kg/ha, but may reach 2400 kg/ha.

Handling after harvest Threshing is only possible when the plants are thoroughly dry. The seed is sacked up together with an amount of husks to reduce relative humidity, which is important in controlling storage insects. The seed stores well.

Both dry and wet-milling processes are applied in industrial processing of mustard seed. In dry milling the seed-coat is usually partly removed (except in Japan), in wet milling the seed-coat of white mustard is usually left in the product. The variety of mustards produced is enormous, ranging from traditional cottage-industry products to newly designed 'regional' products for the tourist trade and to formulations which incorporate ingredients such as horseradish, beer, whisky or lemon peel. It is said that a new mustard product is launched on the United States market every week.

Genetic resources and breeding Germplasm collections are available at the national gene banks of the United States, Canada and the Netherlands. *S. alba* is cross-fertilizing and requires a recurrent population improvement breeding scheme to develop populations with improved ecological adaptation, but with a broad genetic variation for further improvement. This procedure has been successfully employed to develop a cultivar low in erucic acid. Breeding for improved levels of resistance to the beet cyst nematode and increased green-manure production is following the same method.

Prospects World consumption of mustard is slowly expanding and the present production centres will be able to increase supplies gradually. Prospects for production in South-East Asia seem limited to areas with a cool season with long days.

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H. Toxopeus & J.H. Lubberts

Stevia rebaudiana (Bertoni) Bertoni

Anales Cient. Parag., ser. 1, 5: 3 (1905).

COMPOSITAE

$2n = 22$

Synonyms *Eupatorium rebaudianum* Bertoni (1899), *Stevia rebaudiana* (Bertoni) Hemsley (1906).

Vernacular names Stevia, sweet herb of Paraguay, honey-yerba (En). Indonesia: stevia. Thailand: ya-wan. Vietnam: c[or] ng[oj]t.

Origin and geographic distribution Stevia originated from the Sierra Amambay in north-eastern Paraguay and possibly from adjacent areas in Bolivia and Brazil. The sweet principle of stevia is believed to have been used by the Paraguayan Indians for centuries. Stevia is now cultivated in parts of South America, but most widely in the Far East (China, Korea and Japan in particular). It is grown on a smaller or experimental scale in Thailand, Israel, Canada, United States, Mexico and Europe. In the early 1970s stevia reached Indonesia through seed imported from Japan.

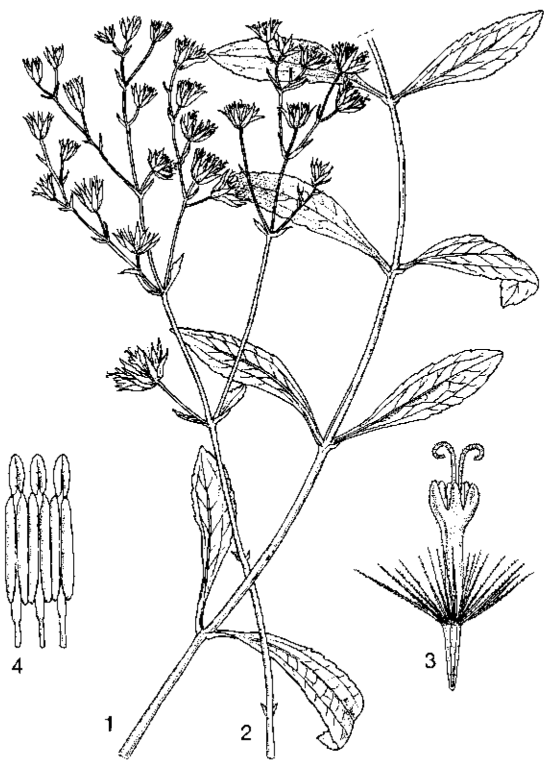
Uses In Paraguay and Brazil, fresh, or more usually dried, pulverized leaves of stevia are used as a sweetener in tea and maté or as a herbal remedy for diabetes. Some intense natural sweeteners can be extracted from the leaves, the most important being the steviol glycosides stevioside and rebaudioside A. In Japan, stevioside is used to increase the sweetening intensity or to reduce the energy value of other sweeteners. It is added to sugarless chewing gum to enhance sweetness and flavour. Stevioside can be added to sugar cubes to increase their sweetness without adding to their energy value. After a slow start in the 1970s, stevia is now used in a wide range of applications in Japan, e.g. in soft drinks, pickles, dried seafood,

flavourings and confectionery. It can also be used to modify and suppress flavour, for instance the pungent flavour of sodium chloride used in the preparation of soya sauce.
Stevia is now used as a food additive in the Far East, Malaysia, the Philippines, several countries in South America, Canada, the United States, Israel and the Ukraine and is being evaluated for approval as a sweetener in Europe and the United States. Experience of its use by humans and data from animal feeding trials indicate that it is probably safe for human consumption. Medicinally, replacing sugar in the diet with stevioside could alleviate some types of diabetes, obesity and could lower blood pressure. An aromatic resin in the plant has a tonic action on digestive organs. Crushed leaves are made into cosmetic products, such as facial masks used to invigorate the skin.

Production and international trade No production statistics are available for Paraguay and Brazil. Japan has developed stevia production since the 1950s, overcoming the problems of eliminating undesirable flavours by refining. In 1981, 650–750 t of dried stevia leaves were used for stevioside extraction; 60% of the leaves originated from Japan, 40% were imported from other Asian countries, mainly from China. In 1981, about 50 t stevioside was produced in Japan, in 1996 over 200 t in Japan and 700 t in China. In 1982, the stevioside price was US$ 90 000–130 000 per t (90% purity). In the United States the regulatory status 'generally recognized as safe' (GRAS) was accorded to stevia in the mid 1980s, but this was withdrawn in 1991 following reports that some chemical compounds from stevia or their derivatives might be harmful to humans. At the same time an aggressively formulated detention order and import ban was issued by the Food and Drug Administration. Rumours of pressure from the American sugar industry and manufacturers of chemical sweeteners such as aspartame, which incidentally was accorded GRAS status around 1991, persist. Following a change in general regulations in 1995, the import ban was lifted. Stevia is now permitted, but only for use as a dietary supplement. Its use as an industrial sweetener remains prohibited. Admission for use as a sweetener has also been applied for in Europe.

Properties Stevia owes its sweetness to a number of diterpene glycosides consisting of a steviol unit to which 3 or 4 glucose (or rhamnose) units are attached. The most important ones and their typical concentrations (on a leaf dry-weight basis) are stevioside 9%, rebaudioside A 4%, rebaudioside C 0.8% and dulcoside 0.3%. While the dried and ground leaves are about 30 times sweeter than sugar, the steviol glycosides are even sweeter, stevioside being 110–270 times sweeter, rebaudioside A 150–300 times, rebaudioside C 40–60 and dulcoside A about 30 times. In organoleptic tests rebaudioside A is preferred to stevioside, the latter having a slightly bitter after-taste. The steviol glycosides have excellent properties as domestic and industrial sweeteners: stevioside is stable in the pH range 1–9, only when heated at pH 10 does it disintegrate; it is stable up to at least 200°C, is non-fermentable, blends well with other sweeteners such as aspartame and glycyrhizin and does not darken upon cooking or storage (rebaudioside A may cause slight discolouration). Dried leaves keep their sweetening ability for a very long time. Herbarium samples tasted intensely sweet even 62 years after collection. All tests conducted indicate that stevia and its products are safe for humans. Acute toxicity tests indicated a LD50 of 8.2 g/kg. Doubts remain about its carcinogenic properties, because steviol is produced in the ceca (enlarged appendix) of mice and rats fed with stevia, and in an activated form it is suspected of being carcinogenic. The presence of steviol has been demonstated in the colon of humans who have taken stevia, but a review on the carcinogenity of stevia concluded that stevia is safe for use.
Stevia leaves also contain about 8% tannins, while the leaves and inflorescence contain 0.1% and 0.4% essential oil, respectively. The composition of the essential oil varies. In a sample tested the main components were the sesquiterpenes β-caryophyllene, trans-β-farnesene, α-humulene, δ-cadinene and the monoterpenoids linalool, terpinen-4-ol and α-terpineol. In other samples spathulenol, β-cubebene and γ-elemene were found as major components.
Stevia pollen can be highly allergenic.
The weight of 1000 achenes is 0.15–0.30 g.

Description A slender, erect, perennial herb, 50(–100) cm tall in natural stands and up to 120 cm under cultivation. Rhizome vigorous; root system shallow, with conical, hardly branched roots. Stem semi-woody, pubescent. Leaves opposite, subsessile, glabrescent; blade spatulate-lanceolate, 3–6.5 cm × 0.8–1.9 cm, faintly 3-veined, the margin crenulate above the middle. Inflorescence a terminal head, aggregated in panicles or small corymbs, with 2–6 flowers; involucral bracts 5, thin and narrow; flowers regular, 7–15 mm long, bisexual but self-incompatible; corolla tubular,



Stevia rebaudiana (Bertoni) Bertoni – 1, leafy twig; 2, flowering branch; 3, flower; 4, anthers.

5–6-lobed, white; stamens 5, connective of anthers ending in an oblong appendix; pistil with 2-lobed style, lobes curved at top. Fruit an angular, glandulose achene, crowned by a pappus of about 20, filiform, scabrid setae that are shorter than the corolla tube. Seed without endosperm.

Growth and development Light promotes germination of stevia seed. Germination takes place under warm (optimum temperature 20°C) and moist conditions 2–7 days after sowing. Seedlings are very sensitive to high temperature and water stress.

Growth is slow during the first 2 weeks, but speeds up during the next 2 months. The length of the period of vegetative growth depends on the planting material used and the photoperiod, stevia being an obligate short-day plant with a critical photoperiod of about 13 hours. Under the critical photoperiod, flowering occurs 50–60 days after sowing. In the case of a ratoon crop flowering may take place within 40 days after cutting. Long days promote leaf production. Older leaves have a higher content of steviosides. Flowers are self-incompatible. Cross-pollination is necessary for seed production.

The biosynthesis of steviosides is a complex process. Steviol synthesis starts in the mevalonic acid pathway and is closely related to the biosynthesis of gibberellins. It occurs in chloroplasts. Glycolysation of steviol occurs under the influence of operationally soluble enzymes and occurs outside chloroplasts. The glycosides are stored in the vacuole.

Other botanical information The genus *Stevia* Cav., confined to tropical and subtropical America, is badly known; species estimates range from 150–300. It is not known if other *Stevia* species than *S. rebaudiana* also possess sweetening properties; an investigation of some 110 species was negative.

A number of genotypes with anomalous glycoside proportions have been reported in Korea and Japan. Two named cultivars with a high rebaudioside content have been developed in Korea: 'Suweon 2' and 'Suweon 11'. They are based on single plant selections and need to be propagated vegetatively. Named cultivars have also been developed in China, e.g. 'Yuubin', 'Zhongpin 1' and 'SM4'.

Diterpene glycosides similar to steviol glycosides have also been isolated from *Rubus suavissimus* S.K. Lee ('sweet tea') from southern China.

Ecology The climate of stevia's native habitat can be characterized as subhumid (sub)tropical with an average annual temperature of 24°C. Average annual precipitation amounts to 1400–1600 mm. Stagnant water and very heavy, prolonged rain are injurious. Stevia occurs naturally on the edges of marshes or in grassland communities up to 700 m altitude, which are permanently moist but not subjected to prolonged inundation. It occurs naturally on soils with a shallow water table, particularly on infertile acid sands or muck with a pH of 4–5. However, stevia grows well on less acid to neutral soils with a pH of 6.5–7.5. It is sensitive to water stress and salinity.

Under cultivation stevia grows best in areas with a long frost-free growing season. Growth will be retarded severely below 15°C. High light intensities and high temperatures promote stevioside production. In Java (Indonesia), stevia is generally grown in mountainous areas with steep slopes, up to 1500 m altitude. Under lowland conditions stevia starts flowering too early.

Propagation and planting Stevia can be propagated by seed, stem cuttings and tissue culture. Since germination rates are poor and seedlings slow to establish, seeds are sown in a nursery. They are sown on a fine seedbed, shaded and covered with a transparent finely perforated polythene sheet. Germination starts within a week, after which the shade should be reduced gradually to harden off the seedlings. The plastic cover must be removed two weeks after sowing. At this time seedlings bear two pairs of leaves and can be transplanted individually into polybags and placed in the nursery. After 4 months in the nursery the young plants have grown to a height of 15 cm and can be planted out in the field.

Cuttings with 4–5 nodes, taken from the apical part of stem and branches, are used for vegetative propagation. Under constant high air humidity and with the use of growth regulators to stimulate root formation, 100% success can be reached after about 17 days. The stem cuttings are then planted in nursery beds and shaded with transparant polythene sheet which is secured on a bamboo framework. The plastic cover can be removed two weeks after planting. When cuttings are taken during the dry season the cover should be removed gradually. Planting out in the field can start at the end of the third week.

In West Java, rooted cuttings are used as planting material, and planting distance in the field is 25 cm × 25 cm, giving 160 000 plants/ha. In Japan, spacing is 50 cm × 60 cm, giving 33 000 plants/ha. Research in Paraña (Brazil) showed that plant densities of 50 000, 80 000 and 100 000 plants/ha did not influence leaf yield in the first year. The highest seed yield, however, was obtained with 80 000 plants/ha.

Recently, a simple and rapid method for vegetative multiplication has been developed by means of in vitro culture: nodal segments of stems are incubated on an artificial growing medium, giving rise to new plants.

In vitro production of active compounds Stevioside can be synthesized in the laboratory.

Husbandry There is little information about cultural practices to make commercial cultivation of stevia more efficient. Weeding is carried out either manually or chemically, using pre- or post-emergence herbicides. In West Java, weeding is preferably performed manually, to prevent possible negative effects of chemicals on the quality of the product; this makes maintenance very labour-intensive.

Irrigation, if necessary, must be regular and shallow, using good-quality water low in salts. Surface irrigation is very suitable, especially during the dry season. Sprinkler irrigation is also practised in Indonesia.

Stevia responds well to farmyard or liquid organic manure. Nutrient uptake per t dry matter is 20–25 kg N, 2–2.5 kg P and 25–30 kg K. Application of fertilizers benefits the leaf dry matter production but not the stevioside content of the leaves. Flower-heads that appear before harvest are removed.

Diseases and pests No serious diseases and pests of stevia are known. In Indonesia 2 pathogenic fungi (*Colletotrichum* sp. and *Sclerotium rolfsii*) have been isolated from a stevia stand in West Java, and in Japan a black leaf spot on stevia was caused by *Alternaria steviae*. In Canada, the most important diseases are *Sclerotia sclerotiorum* rot and *Septoria steviae* leaf spot.

In Indonesia army worms (*Heliothis* spp.) occasionally destroy young leaves and flowers, especially in the highlands. In the lowlands, *Aphis* may destroy young shoots and leaves.

Harvesting Stevia is harvested just prior to flowering when the steviol-glycosides content is highest. First harvest takes place 2 months after planting. The second and following harvests are carried out at intervals of 1 month. Stems and branches are cut at a height of at least 15 cm above the ground; cutting lower gives a high percentage of mortality. Harvesting may continue for a period of 5–6 years.

Yield Dried leaf yields are estimated at 1.5–2 t/ha for Brazil. In Japan, yields in the first year (two harvests) are 400–500 kg/ha. Yields in the second and the third years vary from 1.5–2 t/ha of dried leaves, which is equivalent to 50–75 t/ha of sucrose sugar. In West Java annual yields of 3 t/ha of dried leaves are possible. Seed yields of 8 kg/ha are possible.

Handling after harvest The leaves are separated from the stems by hand and kept in plastic bags at room temperature before drying. Alternatively, the whole plant is dried and leaves are separated by threshing. Stems have a very low glycoside content and are removed to reduce processing costs. The method of drying is of great importance for the quality of the product. Drying can be done in the sun or, during the rainy season, mechanically in a ventilated desiccator. To remove any undesirable taste notes and increase resistance to crumbling and agglomeration during packaging, the leaves are first steamed for 1–2 minutes at 125–130°C, partially dried to 60–63% moisture, rotated at 60–65 rpm, and dried again for 5–7 hours at 75–85°C.

For export, dried leaves should meet the following standards: maximum moisture content 10%, minimum stevioside content (including rebaudioside A) 11%, and no more than 11% impurities. Dried leaves can be stored and transported in plastic bags or in airtight drums.

Several commercial methods of extracting the glycosides from the leaves have been developed and patented in Japan. They mostly involve water or solvent extraction, decolouration and purification using ion-exchange resins, precipitation or coagulation, followed by filtration, crystallization and drying. Newer methods based on ultra-filtration have also been developed.

Genetic resources Due to the removal of the natural vegetation, gene centres of stevia are threatened with destruction. There are germplasm collections of *S. rebaudiana* in Japan, Korea and Indonesia.

Breeding Main objectives of breeding work on *S. rebaudiana* in China, Japan, Korea and Canada are to increase leaf yield and glycoside content, and to increase the ratio of rebaudioside A to stevioside. Heritability for these factors is high. A total sweet-glucoside content of 20% has been reported from China and a ratio of rebaudioside A to stevioside of 9:1 from Japan. Stevioside and rebaudioside A content appear to be inversely correlated.

Prospects Stevioside has not yet been officially approved as a sweetener by the Food and Drug Administration (FDA) in the United States and by the West European countries. If approved, the demand for stevia may increase dramatically. In that case there are good prospects for Indonesia and other South-East Asian countries as suppliers of stevia leaves. Although there will be competition from temperate countries, higher glycoside contents can be obtained in the tropics. Research is needed on weed control, water management, fertilization, labour requirements and efficiency of harvest. Moreover, breeding and selection for higher content of steviosides and higher leaf-to-stem ratio are desirable.

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Syzygium aromaticum (L.) Merrill & Perry

Mem. Am. Acad. Arts & Sc. 18: 196 (1939).

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Synonyms *Caryophyllus aromaticus* L. (1753), *Eugenia aromatica* (L.) Baill. (1876), *E. caryophyllus* (Sprengel) Bullock & Harrison (1958).

Vernacular names Clove (En). Clou de girofle (Fr). Indonesia: cengkeh. Malaysia: chengkeh, chingkeh. Philippines: klabong pako, clavo de comer. Burma (Myanmar): lay-hnyin. Cambodia: khan phluu, khlam puu. Laos: do:k chan, ka:nz ph'u:. Thailand: kanphlu. Vietnam: dinh h[uw][ow]ng.

Origin and geographic distribution The clove tree was first cultivated on some islands of the Moluccas, where it occurs wild, as well as in New Guinea. It is found in abundance as a second-storey forest tree on the lower mountain slopes. The crop and its trade has a long and fascinating history going back to the Han Dynasty in the 3rd Century BC. The story of the clove trade and the spread of the crop is full of intrigue and brutality.

Apart from pepper (*Piper nigrum* L.), no other crop may have played a comparable role in world history.

Early in the 17th Century, when the Dutch ousted the Portuguese from the Moluccas, clove cultivation had spread to many islands. Under Dutch rule, the crop was forcibly eradicated everywhere and concentrated on Ambon (a southern island of the group) and 3 nearby small islands. This is the wettest part of the Moluccas. From the Moluccas the clove tree was taken to other parts of Asia: early in the 19th Century the British took plants to Pinang (Malaysia), Sumatra (Indonesia), India and Sri Lanka. In the 20th Century, much material spread throughout Indonesia. During expeditions in 1753, 1770 and 1772, the French appropriated some offspring from trees that must have escaped the Dutch axe, and took them from the North Moluccas to Mauritius. These plants gave rise to the clove populations outside Asia, in Zanzibar, Madagascar and recently also in Bahia in Brazil.

Uses Since ancient times, the clove has been highly valued as a spice by the Chinese. In the early Middle Ages the spice became increasingly important in Europe and also in India, where to this day betel quid is fastened with a clove. In South-East Asia, however, the clove is not much used to flavour food; medicinal use of both the clove (the flower bud) and the mother-of-clove (the fruit) has always predominated. Cloves suppress toothache and halitosis; they are also a stimulant and carminative.

Now, more than 90% of the cloves are used along with tobacco to produce 'kretek' cigarettes, which are smoked mainly in Indonesia. It is not known where the habit originated. Rumphius reported it from the Moluccas in the 18th Century. He also described the curing of cloves over small fires. Perhaps it was not a great step from inhaling the smoke of the fires to the smoking of tobacco mixed with clove.

When used as a spice, the dried clove buds are added to the food as such or after grinding, or the oleoresin is extracted to standardize the flavour (for use, for instance, in manufactured foods).

Distillation of cloves yields an oil that is used in the flavouring and perfume industry. Lesser quality oils are distilled from the flower stalks ('clove stems'), a by-product of the clove harvest (Zanzibar), and from the leaves (Madagascar, Indonesia). The major component of the oil is eugenol, formerly used to produce vanillin. Because of its flavour and antiseptic properties, eugenol is used in soaps, detergents, toothpaste and pharmaceutical products. The oil is also a potent bactericide and nematicide. It is indicated for inflamed oral and pharyngeal mucosa and is used for topical anaesthesia in dentistry.

In the United States the regulatory status 'generally recognized as safe' has been accorded to cloves (GRAS 2327), clove bud oil (GRAS 2323), clove bud oleoresin (GRAS 2324), clove stem oil (GRAS 2328) and clove leaf oil (GRAS 2325).

The tree's timber is hard, heavy and durable, but, with its dull greyish colour, it is not decorative.

Production and international trade For over a hundred years, Zanzibar was the largest producer of cloves, with an average annual production of 11 000 t from 1960–1970, compared with 9000 t for Indonesia and 6000 t for Madagascar. During that decade, there was a remarkable expansion of the area under cloves in Indonesia, spurred by the rapidly rising demand for 'kretek' cigarettes. From 8200 ha in 1951, the area rose to 80 000 ha in 1971, jumping to more than 500 000 ha in 1981 and nearly 750 000 ha in 1987.

The clove tree caught the fancy of small farmers, who called it 'the 100 000 rupiah tree' and planted a few clove trees in the hope of striking rich one day. However, about half the trees never reached bearing age; production picked up slowly and did not peak until around 1996 when the declining area was reported to be 495 000 ha. In that year production was a phenomenal 90 000 t, but this was only just enough to meet the demands of the cigarette industry (which showed signs of levelling off).

Demand for all other uses worldwide has been stagnant for a long time at 4000–5000 t per year. In the rest of Asia annual production of cloves, including stems, averaged 2750 t over 1996–1998; in Africa during the same period, Madagascar produced 15 000 t, well above Zanzibar's 6000 t. The yield of clove stems is roughly one-fifth that of clove buds. To some extent stems are used as a cheap substitute for buds.

Clove prices have fluctuated wildly throughout the long history of the crop. It takes a long time before growers respond to high prices and even longer before the trees come into bearing, causing a glut. The increasing popularity of 'kretek' cigarettes kept prices high, but during the 1990s production caught up with detrimental results: in New York cloves fetched US$ 11 per kg in 1982 compared with US$ 1.25–1.45 per kg in 1996 and 1997 (for cloves from eastern Africa; top grade cloves from Sri Lanka fetched US$ 3.30 per kg).

However, dwindling stocks and declining production in Indonesia may reverse the trend.

Properties The quality of the spice is determined by its essential oil content and composition. The clove tree produces 3 different types of essential oils: from the flower buds (content 15–17%), from the flower stems (content 6%) and from the leaves (content 2–3%). The major components of those essential oils are eugenol (80–95%), eugenyl acetate (1–5%) and β-caryophyllene (4–12%); the quality of the oil is determined by the varying proportions of those components and of minor and trace components, and is influenced by origin, season, maturity at harvest, post-harvest treatment and method of distilling of the original product. In general, the best quality oil originates from the flower bud, second best from the flower stem, third from the leaf.

Clove bud oil is a clear, colourless to yellow liquid (turning browner with age) with a strong characteristic sweet and spicy clove odour and a warm, almost burning and spicy flavour. Its main components are *eugenol* 70–90%, *eugenyl acetate* up to 17% and β-caryophyllene 5–12%. It stores well in light-proof containers. Clove bud oil is used in seasonings, processed food, perfumery and to a lesser extent in pharmaceutical and dental preparations.

Clove bud oleoresin is obtained by solvent extraction of cloves. The yield is 18–22% oleoresin (90–92% volatile components) using benzene and 22–32% using alcohol. Supercritical fluid techniques are currently used at an industrial scale. The oleoresin is a viscous brown liquid which can deposit waxy particles on standing. The odour and flavour are regarded as superior to distilled oil and much closer to the natural spice. The main advantages of oleoresin over dry spice are little risk of bacterial contamination and standard strength and quality. It is increasingly being used in the food and perfume industries.

Clove stem oil is a colourless to light yellow liquid with a strong spicy somewhat woody odour similar to clove bud oil but less sweet and floral. Its eugenol content is 90–95%, but it has a low eugenyl acetate content. Clove stem oil is used mainly in flavouring and perfumery.

Clove leaf oil (crude) is dark brown, often with a purple or violet tinge, somewhat cloudy and with a harsh, woody, phenolic, slightly sweet odour, quite different to that of clove bud oil. Rectified (redistilled) oil is clear pale yellow with a sweeter, less harsh, odour, closer to that of eugenol. The oil is obtained by steam or water distillation of fresh or dried leaves, but also often including twiglets, undersized buds and opened flowers. The oil may vary considerably in composition but eugenol content is usually 80–88%, eugenyl acetate content low, caryophyllene content high. The leaf oil is mainly used for eugenol and caryophyllene production. Rectified oil is used in less expensive perfumes and soaps. The leaf oil is not well suited for food flavouring because its harsher note does not reproduce the genuine clove flavour.

Monographs on the physiological properties of clove bud oil, clove stem oil, and clove leaf oil have been published by the Research Institute for Fragrance Materials (RIFM).

Adulterations and substitutes The usual adulterants of clove bud oil are clove stem or leaf oil, or the clove terpenes remaining after eugenol extraction. Such adulterations are difficult to detect analytically; for use in flavourings or perfumery, organoleptic evaluation is necessary.

Synthetic clove oil sometimes replaces clove bud oil, especially when prices are high because the natural product is in short supply.

Eugenol, the main product obtained from clove leaf oil, can be isolated from a variety of starting materials (e.g. cinnamon leaf oil) and can also be manufactured synthetically.

Description Slender, evergreen tree, up to 20 m tall, conical when young, later becoming cylindrical, in cultivation usually smaller and branched from the base. Roots form an extensive dense mat close to the surface with some major laterals, from which occasional 'sinker' roots descend. Shoot growth determinate, appearing in flushes, forming a dense canopy of fine twigs. Leaves opposite, simple, glabrous; petiole 1–3 cm long, reddish, somewhat thickened at base; blade obovate-oblong to elliptical, 6–13 cm × 3–6 cm, base very acute, apex acuminate, coriaceous, shining, gland-dotted. Inflorescence terminal, paniculate, about 5 cm long, with 3–20(–40) bisexual flowers, usually borne in cymose groups of 3; flower buds 1–2 cm long, constituting the cloves just before opening; calyx tubular, tube subterete to subquadrangular, 1–1.5 cm long, yellowish-green with a red flush, slightly protruding beyond the ovary (hypanthium), with 4, ovate-triangular, fleshy lobes 2–4 mm long; petals 4, coherent, tinged red, rounded, 6 mm in diameter, shed as an hemispherical calyptra as the flower opens; stamens numerous, up to 7 mm long; pistil with 2-celled ovary, style 3–4 mm long, stigma 2-lobed. Fruit (called mother of cloves) an ellipsoidal-obovoid berry, 2–2.5 cm long, dark red, usually containing only 1 oblongoid seed 1.5 cm long.

Syzygium aromaticum (L.) Merrill & Perry – 1, branches with flower buds and flowers; 2, a clove.

Growth and development Seedlings are raised immediately after harvest, because the seed loses its viability within a few weeks. The young plants grow slowly and are quite delicate. Losses are high until the young trees are firmly established. Under favourable conditions, the juvenile phase lasts about 4 years. Clove yields increase until the tree is about 20 years old, and good yields can be produced until a great age. However yield fluctuates wildly, a heavy crop usually being followed by 2 or 3 light and mediocre crops before another bumper crop is produced.

High or low yields occur simultaneously over an entire region and there is much evidence that a well-marked dry season triggers a heavy crop. Subsequent low yields cannot be due to exhaustion, since the tree is relieved of its natural task of bearing a crop of fruit to maturity; in fact, the dry matter in a heavy crop of inflorescences is only in the order of 10 kg per tree.

Flower initiation seems to take place only in mature shoots that have been quiescent for several months. Thus the shoot-growth pattern in the course of the year governs flowering, and it is surprising that the annual growth rhythm of the clove has hardly been studied. Even the timing of flower initiation and the process of floral differentiation are not clear.

The crop cycle starts with a major flush as soon as the rainy season has settled in. Well before this flush, there is a first indication of the coming crop: rather suddenly the plump, light-green, floral, terminal buds can be distinguished from the pointed reddish vegetative shoot tips which will leaf out during the flush. The inflorescences emerge from the green terminal buds a few weeks after the leaves of the flush have turned green. The inflorescences expand in a series of well-defined stages. First a trident is formed; thereafter the inflorescence branches further, largely in multiples of three, until the proliferation of the inflorescence is complete. The extent of branching varies and strongly affects the size of the crop. In the penultimate stage each flower primordium assumes the typical clove shape. Reversal of floral primordia into leaf primordia sometimes occurs during the early stages. It takes 6–8 months before the flower buds are ready for harvest, an extraordinarily long time in a tropical tree crop. If the tree is not harvested, the fruit matures 3 months later.

Minor flushes of leafy shoots occur at irregular intervals, but in bearing trees, flushing stops in the last few months before harvest. Hence the leaves senesce, and as more leaves fall, the ratio of tops to roots drops. This stimulates renewed flushing after harvest, which is further encouraged by the loss of branches during harvest, which is often severe. The post-harvest shoots are too young for flower induction; moreover, buds or shoots on twigs that have flowered do not as a rule produce flowers for the next crop, resulting in a form of biennial bearing at the shoot level which also occurs in some mango cultivars.

Thus the next crop has to be borne on shoots that emerged early in the cycle and not as laterals of flowering twigs. After maturing into twigs, these shoots bear the buds which are receptive during the dry season when floral induction occurs. If virtually all twigs bear cloves, the bumper crop is followed by crop failure, simply because there are hardly any receptive buds on the tree. The poor crop in the third year can be attributed to the disturbed shoot growth pattern in the second year. Shoot growth does not suffer competition from the developing crop during the off-year; hence flushing becomes more erratic and continues until late in the season. This may again result in a shortage of receptive buds at the crucial time for flower initiation and hence in a disappointing crop in the third year. This explains the cycles of 3 or 4 years. So, in order to produce regular crops, only half the twigs should flower each year. Increases in yield should come from bigger inflorescences, which is a matter of genetic constitution, healthy foliage and timely induction of flowering. Regular bearing in clove is more difficult to achieve, since there is no fruit to assist in stabilizing the growth rhythm and because the tree is severely damaged during harvest. Note that biennial bearing has been observed in young trees, with their greater vitality and ease of harvesting, whereas from the 14th year after planting, the year with the first heavy crop, bearing becomes triennial. It might be possible to suppress late flushing during the off-year by root pruning or application of growth retardants.

This description of clove phenology, based on fragmentary published information, needs verification by field observations. In East Java, for instance, some trees in a plantation have been reported to exhibit profuse return bloom on twigs that had flowered the previous year. In this case small inflorescences emerged from mixed buds which, on breaking, first produced a pair of leaves. These mixed lateral buds were found just below the point of removal of the previous year's inflorescence. It remains to be shown whether these trees are indeed more regular in bearing and, if so, whether this is worthwhile given the expense of picking small inflorescences.

Other botanical information In the past, *Syzygium* Gaertn. has frequently been united with *Eugenia* L. Convincing differences in the structure of flowers and seeds have strengthened the arguments for two separate genera, which means that the clove is assigned to *Syzygium*.

The tree populations in Zanzibar and Madagascar are rather uniform, but in Indonesia three types are distinguished: 'Siputih', 'Sikotok' and 'Bunga Lawang Kiri'; the latter is thought to be identical with the Zanzibar type. The types differ in tree habit, leaf size, and clove size and colour, but few trees are true to type; transitional forms are common. 'Siputih' produces large cloves, valued in the spice trade, but is said to be less productive than the others. In Indonesia, young trees are mainly of the reintroduced Zanzibar type.

Ecology Notions about the ecological requirements of the clove vary, perhaps because of an underlying dilemma: a climate with a marked dry season promotes flowering, but the tree does not cope at all well with stress. There are two ways out of this dilemma. The first is to choose a climate with a pronounced dry season (Zanzibar, East Java), but to limit stress by going for deep fertile soils, providing water and shade during the early years. The other way is to choose a wet climate with a short dry season (Madagascar, Sumatra, Pinang).

The choice is linked with the use of the produce. Cloves from wet areas are less suitable for making cigarettes, since the smoke becomes pungent and there is no crackling ('kretek') sound during the smoking. In Indonesia, cloves for 'kretek' cigarettes are said to require 3 months in which the monthly rainfall is less than 60 mm, whereas for cloves to be used as spice, rainfall should not drop below 80 mm in any month. Annual rainfall should exceed 1500 mm; wet clove areas usually receive 3000–4000 mm. With mean temperatures of 21°C in July and August, Madagascar is the coolest clove country, reaching to the Tropic of Capricorn.

Cloves are almost exclusively grown on islands, but proximity of the sea may not be as necessary as it was once thought to be, nor is the crop restricted to the lowlands. In parts of Sumatra and Java, and in the Nilgiri Hills in south India, cloves are grown successfully far from the sea and at altitudes of 600–900 m. Sheltered sites are preferred, because wind causes additional stress, and strong winds are not tolerated. Shade is necessary for young trees until they are firmly established.

Growth can be sustained on poor and acid soils, but waterlogging is very harmful. Adequate depth of soil is essential and water-holding capacity should be in keeping with the severity of the dry season; if not, irrigation is needed.

Propagation and planting Cloves are propagated by seed. Seed from selected mother trees is extracted from the fresh fruit and germination follows in 2–6 weeks. Seedlings are raised in shaded nursery beds and respond to care: controlled watering, excellent drainage, adequate spacing for sturdy growth, and timely hardening-off by reduced shading and watering. Plants should reach a height of more than 50 cm within one year and should be moved to the field before they get much older. During transplanting, speed, protection of the root system and trimming of the shoots greatly increase the chance of survival.

Propagation trials in the control programme for 'Sumatra disease' in Indonesia have shown that clove can be propagated by air layering (50% success) and approach grafting (more than 80% success), but the results of propagation by cuttings and less cumbersome grafting techniques are still too poor for general use. Approach grafts on rootstocks of, for instance, *Syzygium pycnanthum* Merr. & Perry and *Psidium guajava* L. have also been successful. Progress in tissue culturing is slow and has not yet resulted in in vitro propagation.

Trees are planted in the field under temporary shade. In the dry season, young trees may need extra water. The standard spacing is 8 m × 8 m, but smallholders often plant much closer. A range of spacings from 6 m × 8 m to 8 m × 11 m, to take account of differences in site quality, seems better; the rectangular pattern facilitates intercropping in the early years. Banana and cassava are common intercrops. Intercrops may also provide shade but, near the young clove tree, shade trees such as *Erythrina*, *Gliricidia* or *Leucaena* species are preferred, since these can be pruned to even out irradiance through the year.

Husbandry When the intercrop is phased out, husbandry is often limited to weeding once or twice a year. Careful weeding limits root damage but a more positive approach is to improve the topsoil by mulching under the trees and by cover crops (e.g. *Centrosema pubescens* Benth., *Vigna hosei* (Craib) Backer). There is evidence that the equilibrium of top to root is quite delicate. The trees recover with great difficulty from undue loss of leaves. So, all efforts to keep the topsoil in good condition assist in preventing root stress and maintaining a healthy foliage.

Manure or fertilizers are applied to each tree according to age. Results of trials with nutrients were inconclusive, perhaps because nutrition was related directly to yield; it would be more logical to measure growth response and to interpret the yield response on the basis of the growth reaction. In Indonesia, trees respond to nitrogen and, on poor soils, to potassium; liming is recommended to raise the pH above 5.5.

Diseases and pests In both Zanzibar and Indonesia, the clove is threatened by diseases that kill the tree. Identification of the causal agents has been difficult amidst tree decline through non-parasitic forms of stress.

'Sumatra disease' is the main problem in Indonesia, killing up to 10% of the mature trees each year in parts of Sumatra and West Java, with an estimated annual crop loss of US$ 25 million. A tenacious research effort identified *Pseudomonas syzygii* as the cause. The bacteria live in the xylem vessels and apparently spread upwards from the roots. The symptoms are dieback, starting in the crown, vascular discolouration and root decay. Injections of oxytetracycline, the most effective antibiotic treatment, delay the decline but cannot cure the tree. Since then, it has been found that *Hindola striata* and possibly *H. fulva* act as vectors. Nearby forest is an important source of these tiny insects (tube-building cercopids of the family *Machaerotidae*), but they can complete their life cycle on the clove tree. This opens up prospects for the control of the disease: in the 1990s researchers identified egg parasites of *Hindola* and tested insecticides for specific action on *Hindola*; plants infected with non-virulent strains of the bacterium have been found to be immune to the virulent strain. Resistant clove cultivars have not been found, but grafts on resistant related species are being tested.

Leaf blister blight, named 'cacar daun' in Indonesia, is second only to Sumatra disease in the loss of crop and trees it causes. The causal fungi are *Phyllosticta syzygium* and *Guigordia hevea*. Fungicides can be effective, but research into the biology of the fungi, occurrence of resistence, etc. is needed to control the disease efficiently. A number of fungi and parasitic algae cause leaf spots; other fungi are involved in root decay.

Insect pests recorded on clove include stem, branch and twig borers, root feeders, a few sucking insects and caterpillars. However, crop losses are largely incidental, recurrent damage being caused mainly by borers. Termites may cause havoc in a young plantation and the fiery red tree ants make life difficult for the clove pickers.

Harvesting At harvest, the complete inflorescence is picked, just before the first buds are about to open. Earlier picking reduces yield, and undersized cloves spoil the appearance of the produce; late harvesting means a sharp drop in oil content and spice value. The right stage for harvesting lasts only a few days, and a tree is picked 3–8 times in a season. The timely harvest of a good crop demands skilled management; often a substantial portion of a bumper crop is not harvested at all. Pickers equipped with baskets, ropes and crooks to pull the branches towards them climb the trees, or they use ladders with props. An experienced picker harvests some 40 kg of green cloves from good trees in a day. Improvements in harvesting equipment based on work study are needed to reduce damage to the tree and to raise efficiency.

The harvest season shifts substantially from year to year, apparently in response to timing and severity of the dry season. There may also be freak off-season crops. In South-East Asia, the main season ranges from May–June in East Java to November–December in Ambon and Pinang. Migrant workers follow the maturing crop through some of the major areas of production.

Yield Yield varies so much from tree to tree and year to year that it is practically impossible to give normal values. It is clear, however, that yields are low. Dividing the production in Indonesia in 1996 by the area gives a yield of 200 kg/ha: about 1 kg of dried cloves per tree! However, this figure includes non-bearing young and decrepit trees. More precise is the series of production data from a large trial in Cibinong, West Java, planted in 1956. Over the 10-year period 1968–1977, mean annual production was consecutively 5.7, 0.0, 9.7, 4.6, 0.7, 10.3, 0.0, 2.0, 6.3 and 1.3 kg per tree; the overall average amounted to 4.1 kg per tree. Top yields of 50 kg have been reported for individual trees in different parts of the world, and an average yield over a 5-year period of 16 kg/tree/year for an outstanding group of trees in Pemba (Zanzibar).

Handling after harvest After harvest, the inflorescences are separated into buds and 'stems' (the flower stalks) and dried in the sun for several days. The dry weight of buds and stems is about a third of fresh weight. The dried product is sold in bags. An increasing portion of the clove production is being used for essential-oil and oleoresin production by hydrodistillation or steam distillation or by solvent extraction.
For distillation of the leaf oil, fallen leaves may be gathered every 2–3 weeks. The yield is about 1.5 kg of sun-dried leaves per tree each time. It is more common, at least in Madagascar, to cut and bunch small branches, which are taken to the still. Regular pruning of closely planted hedges is recommended for this manner of harvesting; the clove yield is then negligible. It takes about 60 kg of prunings to produce 1 kg of oil.

Genetic resources Germplasm of clove has been collected in Indonesia, but little information is available on the collections. Naturally set seed results mostly from cross-pollination, but the floral biology of the clove also favours self-pollination and fairly uniform populations developed in the areas where only a few trees were introduced initially. The eradication of the trees in nearly all places in the Moluccas may have decimated the germplasm in the cultivated clove and widened the gap from the wild cloves. Wild cloves are hardier and more vigorous, but they are hardly aromatic. Perhaps aromatic trees occur only sporadically in wild populations but they are easy to recognize; so their seed may have been collected for cultivation through the ages.

Breeding Hybrids of wild and cultivated cloves are similar to the wild parent. Hence the only direct way to widen the genetic basis is to trace clove populations descended from trees that escaped the eradication campaign (e.g. in New Guinea). Presumably the Zanzibar type is such a population. Hybrids between trees from Zanzibar and Indonesia are superior to both parents in both vigour and yield in the early years. Clonal propagation of selected mother trees may result in a breakthrough in productivity; early results in East Java show that rooted cuttings exhibit the same outstanding yield features as the mother trees.

Prospects The world powers no longer wage war for the control of the clove trade. The clove has become very much an Indonesian crop and product. The spectacular developments in that country during recent decades have subsided into a more stable situation. Much depends on the future demand for cloves for the cigarette industry, as world demand for the spice and the oil are unlikely to change much.
If a reasonable price level is restored, there is much scope for agronomic improvements:
- Further segregation (in respect of growing conditions and crop care) of production for the cigarette industry, for use as a spice and for distillation of leaf oil.
- Control of Sumatra disease and leaf-spot.
- Clonal propagation of superior trees, cutting out the juvenile phase.
- Manipulation of the growth rhythm to reduce yield fluctuations and to extend the harvest season.

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E.W.M. Verheij & C.H.A. Snijders

Syzygium polyanthum (Wight) Walpers

Repert. bot. syst. 2: 180 (1843).

MYRTACEAE

$2n$ = unknown

Synonyms *Eugenia polyantha* Wight (1831), *E. nitida* Duthie (1878), *E. balsamea* Ridley (1922).

Vernacular names Salam, Indonesian bay-leaf (En). Indonesia: salam (general), manting (Javanese), ubar serai (Sumatra). Malaysia: samak, kelat samak, serah. Cambodia: pring srâtoab. Thailand: dokmaeo (peninsular), daengkluai (central), mak (Chumphon, Ranong). Vietnam: s[aws]n thuy[eef]n.

Origin and geographic distribution *S. polyanthum* is widely distributed in Burma (Myanmar), Indo-China, Thailand, Malaysia, and Indonesia (Java, Sumatra, Kalimantan).

Uses The aromatic leaves of salam, either fresh or dried, are used as a spice in many South-East Asian meat, fish, rice and vegetable dishes. Its use is comparable to that of laurel leaves (bay-leaves) in European cuisine. The leaves are added early on and are left to cook with the dish, as the flavour develops only gradually. Ripe fruits are edible, although slightly astringent.

Leaf and bark extracts are used medicinally against diarrhoea. Pounded leaves, bark and roots are applied as poultices against itches. The bark is used for tanning fishing-nets and for dyeing bamboo matting brown-red (for further blackening the matting is subsequently immersed in mud). Timber of *S. polyanthum* belongs to the trade group 'kelat', which is a medium-weight to heavy hardwood. It is used for house building and furniture.

Production and international trade No statistics are available on production and trade. Production and local trade is considerable because, for example in Indonesia, young leaves are sold on almost all local markets and by street vendors, and the bark is extensively used for dyeing purposes.

Properties Dried salam leaves contain about 0.17% essential oil. Eugenol and methyl chavicol are important components. Ethanolic extracts of the leaves show antifungal and antibacterial activity, methanolic extracts show strong nematicidal activity against the pine-wood nematode *Bursaphelenchus xylophilus*.

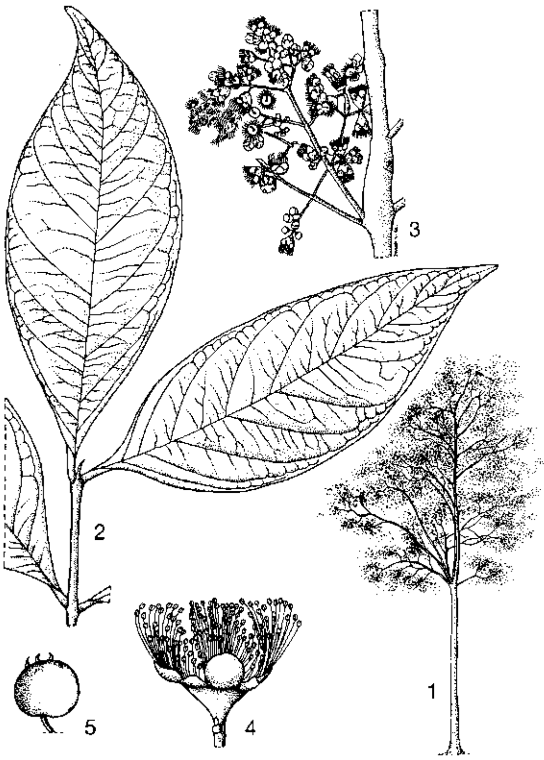
The wood is pale brown to pinkish-brown with a purplish tinge; the density is 540–790 kg/m^3 at 15% moisture content.

Adulterations and substitutes In South-East Asia, salam leaves are used as a substitute for the laurel leaves of European cuisine. Salam leaf oil can be distinguished from laurel leaf oil by its optical rotation, salam leaf oil being dextro-rotatory, laurel leaf oil laevo-rotatory.

Description Medium-sized tree up to 30 m tall with dense crown, bole up to 60 cm in diameter; bark surface fissured and scaly, grey. Leaves opposite, simple, glabrous; petiole up to 12 mm long; blade oblong-elliptical, narrowly elliptical or lanceolate, 5–16 cm × 2.5–7 cm, with 6–11 pairs of secondary veins distinct below and a distinct intramarginal vein, dotted with minute oil glands. Inflorescence a panicle, 2–8 cm long, usually arising below the leaves, sometimes axillary, but trees flower very profusely; flowers sessile, bisexual, regular, fragrant, white, in threes on ultimate branchlets of the panicle; calyx cup-shaped, about 4 mm long, with 4 broad persistent lobes; petals 4, free, 2.5–3.5 mm long, white; stamens numerous, arranged in 4 groups, about 3 mm long; disk quadrangular, orange-yellow. Fruit a 1-seeded berry, depressed globose to globose, up to 12 mm in diameter, dark red to purplish-black when ripe.

Growth and development *S. polyanthum* may flower as soon as 3 years old. Flowering and fruiting are more or less year-round. The flowers last for 4–7 days and are usually pollinated by beetles and butterflies. Branches break off easily during strong winds.

Ecology *S. polyanthum* is widely distributed and locally common as understorey tree in lowland primary and secondary forests, also in thick-



Syzygium polyanthum (Wight) Walpers – 1, tree habit; 2, twig with leaves; 3, branchlet with inflorescence; 4, flower; 5, fruit.

ets, bamboo forest and teak plantations, in Java up to 1000 m, in Sabah up to 1200 m, and in Thailand up to 1300 m altitude.

Propagation and planting Salam is propagated by seed, cuttings or air layering. Wildlings can be collected from under adult trees.

Seed loses its viability very rapidly and after 4–6 weeks it hardly germinates. Seed should be sown fresh from the fruit, on the surface of loose soil and under shade. It should not be buried, as this seriously reduces the germination percentage. Germination is rapid, starting 1–3 weeks after sowing, and is complete after 5–12 weeks.

Natural regeneration is generally profuse and seedlings can survice under shade for several years. Wildlings should be hardened off in a nursery before being planted.

Trees are planted in the field at a spacing of 6 m × 6 m. However, in forestry a spacing of 2 m × 3 m is used because 6 m × 6 m is considered too wide for timber production, as it gives rise to an unfavourable stem form and undesired branching.

S. polyanthum is often used for underplanting in forest plantations (teak, pine, kauri) to reduce excessive development of weeds. The leaves decay relatively slowly and provide large quantities of mulch.

Husbandry Salam is a common home-garden tree, receiving little specific attention. Regular pruning seems to be tolerated.

Diseases and pests The tip-boring caterpillar *Argyroploce mormopa* may cause damage.

Harvesting Leaves are harvested by pruning the tree or by cutting off the tips of twigs.

Yield No information is available on the yield of leaves.

In pure timber plantations on fertile soils in Java, mean annual increments of 7–22 m^3 of wood per ha at different tree ages and at different tree spacings have been obtained. In natural forest in Riau, a mean annual increment of 10.5 m^3 of wood per ha has been measured.

Handling after harvest The leaves must be properly dried before storage.

Genetic resources and breeding Some ex situ germplasm conservation has been carried out in Malaysia, but there are no known extensive germplasm collections or breeding programmes.

Prospects The lack of information on the spice aspects of the salam tree is in great contrast with its widespread use in South-East Asian cuisine. Its competitiveness vis-à-vis laurel would be an interesting subject for study.

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S. Sardjono

Thymus vulgaris L.

Sp. pl.: 591 (1753).
LABIATAE
$2n = 30$

Synonyms *Thymus aestivus* Reuter ex Willk. & Lange (1868), *T. ilerdensis* F. Gonzalez ex Costa (1877), *T. webbianus* Rouy (1884).

Vernacular names Thyme, garden thyme, common thyme (En). Thym vulgaire, thym des jardins (Fr). Indonesia: timi.
Note: the word 'thyme' or combinations thereof does not refer exclusively to the botanical species *T. vulgaris*; the taxonomy of the genus *Thymus* L. is badly known and the word 'thyme' in the literature can refer to a great number of different taxa.

Origin and geographic distribution Thyme originated from the European part of the Mediterranean (from Portugal to Greece) where it is also cultivated. At present it is cultivated worldwide in non-tropical regions (e.g. in most European countries, the Mediterranean area, Russia, Canada, United States, China and Japan), but occasionally also at higher altitudes in the tropics (e.g. in Java (Indonesia) and the Philippines).

Uses Since ancient times the leaves and flowering tops of thyme have been used fresh and dried as a condiment and culinary herb, and the entire plant (excluding the roots) for the distillation of essential oil. Thyme honey is well known for its fine flavour and sweetness. Thyme is used to flavour numerous kinds of food, such as butter, cheese, fish, meat, olives, onions, pickles, sauces, soups, stews, stuffings and vinegar. The essential oil is used to scent perfumes and soap but also to flavour food. In the United States the regulatory status 'generally recognized as safe' has been accorded to thyme (GRAS 3063) and thyme oil (GRAS 3064). The maximum permitted level of thyme oil in food products is about 0.003%.
Thyme has a long history in traditional medicine and has been reportedly used in bronchitis, catarrh-colic, diabetes, fever, sore throat, spleen disorders, uterine disorders and warts, and is considered antispasmodic, carminative and tonic. Thyme tea (1 teaspoon fresh leaves steeped in 1 cup boiling water) is believed to cure headache and tumours of the digestive tract, whereas thyme juice with vinegar is said to cure tumours and cancers. In Indonesia the fluid extract and syrup from the shoot are used traditionally as a cough medicine. The smoke of burning thyme is supposed to repel insects. The essential oil is a strong germicide, used as disinfectant and an antiseptic gargle and mouthwash but also as fungicide and insecticide. *Thymus* spp. are often grown as ornamentals.

Production and international trade Annual world production of thyme is estimated at 1500 t, mainly produced around the Mediterranean. Statistics are rare. In 1988 the United States imported more than 900 t unprocessed thyme valued at US$ 2 million (mostly from Spain) and 18 t of processed thyme valued at US$ 20 000 (mostly from Denmark). Annual production of thyme essential oil is estimated at 30 t, with a value of US$ 1.5 million, but this estimate refers to essential oils of several *Thymus* species (*T. capitatus* (L.) Hoffm. & Link, *T. mastichina* L., *T. pulegioides* L., *T. vulgaris* and *T. zygis* L.). For *T. vulgaris* alone the annual essential-oil production is estimated at 4 t.

Properties Per 100 g edible portion ground dried thyme contains: water 7–8 g, protein 7–9 g, fat 5–7 g, carbohydrates 44–45 g, fibre 19–24 g, ash 12–13 g (Ca 1.9 g, P 0.2 g, Fe 0.1 g, Mg 0.2 g, Na 55 mg, K 0.8 g, Zn 6 mg), vitamin A 3800 IU, thiamine 0.5 mg, riboflavin 0.4 mg, niacin 4.9 mg, phytosterols 0.2 g, saturated fatty acids total 2.7 g, mono-unsaturated 0.5 g and poly-unsaturated 1.2 g. The energy value is 1155 kJ/100 g.
Upon distillation, thyme usually yields (1–) 2–2.5(–3)% essential oil. Thyme essential oil is a pale, yellowish-red liquid with a rich, sweet, aromatic, herbaceous odour, yielding a sweet, phenolic, somewhat medicinal perception upon drying out. The taste is sharp, biting, warm and spicy. The characteristic constituents of the oil are thymol and carvacrol; other more variable components are 1,8-cineole, citral, camphor, carvone, monoterpene alcohols and their acetates and sesquiterpene alcohols. The essential oil from *T. vulgaris* may contain up to 30% monoterpene hydrocarbons and more than 50% 1,8-cineole, camphor and monoterpene alcohols, whereas thymol and carvacrol are present at levels lower than 5%. The essential oil from *T. zygis* may contain more than 50% thymol and carvacrol, with up to 30% monoterpene hydrocarbons and less than 10% monoterpene alcohols and esters.
The seeds yield 37% of a drying oil consisting mainly of linolenic, linoleic and oleic acids. Triterpenoid saponins, flavones, ursolic acid, caffeic acid, tannins and resins also occur in the herb.
Thyme oil itself is quite poisonous. Thymol has caused dermatitis in dentistry and when used in toothpaste. Thyme oil in bath preparations has been reported to cause hyperaemia and severe inflammation.

A monograph on the physiological properties of thyme oil has been published by the Research Institute for Fragrance Materials (RIFM).

Adulterations and substitutes Thyme oil is sometimes adulterated by the addition of terpenes and lowering of phenol content. If synthetic carvacrol is used it can be detected by non-crystallizable phenols.

Description Small, erect or ascending, aromatic, evergreen perennial subshrub, 10–30(–50) cm tall, often copiously branched. Stem and branches stiff and woody, obscurely quadrangular, faintly furrowed in the upper part, with very short internodes; branchlets very densely coated with minute grey hairs. Leaves opposite, sometimes seemingly whorled by the presence of axillary leaves; petiole up to 0.5 mm long; blade linear to elliptical, 3–8 mm × 0.5–2.5 mm, margin entire but recurved and not ciliate, coriaceous, both surfaces densely minutely hairy and dotted with numerous orange-brown oil glands. Inflorescence composed of axillary many-flowered whorls, the whole forming a terminal spike up to 5 cm × 1 cm; bracts similar to the leaves but somewhat wider and sometimes with almost flat margins, grey-green; pedicel 1–3 mm long; calyx tubular, 3–4 mm long, short-haired, 2-lipped, upper lip with 3 very short triangular teeth, lower lip with 2 longer teeth; corolla tubular, 2-lipped, 4–6 mm long, upper lip 2-lobed, lower lip 3-lobed, lilac to pale purple; stamens 4, didynamous, exserted; pistil with 4-lobed ovary and single style which is 2-lobed at top. Fruit consisting of 4 one-seeded, brown, globose nutlets about 1 mm long.

Thymus vulgaris L. – 1, flowering branches; 2, flower.

Growth and development Thyme can be grown as an annual or as a perennial. Flowering starts about 2–3 months after sowing and pollination is mainly by honeybees, but some self-pollination also occurs. In natural populations of *T. vulgaris* often more than 50% of the plants have functionally male-sterile flowers in addition to plants with bisexual flowers. Seed set is usually abundant. Commercial plantations are renewed after 2–3(–5) years because the crop tends to become woody, straggling and low-yielding.

Other botanical information *Thymus* is confined to the Old World and is taxonomically badly known. The estimated number of species ranges from 35–350 and this great divergence is due to the existence of numerous local *Thymus* taxa which some consider to be separate species, but others see as forms of complex large species. When growing under favourable conditions, most *Thymus* taxa have aromatic leaves and flowers and are used locally as a condiment, ornamental plant and for honey production. Only a few are grown commercially.

The major useful species (besides *T. vulgaris*) are mentioned below, but their identity needs better investigation:

- *T. caespititius* Brot., Azores thyme, native to north-western Spain, Portugal, Canary Islands and the Azores. Its fresh leaves are used to flavour foods.
- *T. capitatus*, Spanish oregano, native to the Mediterranean from Portugal to Israel and collected from the wild for its essential oil (Spanish oregano oil, annual production about 7 t, mainly used to scent toiletries and to flavour foods).
- *T. ×citriodorus* (Pers.) Schreb., lemon thyme, the leaves smell of lemon. It is a hybrid between *T. pulegioides* L. and *T. vulgaris*, often appearing spontaneously in Europe in areas where *T. vulgaris* is cultivated. It is the principal thyme of commerce after garden thyme, also as an ornamental. Much confusion exists about the term 'lemon thyme', because several other species also have lemon-scented forms.
- *T. herba-barona* Lois., caraway thyme, a native

of Corsica and Sardinia, and a popular condiment for meat.

- *T. mastichina*, mastic thyme or Spanish marjoram, native to Portugal and Spain and collected from the wild for its essential oil (Spanish marjoram oil, annual production about 36 t, used to flavour meat sauces and soups).
- *T. praecox* Opiz, creeping thyme, native to central Europe and a popular ornamental. In a wide species concept it is considered as belonging to *T. serpyllum* L. The taxon is very complex and many subdivisions exist.
- *T. pulegioides*, large wild thyme of Europe, source of about 2 t commercial essential oil annually. It is widespread in Europe and is very variable.
- *T. quinquecostatus* L., Japanese thyme, native to north-eastern China and Far-Eastern Russia and grown in Japan and Korea where it is used to flavour soup and meat.
- *T. serpyllum* L., wild thyme of Europe, a complex species growing wild all over Europe and used as a culinary herb and for essential-oil production.
- *T. zygis*, Spanish thyme, native to Portugal and Spain. Its leaves are used as a condiment and to produce Spanish thyme oil (annual production about 25 t, representing 85% of the total thyme-oil production).

T. vulgaris is very variable in shape of leaves, bracts and inflorescence and many subdivisions exist in the botanical literature. For the cultivated forms a classification into cultivar groups and cultivars would be most appropriate, but is only possible after a thorough revision of the species and its relatives. The species is extremely variable: there are cultivars with narrow, broad and variegated leaves, and cultivar group distinction may also be possible based on differences in the composition of the essential oils.

Ecology The natural habitat of thyme is the Mediterranean area, with hot, dry summers and cool, wet winters. Thyme grows at temperatures between 4–28°C, but optimally at 16°C. It is hardy to at least −15°C. It is drought tolerant but some supplementary water during dry periods is beneficial. In cultivation thyme prefers warm, sunny conditions with moderately fertile but well-drained soils such as sands or sandy loams, preferably slightly alkaline. In heavy, wet soils, thyme is short-lived and less aromatic. In South-East Asia it should be grown at higher elevations. Thyme is cultivated in the Philippines in the cool area of Cavite, about 600 m above sea-level.

Propagation and planting Thyme seed can be stored for more than 6 years in airtight containers at 20°C with only slight loss of viability. Thyme is most easily propagated by seed, either directly in the field or in a nursery with later transplanting. The tiny seeds are covered with a thin layer of soil to avoid desiccation. Germination takes 2–3 weeks at 21°C. Plant spacing in the field is 10–15 cm between plants in the row and 20–25 cm between rows. If grown first in the nursery, young plants are ready for transplanting when they are 5–8 cm tall. Thyme can also be propagated vegetatively by cuttings, layering or root division.

Husbandry Mulching of thyme is practised to control weeds, particularly in new plantings, and to help the crop to overwinter. Stem tips should be pruned regularly to encourage bushy growth. Thyme has been called the 'poor man's herb', because it can be grown in various soils without adding fertilizers. A moderate application of well-balanced fertilizer or composted manure is beneficial. If the crop receives additional irrigation, the soil should be allowed to dry between applications.

Diseases and pests Thyme seldom suffers seriously from diseases and pests. A major problem can be caused by dodder (*Cuscuta* sp.) which sometimes overgrows thyme completely.

Harvesting Thyme is harvested just before or during flowering, once during the first year of growth and 2–4 times in the succeeding years. Plants are cut 8–12 cm above the ground manually or mechanically. Cutting too low may cause plant death.

Yield In the first year annual yields of thyme are about 5 t/ha fresh or 1 t/ha dried herb, in the following years about 12–14 t/ha fresh or 2–3 t/ha dried. The frequency of harvest affects the yield; when harvested every 4 months an annual yield of 4.6 t/ha was obtained as compared with 2.6 t/ha when harvesting was every 2 months.

Handling after harvest When intended for the fresh market, the harvested shoots of thyme are simply cooled and bunched or packed in polythene bags. The shoots can also be dried, either by spreading them thinly in trays with muslin or fine wire-mesh bottoms in a well-ventilated, shaded area to preserve the greyish-green colour, or by drying artificially at temperatures between 29–43°C. After drying, leaves and flowering tops are stripped from the stems and stored in polythene bags. For essential-oil distillation, fresh but dry material from which any woody and wilted parts have been removed should be used immediately after harvesting.

Genetic resources Small germplasm collections of thyme are available at most gene banks in Europe, e.g. in France (Conservatoire des Plantes Médicinales, Aromatiques et Industrielles, Milly-la-Forêt) and in Portugal (Portuguese Plant Germplasm Bank, Braga).

Breeding Breeding prospects for thyme are promising because of the natural high rate of male sterility and the ease of vegetatively propagating desired types. One of the breeding objectives is to obtain cultivars with a desirable essential-oil composition. The Mediterranean *T. vulgaris* consists of 6 chemotypes with different major monoterpenes. The nature of these monoterpenes is controlled by a series of loci, probably with dominant and recessive alleles. Epistatic relationships between these loci have been interpreted by assuming the terpenes as end-products of branches from the same biosynthetic pathway. The most dominant types, which correspond to the monoterpenes produced at the beginning of the chain, show the most important genetic diversity.

Prospects The demand for thyme is expected to grow faster than the demand for most other culinary herbs, particularly in the major European markets. However, the current market for dried herbs in general is not limited by supplies, and producers/exporters seeking entry will have to compete with traditional suppliers. Provision of a consistent high-quality product with good appearance can help newcomers in the trade to penetrate the market.

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S.H. Widodo

Trachyspermum roxburghianum (DC.) H. Wolff

Das Pflanzenreich IV. 228, Heft 90: 129 (1927).

UMBELLIFERAE

$2n = 20$ (polyploids with $2n = 40, 42, 44$ have also been reported)

Synonyms *Ptychotis roxburghiana* DC. (1830), *Carum roxburghianum* (DC.) Benth. (1867), *Trachyspermum involucratum* (Royle) H. Wolff (1927).

Vernacular names Indonesia: surage (Sundanese), pletikapu (Javanese), renggireng (Aceh). Philippines: kanuikui (Manobo), malungkoi (Subanun). Thailand: phakchi-lom (Kanchanaburi). Vietnam: hoa kh[oof]m.

Origin and geographic distribution Surage is a cultigen of unknown origin, but it occurs cultivated and subspontaneously (but not naturalized) throughout South and South-East Asia. In West Java surage is probably a disappearing crop; it has been found cultivated only in home gardens and upland fields in a very restricted area around Cileungsi and Kalapanunggal (Bogor Regency).

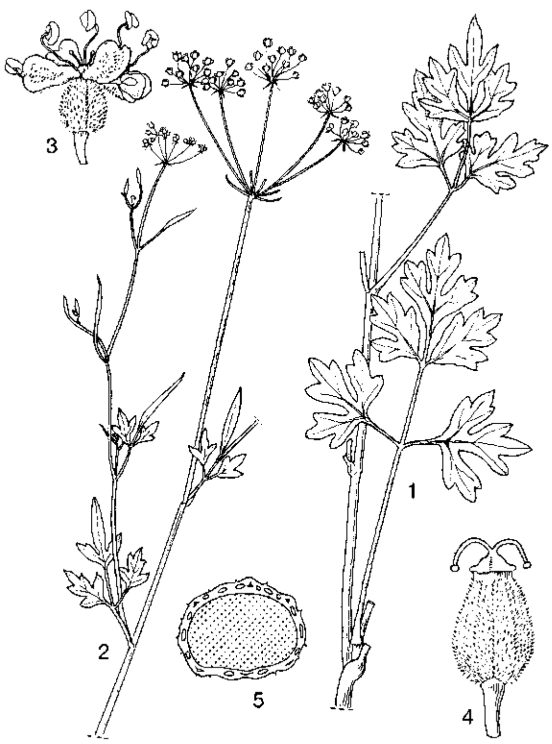
Uses Surage is a culinary herb whose leaves are used similarly to parsley for flavouring various dishes. The leaves are also eaten raw or steamed with rice and, in Indo-China, to make a kind of tea. In India, the fruits ('ajmud' in Hindustani and 'randhuni' in Bengali) constitute one of the lesser-known ingredients of curries. They are also used in pickles, chutneys and preserves. The fruits are a reputed drug in Indian medicine and are used as carminative, stimulant, cardiotonic, emmenagogue, and to alleviate dyspepsia, bronchitis and asthma. Extracts or powders from various parts of surage are very effective against insect pests of stored grains (*Callosobruchus chinensis, Sitophilus oryzae, Trogoderma granarium*), and against housefly (*Musca domestica*).

Production and international trade *T. roxburghianum* is only produced and traded locally; no export trade exists. Production is quite considerable in India, but is small in South-East Asia (no statistics are available).

Properties No information is available on the composition of the leaves of surage. The fruits are very aromatic, both odour and taste are reminiscent of celery; the taste is at first slightly bitter, becoming strongly aromatic and producing a slight numbness of the tongue. They yield up to 2.5% essential oil, up to 4.5% fixed oil, and up to 0.1% of a crystalline ketonic compound. The latter ($C_{13}H_{12}O_3$) has powerful antispasmodic activity, it lowers blood pressure by direct action on the blood vessels.
The essential oil can be obtained by steam distillation. It is greenish-yellow and its main components are limonene 35.1%, α-terpinene 19.4%, piperitone 13.6%, terpineol 5.7%, linalool 4.7%, and thymol 1.7%. The essential oil also lowers blood pressure and has diuretic properties. The fruit residue after essential-oil extraction has cardiotonic properties.

Adulterations and substitutes The leaves of *T. roxburghianum* can be used as a substitute for parsley, the fruits can be substituted for celery.

Description Annual, erect, aromatic herb, 15–90 cm tall. Stem striate, subglabrous, usually much branched. Leaves alternate, pinnately compound; petiole sheathing, up to 1.5 cm long; blade ternately pinnate or 1–2-pinnate, in outline ovate-lanceolate, 3–8 cm × 1–3 cm, segments (leaflets) pinnatifid to pinnatipartite, linear, 0.3–3 cm × 1–3 mm, those of the upper leaves gradually becoming nearly filiform. Inflorescence a regular, terminal or axillary, compound umbel; peduncle 2–8 cm long; involucral bracts 2–5, linear-lanceolate, 3–10 mm long, acute; primary rays 2–9, 1–3.5 cm long; involucel bractlets 5–8, filiform, 2–3 mm long, finely ciliate; secondary rays (pedicels) 5–15, 2–7 mm long; calyx teeth 5, small or obscure, hardly 0.1 mm long; petals 5, obcordate with broadly inflexed obtuse apices, about 1.3 mm × 0.8 mm, white or greenish-white, hirsute; stamens 5, radiating; pistil with compressed, glandular hairy ovary, 2 deflexed styles arising from a conical stylopodium, each style ending in a semi-globose stigma. Fruit a laterally flattened, ovoid to subglobose schizocarp, 1–2.5 mm × 1–2 mm, rather densely covered with short, thick, white hairs, easily splitting into 2, one-seeded mericarps; mericarp convex dorsally, flat ventrally, with 5 prominent longitudinal ribs alternating with a furrow in each of which 3 undulating oil ducts (usually 1 large and 2 smaller ones) are present and with 2 oil ducts on the commissural side. Seed with testa adnate to the mericarp wall.



Trachyspermum roxburghianum (DC.) H. Wolff – 1, leafy shoot; 2, flowering shoot; 3, flower; 4, fruit; 5, cross-section through mericarp.

Growth and development Almost nothing has been published on growth and development of *T. roxburghianum*. It can be found flowering year-round. If its growth is comparable to that of *T. ammi* (L.) Sprague ex Turrill, flowering starts 3–4 months after sowing and fruits are mature 2 months later. In *T. ammi* 70–80% cross-pollination occurs.

Other botanical information The taxonomy of *T. roxburghianum* and related species is not well settled and the authority of the name is often erroneously given as (DC.) Craib or (Wall.) Craib. A complete revision of the genus *Trachyspermum* Link and related genera is badly needed. The number of oil ducts (vittae) in the fruit wall is considered an important diagnostic character. According to the latest revision of *Trachyspermum* by Wolff, the oil ducts in each furrow (vallecula) should be singular, but contrary to this concept trivittate species (like *T. roxburghianum*) were also included in *Trachyspermum*.
T. stictocarpum (C.B. Clarke) H. Wolff is considered as the wild ancestor of *T. roxburghianum*. It is common in India and occurs in Sri Lanka as a rare introduction from India. The plant and its

fruits are usually smaller than those of *T. roxburghianum*, and it also has 3 oil ducts between the ribs of the fruits.

T. ammi ('bishop's weed') is a well-known and much cultivated fruit spice in India ('ajowan'), the Mediterranean and Ethiopia ('netch azmud'), and is also used medicinally (the thymol in its essential oil has strong antiseptic properties). In South-East Asia it is primarily used and occasionally cultivated as a medicinal plant. Its fruits always have only one oil duct between the ribs.

Ecology In South-East Asia surage is grown on a small scale in home gardens, in flowerpots, on drained rice fields, and in upland fields, up to about 750 m altitude. It seems to prefer not too heavy, fertile, calcareous soils.

Agronomy Propagation is by seed. Agronomic practices are probably similar to those for *T. ammi*, which is sown broadcast, as a sole crop in home gardens or more often in fields mixed with grain crops. The seed needs a light covering of soil. In India *T. ammi* is sown in rows 45 cm apart and 30 cm between plants. Its cultivation needs no particular care except weeding. The crop is not usually manured or fertilized, though this may improve yield. On light soils in India *T. ammi* is irrigated if rainfall is insufficient. Disease and pest problems are not serious. A leaf-spot caused by *Cercospora roxburghii* has been reported on *T. roxburghianum* in India. Fruits may be attacked by spice beetle or drugstore beetle in storehouses. If stored dry in an airtight container, the fruits keep their flavour for a very long time (at least 40 years), even in hot climates.

Genetic resources and breeding There are no known germplasm collections or breeding programmes for *T. roxburghianum*.

Prospects *T. roxburghianum* deserves more attention in South-East Asia. The leaves and fruits are useful as a condiment, the fruits yield an essential oil which can also be applied medicinally. It is easy to grow, store and transport.

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J.S. Siemonsma & P.C.M. Jansen

Trigonella foenum-graecum L.

Sp. pl.: 777 (1753).
LEGUMINOSAE
$2n = 16$ (diploid)

Vernacular names Fenugreek, goat's horn, Greek hay-seed (En). Fenugrec, sénegré (Fr). Indonesia: kelabet (Indonesian), klabet (Javanese). Malaysia: halba (Malay), kelabat (Malay), venthiam (Malayalam). Burma (Myanmar): penantazi. Vietnam: h[oof] l[oo] ba.

Origin and geographic distribution *T. foenum-graecum* is probably indigenous to the eastern Mediterranean, western Asia and India, but its natural distribution is hard to ascertain as it has been cultivated since antiquity, the first written record dating back as far as 4000 BC. Its cultivation spread to China, Ethiopia, Europe, the southern parts of the former Soviet Union and throughout the Arab world. In Europe and North America it is now grown on a small scale only. It has been tried successfully in Java (Indonesia), but is currently not grown in South-East Asia.

Uses Through the ages fenugreek has been held in high repute in India, the Mediterranean and the Middle East for culinary and medicinal purposes. It was used as a fodder crop even before its medicinal powers became known in ancient Egypt and Greece, hence its name meaning Greek hay in Latin. The use of fenugreek spread through South-East Asia under Indian and Arab influence. Fenugreek, especially the seeds and the leaves, is used as a culinary spice. Ground or whole, sometimes roasted fenugreek seed with its nutty taste combined with flavours reminiscent of celery and maple is applied in spice blends and curry powders in Asian cuisine. It enhances the taste of meat, poultry and marinated vegetables. In North

Africa, it is mixed with breadstuffs and in Arab cooking it is applied in the preparation of 'hulba'. Boiled or parched seeds mixed with honey are also eaten as a snack. In the West fenugreek and its oleoresin are important in preparing artificial maple syrup and are also used in substitutes for caramel, vanilla, butterscotch, rum and liquorice. In Egypt and Asia the roots of sprouted seeds grown to 5–8 cm in length are eaten as a vegetable. An invigorating drink and milk substitute is prepared from dried and ground sprouted seeds. Roasted seeds are a substitute for coffee. In India the leaves are important as vegetable and condiment in spite of their bitter taste. Chopped young shoots add a bitter bite to salads. Dried leaves of a special variety named 'Kasuri Mehti' are used to flavour sauces and gravies.

The herbage of fenugreek, and to a lesser extent its seed, has been used as fodder or as an admixture to hay to promote animal health and to improve the acceptability of spoiled hay. In Canada it is being developed as a high quality hay crop. Fenugreek is also grown as a green manure and cover crop.

The seeds are the source of a dye in India and of an industrial galactomannan mucilage. The oleoresin extracted from the seed is used in perfumery, cosmetics and hair tonics. It should be used with great care because it can ruin a perfume when used in the wrong combination, but works wonders in the right one. In the United States the regulatory status 'generally recognized as safe' has been accorded to fenugreek (GRAS 2484) and fenugreek oleoresin (GRAS 2486). The maximum permitted level of fenugreek oleoresin in food products is about 0.05%.

Fenugreek has numerous uses in traditional medicine. The mucilaginous seeds have emolient, laxative, and vermifugal properties and are used to treat oral ulcers and chapped lips. Fenugreek poultices are said to soothe abscesses and wounds. Other properties attributed to the seeds are: aphrodisiac, emmenagogue, galactagogue and restorative. In China the seeds are applied to treat many afflictions, including abdominal pain, nephrosis, hernia and arthritis. In modern pharmacology the seed is important as a source of diosgenin, a precursor of oral contraceptives and corticosteroids. The leaves lower blood glucose levels in diabetic laboratory animals and have analgesic properties.

Production and international trade Few statistics are available on production and international trade of fenugreek. However, the total export of fenugreek from India in 1995–1996 was 15 135 t, valued at US$ 5.6 million; in 1996–1997 it was 8100 t, valued at US$ 3 million. The oleoresin is traded in the United States at US$ 25–30 per kg.

Properties Seeds of fenugreek contain per 100 g edible portion: water 7.8 g, protein 28.2 g, fat 5.9 g, carbohydrates 46.5 g, fibre 8.0 g, ash 3.6 g (Ca 220 mg, P 358 mg, Fe 24.2 mg), β-carotene equivalent 55 μg, thiamine 0.32 mg, riboflavin 0.30 mg, niacin 1.5 mg, and tryptophan 274 mg. The energy value is 1540 kJ/100 g. Seeds also contain the alkaloid trigonelline.

The oleoresin content of the seed is usually less than 0.02%. The hydro-alcoholic extract is very dark and resinous and has an intensely sweet, rootlike odour, while the petroleum extract is lighter in colour and less sweet. A minor compound, sotolon (3-hydroxy-4,5-dimethyl-2(5H)-furanone), is responsible for the characteristic curry aroma of fenugreek. A monograph on the physiological properties of fenugreek oleoresin has been published by the Research Institute for Fragrance Materials (RIFM).

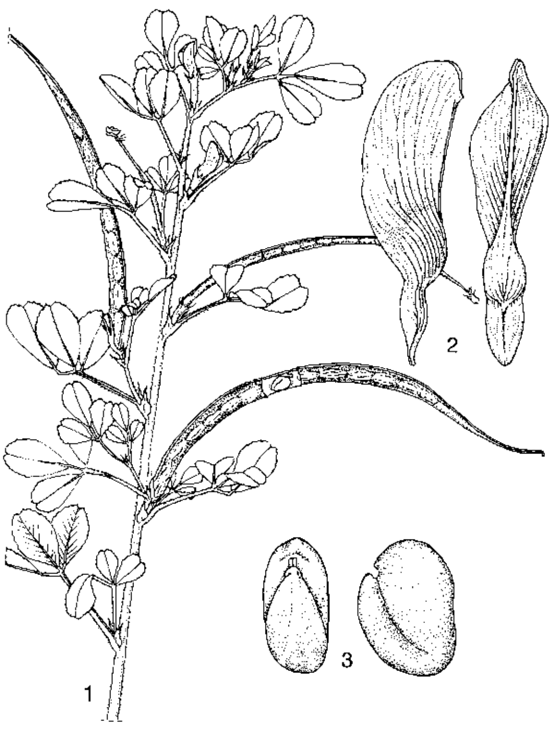
The chemical composition of the seed oil resembles that of cod-liver oil and is rich in phosphates, lecithin and nucleoalbumin. It contains considerable quantities of Fe in an organic form which can be readily absorbed and substances similar to the alkaloids in cod-liver oil that stimulate appetite.

Fresh fenugreek forage is comparable to lucerne hay in digestibility. Fresh leaves contain per 100 g: water 87.6 g, protein 4.6 g, fat 0.2 g, carbohydrates 4.8 g, fibre 1.4 g, ash 1.4 g (Ca 150 mg, P 48 mg). Generally, the straw is a medium-protein roughage suitable for maintenance of dairy cattle. The protein concentrate of fenugreek seeds has an in vitro digestibility of over 95%. It contains lysine (6.5%) but is poor in sulphur-containing amino acids. The seeds are reported to contain trypsin and chymotrypsin inhibitors.

Fenugreek seeds contain 0.5–2% diosgenin and small amounts of similar steroids, which are used in the synthesis of hormones for oral contraceptives and corticosteroids. *T. corniculata* (L.) L. which is occasionally grown as a vegetable, also contains diosgenin and may become an alternative source of it.

The weight of 1000 seeds is 10–20 g.

Description An erect, stiff, strongly scented, annual herb, up to 60 cm tall; taproot well-developed and roots much branched. Stem solitary or basally branched, terete, slightly pubescent, green to purple. Leaves alternate, trifoliolate; stipules



Trigonella foenum-graecum L. – 1, flowering and fruiting shoot; 2, standard (abaxial and side view); 3, seed (hilum view and lateral view).

triangular, small, adnate to the petiole; petiole grooved above, 1–4(–6) cm long; rachis short; leaflets obovate or oblong, 1.5–4 cm × 0.5–2 cm, upper part of margin denticulate. Flowers solitary, axillary, subsessile, 12–15 mm long; calyx campanulate, finely pubescent, tube 4.5 mm long, lobes 5, 2 mm long; standard hood-shaped, obovate, 11–15 mm × 6–7 mm, clawed, pale yellow; wings obovate, 12 mm × 2.5 mm, clawed, auriculate, pale yellow; keel ladle-shaped, 7 mm × 2 mm, clawed, entirely split dorsally, ventrally split near the base, bi-auriculate, pale yellow to white; stamens diadelphous (9 + 1); pistil with sessile ovary, glabrous style and capitate stigma. Fruit a straight to occasionally sickle-shaped, linear pod, 5–19 cm × 0.2–0.4 cm, glabrous, with fine longitudinal veins, slightly bulging over the 10–20 seeds; beak 2–3 cm long. Seed oblong-rhomboidal, 3–5 mm × 2–3 mm, with a deep furrow dividing it into two unequal lobes, with rounded corners, rather smooth, brownish. Seedling with epigeal germination.

Growth and development Germination of fenugreek takes 4–5 days. The first leaf is simple, the second one usually trifoliolate. Fenugreek forms root nodules with *Rhizobium meliloti*. It matures 3–5 months after planting.

Other botanical information Most probably fenugreek is only known from cultivation. Seemingly wild plants always appear to be remnants or escapes from cultivation.
Long-continued selection in various parts of the Old World has led to the development of different regional forms, e.g. in India, Ethiopia and in the Mediterranean. These forms have been grouped into 2 subspecies, but a classification into cultivar groups and cultivars would be more appropriate.

Ecology Fenugreek is suitable for areas with moderate or low rainfall (500–700 mm per year) and is a sun-loving crop. It is fairly drought resistant. In warm climates it is usually grown as a cool season crop, while in temperate areas it is grown as a summer crop. Even where the winter is rather severe, it may be sown under cover in autumn, in this way tolerating frost to –15°C. Fenugreek prefers well-drained fertile loams or sandy loams, but grows fairly well on gravelly and sandy soils. It is not adapted to heavy clay soils. Moderately saline soils are tolerated, but not acid soils. The acceptable pH range is 5.8–8.2.

Propagation and planting Fenugreek is propagated by seed. Deep ploughing and thorough harrowing are most important and the seedbed should be free from weeds. Seed is sown 1–2 cm deep at a distance of 7.5 cm within the row and 20–45 cm between rows. Alternatively, it may be broadcast at a rate of about 25 kg seed per ha. When grown irrigated, seed is broadcast rather thickly at a rate of 25–30 kg/ha and then stirred into the soil. In southern India, fenugreek is intercropped with coriander, sesame or chickpea.

In vitro production of active compounds Hair-root cultures grown from root tips in vitro with *Agrobacterium rhizogenes* have been tried as a method of sapogenin production. Initial results were promising, although the sapogenin content of the roots was only about 0.03 g per 100 g dry matter.

Husbandry Competition from weeds is the most common problem in fenugreek cultivation and several weedings are required. It is not a demanding crop and can fix atmospheric nitrogen. For seed production fenugreek needs potash and phosphate fertilizers; when grown for fodder, nitrogen is also advisable. Inoculation with *Rhizobium meliloti* strain M1-1 in alluvial soils where fenugreek had not been grown before nearly doubled grain yield. Though the application of nitrogen and phosphate will increase seed production, the diosgenin content of the seed decreases with increasing applications. If rainfall is inadequate, a few irrigations are beneficial. Application of sodic irrigation water in light-textured sodic soil has been reported to reduce seed yield.

Diseases and pests In fenugreek a root rot and wilt disease of unknown cause may result in some damage. In India fenugreek is often infested by the mite *Tetranychus cucurbitae*, resulting in no or poor fruit set. *Aphis craccivora* and *Myzus persicae* may also cause damage. Fenugreek is affected by various viruses and nematodes.

Harvesting Fenugreek can be harvested for seed 3–5 months after planting by uprooting. Plants are hung upside down to dry in a warm shady place. In Gujarat (India), fenugreek grown as a leafy vegetable is harvested by clipping leaves and young shoots, and allowing the crop to regrow until the next harvest.

Yield Fenugreek may yield 600–900 kg/ha of seed per harvest. In India fenugreek only grown as a seed crop produced up to 1675 kg/ha of seed, whereas seed yields dropped to 595 kg/ha after one leaf harvest 45 days after sowing. In Egypt, fenugreek planted in rows 20 cm apart produced a seed yield of 1.4 t/ha, while in the United Kingdom yields of 3.7 t/ha have been obtained.
Forage yields of 10–12 t/ha dry weight have been achieved in Canada, India and the United Kingdom.

Handling after harvest Seeds are threshed, winnowed, further dried and stored, preferably in airtight containers.

Genetic resources A germplasm collection of fenugreek is maintained at the All-Russia Research Institute for Plant Breeding, St. Petersburg, Russia.

Breeding Breeding of fenugreek has been conducted, among others, for adaptation to stress, to increase the number of double pods per plant, to raise the ploidy level and to increase the yield of diosgenin.
Hybridization followed by pedigree selection is helpful in regularizing the meiotic behaviour and improving the vigour and seed fertility of fenugreek. Cultivars commonly used in experimental studies are 'Kasuri', 'Pusa Early Bunching' and 'UM 5'.

Prospects Fenugreek is not only an important spice but also a potential plant resource for herbal health products. As it produces diosgenin in a shorter period than *Dioscorea* spp. it may become an important alternative source. Although prospects for its cultivation in tropical lowland South-East Asia are not promising, research on its adaptation to highland conditions is worthwhile.

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C.S. Tawan & N. Wulijarni-Soetjipto

Vanilla planifolia H.C. Andrews

Bot. repos. 8: pl. 538 (1808).
ORCHIDACEAE
$2n = 25, 26, 28, 30, 31, 32$

Synonyms *Vanilla mexicana* P. Miller (1768) p.p., *V. viridiflora* Blume (1825), *V. fragrans* (Salisb.) Ames (1924).

Vernacular names Vanilla (En). Vanille (Fr). Indonesia: panili. Philippines: vanilla. Thailand: wanila.

Origin and geographic distribution Vanilla is indigenous to south-eastern Mexico, Guatemala, and other parts of Central America and the Antilles. In Central America the fruits were used by the Aztecs to flavour cocoa. The fruits became known in Europe in the 16th Century but not until the second half of the 19th Century did large-scale cultivation start outside the natural distribution area. Nowadays vanilla is cultivated pantropically but the important production areas are Indonesia, Madagascar, Comores, Tonga, Réunion, Mexico and French Oceania. In Indonesia vanilla is mainly cultivated in Java and Bali.

Uses The interesting part of vanilla is the fruit (also called 'bean'). The fruits or their extract are used as a spice, e.g. in the flavouring of chocolate, biscuits, confectionery and ice-cream. In the United States the regulatory status 'generally recognized as safe' has been accorded to vanilla beans (GRAS 3104), vanilla extract (GRAS 3105) and vanilla oleoresin (GRAS 3106). The maximum permitted level of vanilla extract in food is 1%. Vanilla is the second most expensive spice (after saffron), so it is not surprising that the synthetic substitute vanillin has taken the place of vanilla in the perfume industry and is also widely used in the food industry. Poorer quality vanilla is used to aromatize tobacco in Java. In the United States and Western Europe vanilla is one of the major flavourings in ice-cream and high-quality confectionery and foodstuffs.

In major consuming countries (United States, European Union) vanilla is the only spice which benefits from a 'Standard of Identity' which helps shield vanilla beans from competition from substitutes.

In traditional medicine vanilla fruits are used as an aphrodisiac, carminative, emmenagogue and stimulant; they are said to reduce or cure fevers, spasms and caries. Vanilla extracts (especially tinctures according to pharmacopoeias) are used in pharmaceutical preparations such as syrups, primarily as a flavouring agent.

Production and international trade Most vanilla is grown by smallholders. During the period 1991–1995, annual world production averaged 4843 t (from 41 566 ha), rising to nearly 5000 t in 1997. In South-East Asia the only country with data on vanilla production is Indonesia, with an annual production of 1792 t and a harvested area of 14 500 ha (1991–1995), reaching 2000 t in 1997.

World exports from producing countries ranged from 1560–1850 t annually during the period 1991–1995. The major producing and exporting countries and their exported amounts and average world market share were: Indonesia (682 t, 40%), Madagascar (673 t, 40%), Comores (2110 t, 12%), Tonga (38 t, 2%). Other South-East Asian countries which export or re-export small quantities of vanilla are Malaysia, the Philippines, Thailand and Singapore.

The United States is the leading importer of natural vanilla, with an average of 1326 t per year during the period 1991–1995 (49% of world imports), followed by Germany (326 t), France (295 t) and Canada (160 t).

The price of Bourbon vanilla (produced in the Indian Ocean Islands) on the United States market averaged US$ 70 000 per t during the years 1988–1992. In the same period Indonesian vanilla fetched a price of US$ 26 000 per t.

Properties Freshly harvested green fruits contain about 80% water which is reduced to about 20% by curing and drying. Per 100 g edible portion cured fruits contain approximately: water 20 g, protein 3–5 g, fat 11 g, sugar 7–9 g, fibre 15–20 g, ash 5–10 g, vanillin 1.5–3 g, a soft resin 2 g and an odourless vanillic acid.

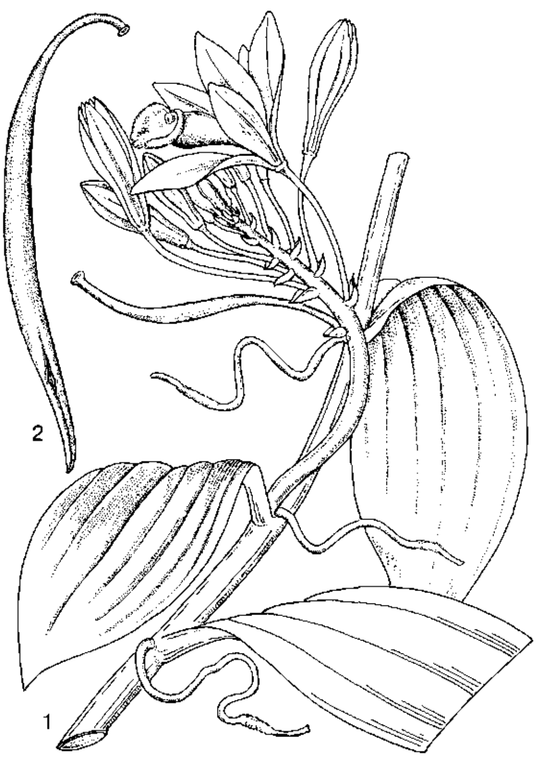
The vanillin content of cured Indonesian vanilla is high (2.75%) in comparison with cured vanilla from other sources: Mexico 1.75%, Sri Lanka 1.5%, Tahiti 1.7%. Vanilla fruits from Tahiti contain heliotropin which gives them their distinctive flavour. Calcium oxalate crystals are present in the plant, which may cause dermatitis in vanilla workers.

A monograph on the physiological properties of vanilla extract (tincture) has been published by the Research Institute for Fragrance Materials (RIFM).

Adulterations and substitutes Vanilla is the spice most subject to competition from artificial flavourings. Four types of these substitutes exist to date: synthetic vanillin, ethyl vanillin, other natural flavours and tissue culture products. Synthetic vanillin (prepared e.g. from lignin and eugenol) accounts for more than 90% of the United States vanilla flavouring market and is only 1% of the price of the natural product. Natural vanillin is superior, probably due to the presence of subsidiary substances.

For substitute *Vanilla* species, see Other botanical information.

Description A fleshy, herbaceous, perennial vine, climbing up trees to a height of 10–15 m by means of long, whitish, adventitious roots, opposite the leaves. Stem long, cylindrical, 1–2 cm in diameter, simple or branched, succulent, dark green. Leaves alternate, fleshy, subsessile; blade oblong-elliptical to lanceolate, 8–25 cm × 2–8 cm, somewhat rounded at base, acute to acuminate at top, with numerous parallel veins. Inflorescence a short axillary raceme, 5–10 cm long, 6–15(–30)-flowered, with usually only 1–3 flowers open at one time, starting from the base; pedicel very short; flower about 10 cm in diameter, waxy, fragrant, yellow-green; sepals 3, oblong, 4–7 cm × 1–1.5 cm; 2 upper petals resembling the sepals but



Vanilla planifolia H.C. Andrews – 1, flowering branch; 2, fruit.

slightly smaller, labellum (lower petal) trumpet-shaped, 4–5 cm × 1.5–3 cm, obscurely 3-lobed at top, inside hairy at base; column 3–5 cm long, attached to labellum, bearing at its tip 2 pollinia covered by a cap; stigma concave, separated from the pollinia by a thin flap-like rostellum. Fruit a pendulous, narrowly cylindrical capsule, 10–25 cm × 0.8–1.5 cm, obscurely 3-angled, splitting longitudinally when ripe. Seeds numerous, globose, about 0.4 mm in diameter, black.

Growth and development Commercial vanilla is always propagated by stem cuttings. Shoots develop on the cutting 30–40 days after planting. Under favourable conditions a vine may grow 0.6–1.2 m per month.

When cultivated, vanilla flowers on shoots that hang down from the branches of a support tree. Under natural circumstances flowering occurs on upward climbing vines at a height of 10–15 m. This may indicate that a certain amount of vegetative growth is necessary for flowering. Vanilla usually starts flowering 3–4 years after planting and reaches maximum production 7–8 years after planting. About 10 years after planting the commercial value of the vines decreases, so plants are discarded.

A dry period initiates flowering. Per year a plant usually flowers during a period of 2 months, producing 10–20 inflorescences, each with up to 30 flowers. In one day 1–3 flowers per inflorescence open early in the morning and close in the afternoon. If pollination does not occur the flower withers and drops in 1–2 days. The fruit reaches its maximum length about 6 weeks after fertilization, and ripens 7–9 months after flowering.

Other botanical information Although several vanilla qualities or grades are distinguished in commercial trade, no formally named cultivars of *V. planifolia* are known. Perhaps the botanical variability has remained rather limited in plantations because propagation has been mainly vegetative. Nevertheless, in Indonesia at least 7 morphotypes or types are known, i.e. Chili, Madagaskar, Malang, Ungaran Daun Tipis, Ungaran Daun Tebal, Anggrek, and Gisting. All types are susceptible to *Fusarium*, but Gisting shows highest tolerance. Anggrek is most productive, but Gisting has the highest number of flowers per plant and number of bunches per vine.

The genus *Vanilla* P. Miller comprises about 100 species, distributed pantropically, most occurring in tropical America. Numerous species have slightly aromatic fruits but only a few are or have been used as substitutes for vanilla:

- *V. abundiflora* J.J. Smith. Known from South-East Asia – see Minor spices.
- *V. gardneri* Rolfe. Much like *V. pompona* but leaves half their size, and smaller flowers and fruits. It occurs in Brazil and is called Brazilian or Bahia vanilla. It is occasionally used as an adulterant of true vanilla.
- *V. phaeantha* H.G. Reichenb. Like *V. planifolia* but with much larger flowers and shorter fruits (up to 7.5 cm long). It occurs in Florida, the Bahamas and the Antilles and has been cultivated because of the aromatic fruit. It is most important now for its resistance to *Fusarium* root-rot disease of vanilla.
- *V. pompona* Schiede. Like *V. planifolia* but with larger leaves (10–30 cm × 4–10 cm), larger and more fleshy flowers, and shorter and thicker fruits (15–17 cm × 2.5–3.3 cm). It occurs in Central America, northern South America and the Lesser Antilles and is also occasionally cultivated. It is called West Indian vanilla, great vanilla or pompon and is perhaps the most used natural substitute of real vanilla. The fruit is also used to extract heliotropin which is used in the per-

fume industry and to flavour tobacco. As a spice it is much less important than *V. planifolia* and much cheaper. The fruits are harvestable in a different season than those of true vanilla, which also makes cultivation interesting; however, they are more difficult to dry.

- *V. tahitensis* J.W. Moore. Less robust than *V. planifolia*, with more slender stems, narrower leaves (12–14 cm × 2.5–3 cm), smaller fruits (12–14 cm × 9 mm) tapering towards both ends, not splitting open at maturity. It is indigenous to Tahiti and also cultivated there and in Hawaii (Tahitian vanilla). The fruits have a lower vanillin content, but the aroma is sweeter, best suited for cosmetics.

Ecology Vanilla thrives in warm, per-humid or humid climates without a pronounced dry season. Temperatures may range between 21–32°C, with an average of 26°C. Rainfall is preferably up to 2000–2500 mm/year and evenly distributed. A drier period of 2 months favours flowering. Such climates are found e.g. on tropical islands between 20°N and 20°S. In Java (Indonesia), vanilla can be grown up to 400–700 m altitude. Rainfall should not be too heavy while the fruits are ripening.

Vanilla requires a light soil with good drainage, rich in Ca and K, with a thick surface layer of humus or mulch in which the roots can spread, with pH between 6–7. The plantation should preferably be on a slight slope. Partial shade is necessary and can be provided by shrubs or small trees up which the vines are grown.

Propagation and planting Commercial vanilla is propagated by stem cuttings. These should be taken from healthy, vigorous vines. It is advisable to keep separate 'mother vines' for propagation. These should be prevented from flowering. If enough planting material is available, long cuttings of 1.50 m are preferred. Cuttings should be taken during the drier period of the year when growth of the mother-vines has slowed down. The leaves at the base of the cutting should be removed, because they start rotting in the soil. Cuttings are planted directly at the foot of a support tree at a spacing of 2 m × 3 m, with the lower part with 3 nodes buried in the humic layer and mulch. Because of their succulent nature, cuttings may be stored for up to 2 weeks.

Vanilla requires support to climb on, usually offered in the form of a tree. The ideal support tree is easily propagated, strong enough to carry the heavy vines, well-anchored in the soil to withstand strong winds, and not a quick grower to avoid heavy pruning. It should preferably have sufficient lower branches, as this makes it easier to train the vines to hang down over them. Often legumes are used for this. In Bali (Indonesia), coffee is used as support. It is, however, not advisable to use commercial crops like coffee, mango and avocado as support, since the roots of vanilla may be damaged by the operations to harvest these crops. In Madagascar, *Gliricidia sepium* (Jacq.) Kunth ex Walp. is used as a support tree. Cuttings of the support tree are planted 1 year in advance of the vanilla cuttings at a spacing of 1.5–2.5 m × 3 m. Vanilla can also be grown up posts or trellises.

Shade should be provided in the first place by the support tree. Often, other trees are planted as well to provide additional shade when needed. Light should be filtered in such a way that the level of radiation is still adequate for photosynthesis. Air circulation near the vines should be sufficient to have a drying effect, preventing the spread of fungal diseases. Shade trees used include *Albizia lebbeck* (L.) Benth., *Inga edulis* Mart. and *Cocos nucifera* L.

Tissue culture techniques have been developed for rapid and large-scale multiplication of disease-free vines of *V. planifolia*. Multiple plantlets are produced by culturing the aerial root tips of vanilla on media supplemented with various growth regulators (auxins and kinetins). This technique can be used for producing clonal material of *V. planifolia* for use in plantations and in physiological experiments. Tissue culture methods using nodal segments for in vitro propagation have also been reported.

Only for breeding purposes does it pay to follow the difficult path of growing vanilla from seed. Fruits should be picked just before or as they split. Seeds are then washed clean and transferred to a sterilized nutrient medium. Temperature must be kept rather high (30°C). Under these circumstances vanilla will germinate in 1–2 months. The young seedlings should be transferred every 2 months. After a year seedlings are transferred to soil. After another year the then 2-year-old plants can be planted in the open.

In vitro production of active compounds Attempts have been made to produce secondary vanilla metabolites (vanillin, in particular) from *V. planifolia* cell suspension cultures. Callus culture is developed from green bean tissue, from aseptic explants or shoots, or from growing plant shoot tips and seeds, and this is subsequently used to form a suspension culture. However, the production of natural vanilla flavour using biotechnology is still experimental.

Husbandry New shoots of the vanilla cutting planted at the foot of a support tree are trained along its branches to encourage them to develop at a convenient height for pollination and harvesting. When shoots reach a length of about 2.5 m, they are carefully detached from the branch so that they may hang down. The tip (about 10 cm) of the vine is cut off 6–8 months before the flowering season, to encourage the production of inflorescences. New vegetative shoots on the apical part of the hanging vine are pruned, those on the basal part of the hanging vine are trained along the branches of the support tree. The latter will be the productive vines for the next season. At the beginning of the flowering season inflorescences will emerge from the leaf axils at the apical part of the hanging vines. These vines are removed after harvesting. Pollination is absolutely necessary to obtain fruits. In its centre of origin vanilla is pollinated by bees (*Melipona* spp.) and possibly also by humming birds. In the production areas pollination is carried out by hand with a small stick. The flower is held in one hand and the labellum is pushed down with the thumb, releasing the column. The stamen cap is removed by the stick held in the other hand which exposes the pollinia. The thin flap-like rostellum is then pushed up under the stamen with the stick and, by pressing with the thumb and the finger, the pollinia are brought into contact with the sticky stigma to which the pollen mass adheres. Per day a worker can pollinate on average 1000–3000 flowers. Hand-pollination allows the number of fruits per inflorescence and thus also per plant to be regulated. Only basal flowers of an inflorescence are pollinated, resulting in 4–6 fruits per raceme that develop into straight beans. On average a 4–5-year-old plant should not be allowed to bear more than 100–150 fruits, as otherwise it may become unproductive in later years.

Vanilla not only requires a soil with a high organic matter content but also an adequate supply of mulch. The best mulch is a mixture of grasses and legumes. Fruit-bearing vanilla should be mulched especially well. Clean-weeding of the vanillery is not recommended, but rank growth of climbers and other weeds should be controlled.

Chemical fertilizers are seldom used, although adequate application will give a good crop. However, mulched plantings give the best quality vanilla, particularly in terms of aroma.

Diseases and pests The most serious disease of vanilla is root-rot or stem-rot disease, caused by *Fusarium oxysporum* f.sp. *vanillae*. The disease is usually controlled by fungicides or, in Indonesia, by incorporating clove leaves into the soil. Clove leaf oil contains eugenol which appears to inhibit radial growth and sporulation of the pathogen. Anthracnose (*Glomerella vanillae*) attacks all aerial parts of the plant, and is found in all vanilla-producing countries. It is favoured by overshading and humid conditions, so the best control is to decrease shading. Brown spot disease (*Nectria vanillae*) can also affect all aerial parts. Old and weak plants are especially vulnerable. Mildew (*Phytophthora* sp.) may damage all parts of the plant. High humidity facilitates the spread of the disease. There is no cure for it; infected plants should be removed and burnt. Cured vanilla fruits may also be affected by mildew.

Vanilla is attacked by a number of insects but none of them causes great losses. The most serious pests are snails (*Thelidomus lima* in Puerto Rico, *Achatina fulica* in Madagascar) and slugs (*Veronicalla kraussii* in Puerto Rico). Chickens cause much damage by scratching among the mulch and in so doing tearing and exposing the roots.

Harvesting The fruits are hand-picked 7–9 months after flowering. The best moment of harvesting is when the fruits are still dark green, with only the tip turning yellow. If they are harvested earlier the aroma develops poorly; if harvested later they split and give poor quality. Harvesting is done rotationally over a period of 2–3 months.

Yield Yields may fluctuate from year to year. A vanillery may yield 2.5–4 t/ha per year of fresh fruits (being 500–800 kg/ha of cured beans) during a productive crop life of about 7 years (out of a total crop life of about 10 years), but much lower yields are reported.

Handling after harvest The curing process should begin within a week after harvesting. It consists of blanching, fermenting and drying, during which 70–80% of the water is lost and the typical aroma develops. Fruits are immersed once (occasionally twice) in hot water for 30–60 seconds. The fruits are then stored for 24–48 hours in cloth-lined containers for sweating and to start fermentation. Then, for a period of 3–5 days beans are exposed to the sun during day-time on a scaffold and stored during the night. The beans are then conditioned in closed containers, where they develop the full aroma during 2–3 months. The cured beans are graded, smoothed and straightened. Finally, they are exported in sealed tin boxes. Good-quality cured beans should be dark

brown, long, flexible, oily, smooth and aromatic. In Mexico, the curing process takes 5–6 months: sun-drying takes at least 2 months and then the beans are kept in boxes for about 3 months.
At least four major commercial types of vanilla can be distinguished: the Bourbon vanilla (grown in Madagascar, Comores and Réunion), the Java vanilla (grown in Java in Indonesia), the 'Bourbon-like' vanilla (mainly grown in Bali in Indonesia) and the Mexican vanilla. Bourbon vanilla ranks top in terms of quality. The major quality components are: flavour profile, natural vanillin content, bean length, moisture content, appearance, colour and presentation. Vanilla grown in Indonesia ranks fourth (after the product from the three Bourbon-producing countries) because of lower natural vanillin content and less attractive flavour profile. The improved cropping and curing practices recently adopted in Indonesia have led to an improvement in the overall quality of its vanilla beans. This is why in recent years the Malagasy and top-of-the-line Balinese beans have been increasingly seen as the leading vanilla types by the world's major users.

Genetic resources A germplasm collection is held at the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Costa Rica. It comprises about 30 accessions from various countries in Central America.

Breeding One of the main breeding objectives is to obtain resistance to root-rot disease. The resistant *V. phaeantha* H.G. Reichenb. is a promising species in this respect. Breeding programmes carried out until 1974 at the Vanilla Research Station of Antalaha (Madagascar) were not very successful. No new breeding breakthroughs have been reported so far.

Prospects On the world market there is an increasing demand for natural flavouring substances. It is expected that this will favour the demand for natural vanilla. Supply currently lags behind demand, and therefore prices are increasing. Vanilla is a promising crop for different parts of South-East Asia, especially as a high-value crop for areas with high population pressure (e.g. Bali in Indonesia).

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J.T.G. Straver

Zingiber G.R. Boehmer

C.G. Ludwig, Def. gen. pl. ed. 3: 89 (1760).
ZINGIBERACEAE
$x = 11$; $2n = 22$ (*Z. montanum*, *Z. spectabile*, *Z. zerumbet*)

Major species and synonyms
- *Zingiber montanum* (Koenig) Dietrich, Sp. pl. ed. 6, 1: 52 (1831), synonyms: *Amomum montanum* Koenig (1783), *Zingiber purpureum* Roscoe (1807), *Z. cassumunar* Roxb. (1810).
- *Zingiber officinale* Roscoe – see separate article.
- *Zingiber spectabile* Griffith, Not. pl. asiat. 3: 413 (1853).
- *Zingiber zerumbet* (L.) J.E. Smith, Exot. bot. 2: 105, t. 112 (1806), synonyms: *Amomum zerumbet* L. (1753), *Zingiber amaricans* Blume (1827), *Z. aromaticum* Valeton (1918), *Z. littorale* Valeton (1918).

For other *Zingiber* species, see chapter on Minor spices.

Vernacular names Ginger (En). Gingembre (Fr). Vietnam: g[uwf]ng.

- *Z. montanum*: Cassumunar ginger, Bengal root (En). Gingembre marron (Fr). Indonesia: banglai (general), bengle (Javanese), panglay (Sundanese). Malaysia: bunglai, bangle, bolai. Laos: hva:nz ph'ai, hva:nz kè:z hva:nz. Thailand: puloei (northern), phlai (central), wan-fai (central). Vietnam: g[uwf]ng d[aj]i, g[uwf]ng d[or].
- *Z. spectabile*: Black gingerwort (En). Malaysia: tepus tanah, tepai, tepus halia. Thailand: changoe (Pattani), dakngoe (Pattani).
- *Z. zerumbet*: Wild ginger, zerumbet ginger (En). Shampoo plant (Am). Zerumbet, gingembre fou, gingembre blanc (Fr). Indonesia: lampuyang (Sundanese), lempuyang (Javanese), lampojang (Madurese). Malaysia: lampoyang. Philippines: barik, langkawas (Tagalog), lampuyang (Ilonggo). Cambodia: khnhei phtu, prateal vong prenh atit. Laos: hva:nz ph'ai chai hlüang. Thailand: kathue (central), kathue-pa (northern), kawaen (northern). Vietnam: g[uwf]ng gi[os], ng[ar]i xanh.
  - var. *amaricans* (Blume) Theilade: Indonesia: lampuyang pahit (Sundanese), lempuyang pait (javanese), lempuyang emprit (Javanese). Thailand: hiu-dam (Mae Hong Son).
  - var. *aromaticum* (Valeton) Theilade: Indonesia: lampuyang wangi (Sundanese), lempuyang wangi (Javanese), lampojang ruum (Madurese). Malaysia: lampoyang, lempoyang, tepus.
  - var. *zerumbet*: Indonesia: lempuyang gajah (Javanese), lempuyang kapur (Javanese), lempuyang kebo (Javanese).

Origin and geographic distribution *Zingiber* contains about 100 species and its centre of diversity is located in South-East Asia. It is found throughout tropical Asia, in tropical Australia and in Japan.

- *Z. montanum* is probably native to India and is now widely cultivated in tropical Asia. It occurs widely as a home-garden plant in South-East Asia.
- *Z. spectabile* is found in Peninsular Malaysia and peninsular Thailand. Throughout the tropics it is occasionally cultivated as an ornamental.
- *Z. zerumbet* is probably indigenous to India. It is cultivated in India, Sri Lanka, China and throughout South-East Asia as a home-garden plant. It is also cultivated on Martinique. In Java, var. *amaricans* occurs wild and cultivated, var. *aromaticum* is often found cultivated and sometimes wild or naturalized, whereas var. *zerumbet* is only known from cultivation.

Uses *Zingiber* is valued as a spice, for its medicinal properties and for its essential oil.

Z. montanum. Its rhizomes are used for food flavouring, often as a substitute for *Z. officinale*. The plant is applied medicinally throughout tropical Asia, primarily as a carminative and stimulant for the stomach, and against diarrhoea and colic. In Indonesia, the pounded rhizome is used as a poultice against headache, and in a variety of medicinal mixtures. In Malaysia, the rhizome is administered internally as a vermifuge, whereas various poultices, lotions, decoctions and applications are rubbed over the body after childbirth and used against swellings, rheumatism, contusions, numb feet, gonorrhoea and pain in various places. In Laos, it is applied against abscesses, fever, colic, diarrhoea and other intestinal disorders, and as a depurative. It is also used as a poison antidote in Laos. In Thai traditional medicine, the rhizomes are taken against asthma and muscle and joint pain.

Z. spectabile. Used for flavouring in Malaysia. In traditional medicine, pounded leaves are applied to poultice swellings, whereas cold water infusions are used to bathe inflamed eyelids. It is in use by forest tribes (Orang Asli) to treat headache and back-aches. The large inflorescences are sometimes cut for ornamental purposes.

Z. zerumbet. Its rhizomes are used as a spice as well as for medicinal purposes. In Indonesia, *Z. zerumbet* is considered a stimulant for the mucous membrane of the stomach and bowels and it is applied against diarrhoea, dysentery and stomachache, and externally to relieve pain. In Brunei Darussalam, rhizome decoctions are put in a bath after childbirth, whereas warmed leaves are applied as a poultice against arthritis and aching joints. In the Philippines, the dried, powdered rhizome is used as an anti-diarrhetic, whereas rhizome decoctions are administered against asthma and as a topical against rheumatism. In New Guinea, the plant is used in masculine rituals and reported to make women sterile. In Indo-China, the rhizome is considered tonic, stimulant and depurative. Macerated in alcohol, it is taken in the case of vertigo and in the first two weeks after giving birth. It is also reported to be applied to the head of children in convulsions and to the head and stomach of children with fever. The essential oil is applied in India as a perfume in soaps and toilet articles, after blending with other perfumes.

- var. *amaricans*. The rhizomes are used for seasoning, and in Indonesia, rhizomes and rhizome tips are reported to be eaten as 'lalab'. This 'lalab' is also reputed to be depurative and effective against sprue. Young flower spikes, without the bracts, are also eaten, raw or cooked. The juice of fresh rhizomes is taken to stimulate the appetite. In Malaysia, the rhizome is applied against stomachache with leg cramps, against puerperal infection and as a tonic. Externally, it is used against fever and numb feet, where it acts as a rubefacient and irritant.
- var. *aromaticum*. Fresh shoots are eaten as a vegetable in Java. Young ends of rhizomes are consumed raw as 'lalab', like those of *Z. amaricans*. Medicinally, *Z. aromaticum* rhizomes are used in Java against biliousness, chlorosis and whooping cough. In Java as well as Malaysia, powdered rhizomes are applied to the body after childbirth.
- var. *zerumbet*. In Indonesia, rhizome juice or decoctions are reported to be used against biliousness, gall stones, ulcers, rash and languor, and to increase the appetite.

Production and international trade *Zingiber* is either gathered from the wild or planted in home gardens for local use. In Indonesia, companies trading in traditional medicines and cosmetics occasionally purchase some *Zingiber* rhizomes (usually dried), but no statistics are available.

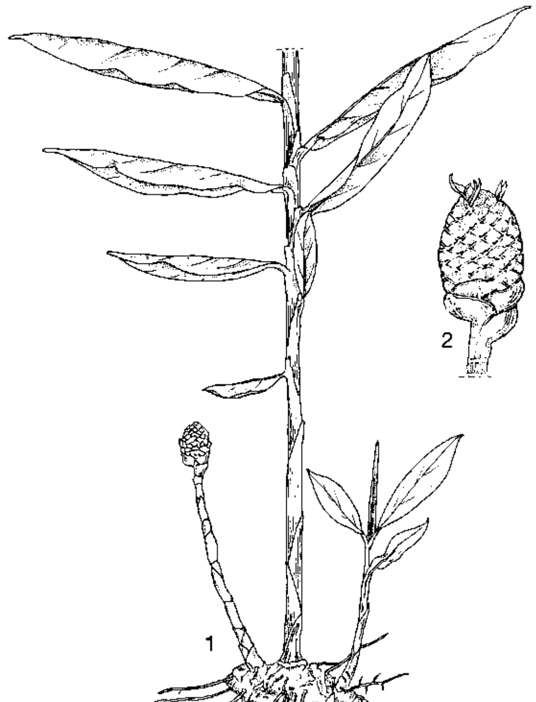
Properties The rhizomes of *Z. montanum* are usually larger than those of *Z. officinale*. They are valued for their aroma and taste. The odour has been described as strong and reminiscent of a mixture of ginger, camphor and turmeric, the taste as hot and camphorous. However, the rhizomes have also been reported to have a bitter and unpleasant taste. Dried rhizomes of *Z. montanum* yield 0.5% essential oil on steam distillation. The main constituent, terpinen-4-ol, is widely used in perfumery in artificial geranium, pepper, rose and other oils, (soap) perfumes and flavour compositions. Terpinen-4-ol has also been found to be effective against a range of pathogenic bacteria, including *Escherichia coli*, *Klebsiella pneumoniae*, *Salmonella paratyphi*, *S. typhi* and *Shigella flexneri*, and to have antifungal activity. The anti-inflammatory and antioxidant activity of *Z. montanum* rhizomes has been linked to the presence of curcuminoids. The anti-inflammatory as well as the analgesic and antipyretic effects have also been related to the presence of phenylbutenoids. The phenylbutenoid (E)-4-(3',4'-dimethoxyphenyl)-but-3-en-1-ol has shown relaxant effects on isolated rat uteri. Methanolic extracts of the rhizomes of *Z. montanum* and *Z. zerumbet* have shown cholagogic effects in anaesthetized rats. The fungitoxic activity of *Z. montanum* rhizomes against *Rhizoctonia solani* has been found to be due to zerumbone. *Z. montanum* rhizome extracts have shown insecticidal activity in bioassays with *Spodoptera littoralis* larvae, due to the presence of phenylbutanoids. *Z. montanum* rhizome extracts have also shown in vitro anthelmintic activity against *Ascaridia galli*.

Essential oil isolated from stems (0.01%) and leaves (0.027%) of *Z. spectabile* from Tahiti were found to contain 60–80% monoterpene hydrocarbons. The addition of powdered leaves of *Z. spectabile* and *Z. zerumbet* to cowpea (*Vigna unguiculata* (L.) Walp.) seeds led to a reduction in the number of *Callosobruchus* eggs.

The rhizomes of *Z. zerumbet* are thicker, but less aromatic than those of *Z. officinale*, whereas they are also said to be more bitter. Therefore, they are less valued for culinary purposes than those of *Z. officinale*. The rhizomes of var. *amaricans* have a sharp and intensely bitter taste, but no aroma, whereas those of var. *aromaticum* have a sharp and bitter taste and a pleasant aroma. The rhizomes of var. *zerumbet* are said to be aromatic, but to have a less agreeable odour and taste than var. *aromaticum*. They are also less sharp, and therefore considered less powerful than those of var. *aromaticum*. Essential oil obtained from fresh *Z. zerumbet* rhizomes (0.35–0.37%) from Vietnam and the Philippines contained monoterpenes and sesquiterpenes. The main constituent is the monocyclic sesquiterpene ketone zerumbone (35–72%). Zerumbone is also the major component of the stem oil (0.05%). The major compound of the essential oils from the leaves (0.07%) and the flowers (0.15%) of *Z. zerumbet* is (Z)-neridol. The methylene chloride soluble fraction of the rhizomes of *Z. zerumbet* contains zerumbone, zerumbone epoxide, curcumin, flavonols and flavonoid glycosides. Zerumbone from *Z. zerumbet* is reported to inhibit the growth of *Micrococcus pyogenes* and *Mycobacterium tuberculosis*. Zerumbone epoxide has shown in vitro cytotoxic activity against tumour (hepatoma) cells but little activity against normal fibroblasts, whereas zerumbone has shown toxicity against both. Curcumin is reported to have antioxidant activity. Methanol extracts of *Z. zerumbet* from Sri Lanka have shown antifungal activity against *Cladosporium cladosporoides*.

Adulterations and substitutes *Z. zerumbet* has been mentioned as an adulterant of *Z. officinale*, *Z. montanum* more as a substitute.

Description Erect, robust perennial herbs, with several leafy stems, 0.5–3.5 m tall. Rhizome horizontal, fleshy, aromatic, at or near soil surface. Leaves distichous, linear to oblong-lanceolate, petiole short or absent, ligulate, entire or deeply 2-lobed, plane of leaves parallel with the rhizome. Inflorescence a spike, usually radical, sometimes terminal on a leafy stem; scape erect, procumbent or very short at base of leafy stem; spike compact, fusiform or ovoid to cylindrical; bracts persistent, closely imbricating or with apices free, 1-flowered, initially green, yellow or reddish, later bright red or yellow; bracteoles 1 per flower, facing the bract, narrower than bract, usually persisting and enclosing the fruit; calyx hyaline, tubular-spathaceous, generally shorter than bracteole, 3-partite; corolla with slender tube, dorsal lobe broader than lateral ones, concave, lateral lobes below the lip, usually partly joined to each other and to the lip; labellum 3-lobed, midlobe oblong-obovate, apex cleft or retuse, with adnate, acute or rounded petaloid lateral staminodes forming the side-lobes, cream or white, sometimes purple-mottled; filament short, anther 1–1.5 cm long, narrow, connective prolonged into a slender, curved beak, embracing the style; stigma protruding below the apex of the appendage, with a circular apical aperture surrounded by stiff hairs; ovary 3-locular, with 2 epigyneous glands. Fruit a capsule, 3-locular, with axile placentation, dehiscing loculicidally within the bracts, wall fleshy when fresh, leathery when dry. Seeds numerous, ellipsoidal, maroon to black, with a white or yellow, saccate, fleshy, lacerate aril.



Zingiber zerumbet (L.) J.E. Smith – 1, habit; 2, inflorescence.

- *Z. montanum*. Rhizome pale orange inside, with strong aroma. Leafy stems 1.2–1.8 m tall with subsessile leaves. Leaf sheath glabrous or hairy near edges; ligule bilobed, hairy, about 2 mm long; blade linear, 20–35 cm × 2–4 cm, evenly narrowed to the tip, lower surface pubescent. Inflorescence fusiform or cylindrical-ovoid, 10–16 cm × 3–3.5 cm, apex acute, on erect scape 20–25 cm long; bracts ovate, 3–3.5 cm long, pubescent, brownish-green, edges papery; bracteole 1–1.5 cm long; calyx 1.2 cm long; corolla 6 cm long, pale yellow, labellum 6 cm long, pale yellow, midlobe 2 cm long, broadly rounded, apex bilobed, deeply split when old, side-lobes oblong.
- *Z. spectabile*. Leafy stems 2.0–3.5 m tall, basal leafless stem part up to 1 m tall, swollen at base. Leaf sheath sparsely pilose, margin scarious; ligule deeply 2-lobed, lobes up to 1.5 cm long, broad, pale green; blade lanceolate, 30–50 cm × 6–10 cm, glabrous or slightly hairy at the base below. Inflorescence a cylindrical spike, 10–30 cm × 6–7 cm, with rounded apex; scape radical, erect, 20–40 cm long; bracts obovate, 4.5 cm long, turning red from yellow through orange, fleshy, curved outwards with the edge incurved forming pouches; bracteole linear, up to 4 cm long; calyx up to 3.5 cm long, cream to pinkish; corolla 7 cm long, yellow, dorsal lobe up to 3 cm × 1.7 cm, lateral lobes 1.8 cm × 0.6 cm, labellum 4–6 cm long, dark purple with yellow spots, midlobe ovate, 1.6 cm × 1.4 cm, shorter than or as long as the lateral corolla lobes, apex cleft, side-lobes 1 cm × 1 cm, broadly rounded; anther yellow, anther appendage purple. Fruit an ovoid capsule, 3 cm × 1 cm, sparsely pilose.
- *Z. zerumbet*. Rhizome tuberous, aromatic, pale to brighter yellow inside. Leafy stems 1.25–1.75 m tall. Leaf sheath sparsely hairy; ligule entire, 1.5–2.5 cm long, papery, scarious; petiole finely

hairy; blade broadly lanceolate, 25–40 cm × 5–8 cm, apex acuminate. Inflorescence a cylindrical to ovoid spike, 6–14 cm × 4–5 cm, apex obtuse; scape radical, erect, 10–30 cm long, sheath green; bracts obovate, 3–4 cm × 2.5 cm, green when young, red when old, convex near upper edge, apex broadly rounded with papery margin; bracteoles linear to lanceolate, 2.5–3.5 cm long; calyx 2.5 cm long, shorter than bracteole, white; corolla 5.5 cm long, lemon yellow, dorsal lobe 2.5 cm × 2 cm, lateral lobes 1.6 cm × 0.7 cm; labellum 5.5 cm long, with crenate margin, white or yellow, midlobe oblong to almost round, 1.5 cm long, apex cleft, side-lobes ovate, 0.8 cm long; anther pale yellow. Fruit a cylindrical capsule, 1.5 cm long, red.

Growth and development In Malaysia, *Z. spectabile* flowers from July to September and fruits in November, whereas *Z. zerumbet* flowers in the period from June to September and fruits from October to January. *Z. spectabile* inflorescences from Malaysia may contain 95–175 flowers. Only a few flowers are produced on an inflorescence at a time, with flowering occurring over 40–55 days in an acropetal sequence. The flowers last less than 24 h and open between 10 a.m. and 2 p.m.

Other botanical information *Z. purpureum* Roscoe or *Z. cassumunar* Roxb. has long been considered to be a different species from *Z. montanum* (Koenig) Dietrich. *Z. montanum* is based on *Amomum montanum* Koenig, a name for which, for a long time, only a description existed. When type material of *A. montanum* was rediscovered it has become clear that the 3 taxa are the same species. *Z. montanum* is related to *Z. zerumbet* but can be easily distinguished by the linear leaves, the very short ligules and the brown bracts.

Z. spectabile can be easily recognized by the large (largest in Malesia), orange inflorescence with incurved bracts forming open pouches.

Z. zerumbet is an extraordinarily variable species, also in respect to the rhizome. The following groups (here considered varieties) have been described as separate species but are not sharply delimitated:

- var. *amaricans*: spikes ellipsoidal, 1.7–2 times longer than wide, apex rounded, bracts with involute apex, occurring wild and cultivated;
- var. *aromaticum*: spikes ovoid, 2–2.5 times longer than wide, apex acute, bracts with flat apex, occurring wild and cultivated;
- var. *zerumbet*: spikes subglobose, 1.5–1.7 times longer than wide, apex rounded, bracts with flat apex; occurring wild and cultivated.

A fourth group, only occurring wild, can be distinguished, but no specific uses are reported:

- var. *littorale* (Valeton) Theilade: spikes spindle-shaped or oblong-globose, 3–5 times longer than wide, apex acute, bracts often with incurved apex, occurring only wild;

The rhizomes of *Z. mioga* (Thunb.) Roscoe (mioga ginger), cultivated in Japan, China and Hawaii, have a bergamot-like flavour and are the source of Japanese ginger, whereas the flowers, fruits and sprouts are used for flavouring.

Ecology *Zingiber* is commonly found in moist, partially shaded evergreen and monsoon forests on soils rich in organic matter, but also in secondary forests, open habitats at forest edges, disturbed sites and bamboo thickets on rocky soils, at altitudes up to 3000 m. *Z. spectabile* grows in evergreen forests, but also along trails, roadsides, streams and forest edges, on hillsides and disturbed sites, at altitudes up to 1000 m. *Z. zerumbet* is cultivated or naturalized in forest margins, brushwood, mixed forests, teak forests and waste places near villages, at altitudes up to 1200 m. In Java, *Z. montanum* is found up to 1300 m.

Propagation and planting *Zingiber* is generally propagated by division of rhizomes. Propagules should be 4–7.5 cm long and weigh 50–80 g, but those of *Z. zerumbet* should weigh 70–100 g. The propagules must be kept moist in order to prevent drying out. To plant 1 ha, 1–2.5 t of planting material is needed.

Z. spectabile has also been propagated in vitro by placing rhizome axillary buds on Murashige and Skoog medium with various combinations of plant growth regulators, such as indole-3-acetic acid (IAA), naphthaleneacetic acid (NAA) and 6-benzyladenine (BA) at 26°C and 16 h photoperiod.

Zingiber can be planted on level fields or on raised beds. Raised beds 40–50 cm high, surrounded by ditches 30–40 cm deep are recommended, because the plants do not tolerate waterlogging. The soil should be well tilled to a depth of 40 cm. Plenty of organic matter, some sand, and limestone can be added to improve the soil. Planting holes should be 5–10 cm deep and plant spacing 30–50 cm × 60–90 cm. When supplemental irrigation is not used, it is advisable to plant during the rainy season to ensure rapid crop establishment and optimal growth.

Husbandry *Zingiber* plots must be weeded and irrigated regularly. The soil around the plants should be loosened every month, taking care not to injure the underground organs. *Zingiber* is prone to lodging, especially in windy areas, so should be staked. One stake per clump is recommended, with stems loosely tied to the stakes halfway up. The crop may be fertilized with standard NPK fertilizer.

Diseases and pests *Udaspes* sp. and *Kerranadiocles* sp. are reported as diseases on *Zingiber* and can be controlled with fungicides. *Zingiber* is attacked by several insect pests, including *Tribolium* sp., which bores into the stem, and *Agrotis ipsilon* grubs attacking the underground organs.

Harvesting Rhizomes of *Zingiber* are generally dug up when about 1 year old, but may be harvested earlier. The soil around the plant should be moistened to facilitate harvesting and to minimize damage to the rhizomes.

Yield In Indonesia, yields of fresh rhizomes of *Z. zerumbet* range from 18–25 t/ha for var. *amaricans* and var. *aromaticum*, and from 20–32 t/ha for var. *zerumbet*.

Handling after harvest Harvested rhizomes of *Zingiber* are used either fresh, in which case they are washed, sliced or grated, or dried. In the latter case they are cleaned, cut into thin strips, air-dried and, once dry, ground into powder.

Genetic resources and breeding As *Z. montanum* and *Z. zerumbet* are widely found throughout South-East Asia, they are not threatened genetically. There are no known germplasm collections and breeding programmes.

Prospects The role of these *Zingiber* species as spices will remain limited compared with that of *Z. officinale*. Increased interest worldwide, and especially in South-East Asia, for traditional medicines and cosmetics may spur commercial production, especially for *Z. montanum* and *Z. zerumbet*. The identification of active components in different plant parts, especially the rhizome, may lead to increased research and production.

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Zingiber officinale Roscoe

Trans. Linn. Soc. London 8: 348 (1807).

ZINGIBERACEAE

$2n = 22$; tetraploids with $2n = 44$ have been chemically induced

Synonyms *Amomum zingiber* L. (1753).

Vernacular names Ginger, common ginger (En). Gingembre (Fr). Indonesia: jahe, jae, lia. Malaysia: haliya, jahi, atuja. Papua New Guinea: kawawar, kawawari. Philippines: luya (Tagalog), baseng (Ilocano), laya (Bicol). Burma (Myanmar): gyin. Cambodia: khnhei, khnhei phlung. Laos: khi:ng. Thailand: khing, khing-daeng. Vietnam: g[uwf]ng, sinh kh[uw][ow]ng.

Origin and geographic distribution Ginger has been grown in tropical Asia since ancient times. Wild forms of ginger have not been found and its origin is uncertain, although it is thought to come from India. It was brought to Europe and East Africa by Arab traders from India. Together with pepper, ginger was one of the most commonly traded spices during the 13th–14th Centuries. From East Africa, the Portuguese brought ginger to West Africa and other regions of the tropics during the 16th Century. At about the same period the Spanish introduced ginger into Jamaica, which still produces high quality ginger. At present, ginger is cultivated throughout the humid tropics.

Uses Ginger is widely used as a spice, with its three main products being fresh ('green') ginger, dried whole or powdered ginger, and preserved ginger. Fresh ginger is prepared from immature or mature rhizomes, the more pungent and aromatic dried ginger from mature rhizomes, and preserved ginger from immature rhizomes. The dried and preserved products are the major forms of internationally traded ginger, whereas fresh ginger is the major form of ginger consumed in the producing regions.

Fresh ginger is widely used in cooking in South-East Asia, as a flavouring or vegetable, and young rhizomes and stem parts are sometimes eaten raw, e.g. as 'lalab'. Fresh ginger is also used to make ginger ale and other drinks. Ground dried ginger is applied worldwide for domestic culinary purposes, and also extensively in the flavouring of processed foods, especially in bakery products and desserts. Preserved ginger is used for domestic culinary purposes and in the production of processed foods such as jams, marmalades, cakes and confectioneries.

The fresh and dried rhizomes yield an essential oil ('ginger oil') and oleoresin ('ginger extract'). Ginger oil has the aroma and flavour of the spice, but lacks pungency. It is used for flavouring beverages, in confectionery, and in cosmetics, perfumes and pharmaceuticals. Ginger oleoresin has the aroma, flavour and pungency of the spice itself. It is used for flavouring beverages and for similar purposes as the ground spice. It is seldom applied in cosmetics and perfumes because of its poor solubility in alcohol, but is used more often in pharmaceuticals. In the United States the regulatory status 'generally recognized as safe' has been accorded to ginger (GRAS 2520), ginger oil (GRAS 2522) and ginger extract/oleoresin (GRAS 2521/2523).

Ginger has been used medicinally in Asia since ancient times, e.g. in China and India. It is still widely used in folk medicine, especially as a carminative, stimulant of the gastro-intestinal tract, rubefacient and counter-irritant. In Asia, the rhizome is also considered to have diaphoretic, diuretic, anti-inflammatory, anti-emetic and sialagogic properties, and it is used as an emmenagogue, abortifacient and vermifuge, whereas it also had a reputation as an aphrodisiac. Rhizome products are applied against a wide range of ailments, including nausea, diarrhoea, dysentery, dyspepsia, flatulence and other gastro-intestinal problems, fever, cough, colds, congestion of the chest, pleurisy, cramps and dropsy. Rhizome juice is used against migraine, catarrh, colic and to relieve menstrual cramps. Crushed rhizomes are applied externally against headache, toothache, rheumatism, intestinal problems, itch, boils and swellings. Various lotions, decoctions or poultices are rubbed on the body after childbirth, applied to swellings and bruises, used against rheumatism and to make baths against fever. In Malaysia, leaves are eaten against stomachache and rheumatism, pounded leaves are used externally for poulticing to treat headache, leaf juice is applied externally against ague in children, and young shoots may be used for lotions against rheumatism. In the Philippines, ginger tea is traditionally drunk to prevent hoarseness. Ginger is also applied as an antidote against snake poison in Indonesia, and fish and crab poison in China.

Ginger products, mainly the oleoresin, are official in several European pharmacopoeias and are used as ingredients in digestive, laxative, antitussive, carminative, antiacid and anti-emetic preparations.

Production and international trade The bulk of the production of ginger is consumed locally in the producing countries, mainly as fresh ginger. In the 1980s, world production was estimated at about 100 000 t per year, of which about 25 000 t were exported, mainly by India (15 000 t). Other sources estimated annual world production of ginger in the early 1980s at 300 000 t, growing steadily to 500 000 t in 1990 and 600 000 t in 1998, with India, China, Indonesia and Nigeria being the main producers. In South-East Asia large amounts are also produced in the Philippines and Thailand. World production of ginger oil in the 1980s was estimated at 30 t annually, of which 20 t were exported, mainly by India (6–12 t) and China, the main markets being the United States, the European Union and Japan. The world production of ginger oleoresin was in the 1980s about 150 t annually, with the major producers being the United States, India and Singapore.

Properties Dried ginger rhizomes contain per 100 g edible portion: water 10 g, protein 10–20 g, fat 10 g, carbohydrates 40–60 g, fibre 2–10 g and ash 6 g. A high fibre content is undesirable in rhizomes to be used as a spice.

The constituents responsible for the pungent taste are non-volatile phenols, the so-called gingerols, shogaols (dehydration products of gingerols), paradols and zingerone (a degradation product of gingerols), with [6]-gingerol being the most important. Freshly prepared dried rhizomes contain 1–2% gingerols.

The odour and much of the flavour is determined by the constituents of the pale yellow to orange-yellow essential oil, which has a rich, warm, spicy, somewhat lemony odour and a warm, spicy, aromatic taste. The essential-oil content of the rhizomes is usually 1–3% for the major types of commercial dried ginger. Though essential-oil yields above 3% are exceptional, yields up to 6% have been obtained from selected strains at experimental stations. The essential oil is a complex mixture of terpenes and non-terpenoid compounds. Compounds usually detected are α-zingiberene, β-zingiberene, ar-curcumene, β-sesquiphellandrene, α-farnesene and β-bisabolene (sesquiterpene hydrocarbons), and neral and geranial (oxygenated monoterpenes). On drying of the rhizomes, the monoterpene content of the oil decreases and the sesquiterpene content increases.

Ginger oleoresin contains pungent principles (gingerols and shogaols) as well as essential oil, together with fatty oil, fatty acids, resins and carbohydrates. It is a dark amber to dark brown viscous liquid, with an aromatic, warm, spicy, sweet odour, and a pungent, warm and biting taste. Extraction of the dried spice with organic solvents yields 3.5–10% oleoresin, containing 15–30% volatile compounds.

The types of ginger entering the world market are identified by their origin of production. Each type possesses a characteristic aroma and flavour mainly influenced by cultivar, ecological conditions and the production and post-harvest practices employed. Major ginger types come from Jamaica, Nigeria, Sierra Leone, India, Australia and China. Jamaican ginger is highly reputed because of its good appearance and delicate aroma and flavour. Cochin ginger from southern India is of comparable quality. Nigerian ginger has a coarser flavour and aroma, with pronounced camphoraceous notes; its high oil content and strong pungency makes it in demand for oil distillation and oleoresin extraction, as is the case with Sierra Leone ginger. Indian ginger has a lemon-like flavour and aroma, is more starchy, rather pungent, and sought after by ginger beer manufacturers. Chinese ginger has been the standard for ginger preserved in syrup. Most gingers are suitable for oleoresin production, but Jamaican ginger oleoresin is preferred by soft-drink manufacturers and African ginger oleoresin by the meat industry.

With regard to the medicinal properties, ginger exhibits antispasmodic and anti-inflammatory activity, helps reduce cholesterol, lower blood pressure and shrink liver tumour in test animals. In humans rhizome powder is effective against nausea, e.g. post-operative nausea, motion sickness and morning sickness. The principles responsible for this anti-emetic activity might be [6]-, [8]- and [10]-shogaols and [6]-, [8]- and [10]-gingerols. Ethanolic rhizome extracts have shown inhibition of skin tumour promotion in mice. Zingiberene, β-sesquiphellandrene, ar-curcumene and [6]-shogaol show anti-ulcer principles. Furthermore, [6]-gingerol has been shown to be a cholagogue after intraperitoneal administration in rats, and [8]-gingerol to have hepatoprotective activity, as it prevents the toxic effects of carbon tetrachloride in rat hepatocytes.

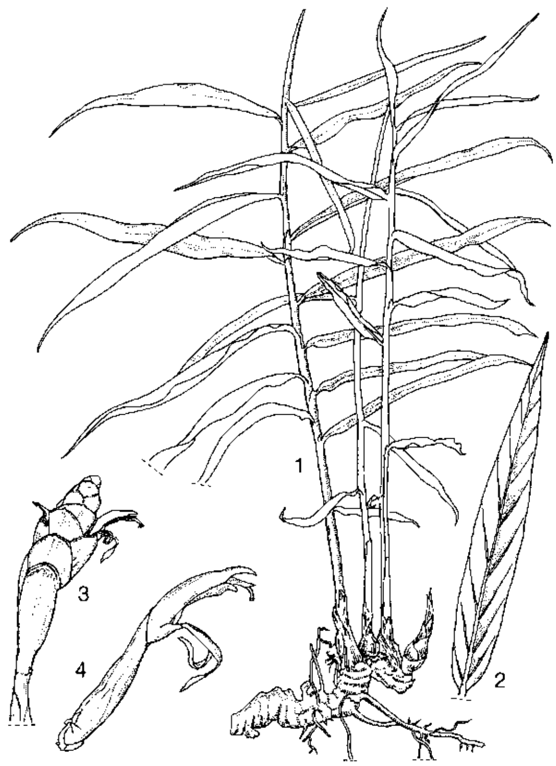
Ginger oil has considerable antifungal and antibacterial activity, and is used as a seed dressing in India. Meat cooked with fresh rhizomes becomes more tender due to the action of the proteolytic enzyme zingibain.

A monograph on the physiological properties of ginger oil has been published by the Research Institute for Fragrance Materials (RIFM) and by the European Scientific Cooperative on Phytotherapy (ESCOM).

Adulterations and substitutes Several *Zingiber* species produce a spice or an essential oil used as adulterants of or substitutes for *Z. officinale*, e.g. *Z. spectabile* Griffith, *Z. montanum* (Koenig) Dietrich, *Z. mioga* (Thunb.) Roscoe and *Z. zerumbet* (L.) J.E. Smith.

Ginger oil is sometimes adulterated with monoterpene hydrocarbons.

Description Erect, slender, perennial herb usually grown as an annual, with a thickened, fleshy, subterranean rhizome and with one or more aerial leafy stems, up to 1.25 m tall. Rhizome robust, fleshy, up to 2 cm thick, growing horizontally underground but at shallow depth, irregularly branched but normally only in the vertical plane, covered with deciduous, thin scales which leave ring-like scars; epidermis corky, pale yellow to reddish, irregularly wrinkled in the dried rhizome; flesh pale yellow, aromatic; on dried rhizomes scars of leafy stems visible as shallow cup-like holes. Stem erect, unbranched, mainly formed by the leaf sheaths, pale green, often reddish at base; scales covering the lower part oblong, about 6 cm × 1 cm, scarcely white-pilose outside, with prominent parallel veins and scarious margins. Leaves distichous; sheath prominently veined, densely appressed pilose, especially so in the upper part, with white, scarious, glabrous margins; ligule up to 5 mm long, bilobed, glabrous to sparsely pilose, scarious; blade linear to lanceolate, up to 30 cm × 2 cm, acuminate at apex, finely parallel-veined,



Zingiber officinale Roscoe – 1, habit; 2, leaf; 3, inflorescence; 4, flower.

glabrous above, scarcely pilose below, light to dark green. Inflorescence arises direct from rhizome, spiciform, 15–30 cm long; scape slender, 10–20 cm long, below the spike covered with scales as on the leafy stem bases, the upper ones sometimes with short leafy tips; spike ovoid to narrow ellipsoidal, 4–7 cm × 1.5–2.5 cm, light green; bracts appressed, ovate to elliptical, 2–3 cm × 1.5–2 cm, yellow-green, margin scarious, incurved, the lower ones with slender whitish acute tips, glabrous, finely parallel-lined; in the axil of each bract one flower may be produced; flowers fragile, short-lived, surrounded by a spatha-like bracteole; bracteole narrower and slightly longer than the bract, usually persisting and enclosing the fruit; calyx tubular-spathaceous, 10–12 mm long, whitish; corolla tubular, pale yellow, widening at top into 3 lobes, tube 18–25 mm long, dorsal lobe long ovate, 15–25 mm × 7–8 mm, with beak-like rounded apex curved over the anther, ventral lobes oblong, 13–15 mm × 2–3 mm, apex rounded, 3-veined, strongly recurved; labellum about circular in outline, 12–15 mm in diameter, tubular at base (tube 3–4 mm), 3-lobed above; central lobe obovate, 12 mm × 9 mm, side lobes elliptical, 5 mm × 3.5 mm; labellum pale yellow outside, inside dark purple or red at top and at margins, mixed with yellowish spots, scattered pilose at throat; filament about 1.5 mm long, anther 2-celled, ellipsoidal, 7–9 mm × 3 mm, pale yellow, connectivum prolonged into a slender, curved, purple, beak-like appendage 7 mm long, enclosing the upper part of the style; ovary globose, 2 mm in diameter, 3-locular; style filiform, 3.5 cm long, white, slightly recurved and widening at top, ending in a funnel-shaped white stigma which is ringed with stiff hairs around its upper margin; 2–3 fleshy, sublinear, white nectaries, 5 mm long, are situated against the style on top of the ovary. Fruit a thin-walled capsule, 3-valved, red. Seed small, arillate, black.

Growth and development The first shoots of ginger appear 10–15 days after planting the rhizomes, and new shoots appear continuously until about 4 weeks after planting. Each shoot has about 8–12 leaves.

Flowering is cultivar-dependent. Some cultivars flower rarely, others regularly, especially when grown undisturbed as perennials. In Malaysia ginger flowers only rarely. Ginger fruits are seldom produced.

Ginger rhizomes normally only branch in the vertical plane, so they are flat on the sides and stand upright in the soil. They have a main axis, with at least one side axis to the left and the right, with these side axes again forming 2 side axes, etc. Only some of the side axes develop aboveground shoots.

Other botanical information Various ginger types have been characterized in Malaysia, e.g. the 'haliya betai', the true ginger possessing pale-coloured rhizomes and the 'haliya bara' and 'haliya indang' with very pungent reddish rhizomes used primarily in medicine. Taxonomically, the two main groups can be named: *Z. officinale* cv. group Officinale, which is cultivated throughout the tropics, and *Z. officinale* cv. group Rubrum ('haliya padi'), grown on a small scale in South-East Asia for medicinal use and as a spice. The latter differs from the former by having smaller, red-coloured rhizomes with a stronger and more pungent odour, the red colouring of the basal parts of leafy stems and petioles, larger leaves, and by the presence of a larger, scarlet-red mottled labellum. In Indonesia, three types of ginger have been distinguished: (1) 'jahe gajah', 'jahe badak' or 'jahe putih besar'; (2) 'jahe merah' or 'jahe sunti'; (3) 'jahe putih kecil' or 'jahe emprit'. Their rhizomes differ in shape, colour, aroma and chemical composition, and all types can be considered as cultivars.

Ecology Ginger is grown in the tropics from sea-level up to 1500 m altitude, but is mostly found at low altitudes. The crop prefers warm, sunny conditions, and though it may benefit from shade during hot periods, especially when young, shading is generally considered unnecessary. The optimum rainfall is 2500–3000 mm, well-distributed over the year. Below 2000 mm, supplementary irrigation is necessary, but ginger seldom succeeds as an irrigated crop in dry areas, because the required humidity cannot be maintained profitably. Ginger is very sensitive to waterlogging.

The preferred soils are medium loams with an adequate supply of organic matter, but ginger is grown on a wide range of soils with a pH of 6.0–7.0. As it is an exhaustive crop, the soil fertility must be high or manure should be applied.

Propagation and planting Ginger is propagated vegetatively by pieces of rhizome called seed pieces or sets. They are normally produced by cutting rhizomes into 3–6 cm long pieces of 30–60 g, with at least one growing point or bud. Medium to large-sized seed pieces produce more vigorous plantlets and higher yields than small ones. To prevent diseases, seed pieces may be dipped in a fungicide solution and air-dried prior to planting. Seed pieces can be pre-germinated to obtain uniform plants, reduce the number of missing hills in the field and allow for once-over harvesting. Pregermination may be promoted by placing the sets 2.5 cm apart on raised beds, covered with compost, sawdust or manure or both and kept moist. The sets are ready for transplanting after 3–5 weeks or when the sprouts are 1–2 cm long.

In vitro micropropagation of ginger from shoot tips, meristems or rhizome sections is possible. A suitable growth medium for shoot multiplication is a modified Murashige-Skoog medium, supplemented with 2–3 mg/l of 6-benzylaminopurine. Through in vitro propagation, it is possible to obtain large quantities of disease- and pest-free planting material, but little is known about the performance of micropropagated ginger in the field. Micropropagated plants in an Indian study needed 10 months to reach the same yield and oleoresin levels as conventionally propagated ginger after 8 months. Under field conditions in Queensland, growth and yield of micropropagated plants of the first generation ex vitro were inferior to those of plants derived from seedpieces, but by the second generation, the differences had disappeared. Micropropagation is already used in the Australian ginger industry for rapid multiplication of promising new cultivars, which are then propagated by more conventional methods.

Before planting ginger, the field should be thoroughly prepared to a fine tilth, free of weeds, roots and residues of previous crops. Normally, ginger is planted in rows, with 25–30(–50) cm between rows and 15–35 cm within the row. In the Philippines, the recommended planting distance is 50–70 cm between rows and 30 cm within the row. The normal planting depth is 5–12 cm, with one seedpiece per hole. In the fully mechanized estates in Queensland, 8–10 t of sets are needed to plant 1 ha: under less intensive conditions in India and Sri Lanka 1.5–4 t/ha are needed.

At planting time the soil must be moist and not dry out once the sets are planted. The preferred soil temperature at planting is 25°C and should not exceed 30°C. Planting in the Philippines takes place in May. Recommended planting time is March–April in India, and September in Queensland.

It is recommended to practise rotation and to grow ginger only once in 3–4 years, to reduce the incidence of pests and soilborne diseases. Ginger is often found in intercropping systems. It is often the first crop on land taken into cultivation.

In vitro production of active compounds The essential oil in ginger rhizomes of plantlets, produced in vitro from shoot-tips on different growth media, has been reported to contain the same constituents as the oil of the original rhizome, but the quantities of these constituents varied with basal medium composition and the amount of growth regulators added.

Husbandry For optimal yields and high quality production it is essential to weed ginger. Manual weeding is common, and any rhizomes that have become exposed are covered at the same time. Manual and mechanical weeding should be shallow, to avoid damaging to the rhizomes.

Mulching may be practised to conserve soil moisture and reduce soil temperature. Materials used for mulching include coconut fronds, sawdust, rice husks or straw, sugar cane trash and sheet polythene.

Normally, 100 kg/ha of N is required, of which at least one third should be applied at planting, and the remainder in 1–3 top dressings. Phosphate should generally be applied in similar amounts as nitrogen, preferably at planting. Potassium is normally applied at planting, but can also be given in several applications. Fertilizers are sometimes applied in the form of specifically manufactured 'ginger mixtures' (e.g. 8-8-16 in India, 13-13-21 in Fiji and 12-14-10 in Australia). In the Philippines 50 t fresh rhizomes removed about 247 kg N, 71 kg P_2O_5 and 100 kg K_2O per ha from a loamy soil. It was therefore recommended that for soils of low fertility 250 kg N, 100 kg P_2O_5 and 100 kg K_2O per ha should be applied at 4 different times during the growing season: 100 kg N and the total amount of P and K just before or at planting, and the remaining N in equal side dressings at 60, 90 and 120 days after planting.

Diseases and pests In general, diseases are more damaging in ginger than pests, so disease prevention or control is an essential component of commercial ginger growing. The most important diseases are rhizome rots, often caused by *Pythium* spp., *Fusarium* spp. and *Rosellinia* spp. The main symptom is degeneration of rhizomes into a black, putrefying mass, whereas aboveground the leaf tips, sheaths, margins, and gradually whole leaves turn yellow, followed by desiccation and death. Another widespread and serious disease is bacterial wilt, caused by *Pseudomonas solanacearum*, which occurs for instance in Indonesia, Malaysia, the Philippines and Thailand. The symptoms include progressive yellowing and wilting from the lower leaves to the whole plant, with badly affected stems and rhizomes yielding a milky exudate when cut. Leaf spots caused by *Colletotrichum* spp., *Helminthosporum* spp., *Cercospora* spp. and *Septoria* spp. are also common.

Most insect pests are only of local importance. However, foliage pests may become damaging in a specific location or season. The most important foliage pest in Asia, especially India, is the shoot borer *Dichocrocis punctiferalis*. In the Philippines the shoot borer *Ostrinia furnacalis* is an important insect pest. Ginger is also attacked by nematodes (*Meloidogyne* spp.), inducing the formation of galls or swellings on the roots. Severe infestations may lead to the death of the crop.

Control measures for the above diseases and pests include choosing a well-drained site for ginger cultivation, practising crop rotation and selecting healthy rhizomes and treating them with fungicides before planting.

Harvesting Timing of harvesting of ginger rhizomes depends on their intended use, as the relative content (on a dry weight basis) of essential oil, pungent constituents and fibre increases with age of the crop. The content of essential oil and the pungent principles of the rhizomes reaches a maximum about 9 months after planting, decreasing later on, whereas the fibre content continues to increase. When intended for consumption as a fresh vegetable (green ginger), rhizomes may be harvested about 5 months after planting. For the production of preserved ginger, they are usually harvested 5–7 months after planting, before they are fully mature and while still tender, succulent and mild in pungency, and with low fibre content. For dried ginger, mature rhizomes that have developed a full aroma, flavour and pungency are used. These are harvested 8–9 months after planting, when leaves begin to yellow and stems start to lodge. Harvesting is accomplished either by hand with a spade, hoe or digging fork, or by mechanical diggers. Harvesting should be done very carefully, to minimize damage to the rhizomes.

Yield Generally, it can be assumed that ginger rhizomes lose about 75–80% of their weight during drying. Yields of dried rhizomes from smallholdings are usually below 3 t/ha, compared with 10–15 t/ha obtained on commercial farms in Australia. In Africa and the Caribbean, yields are seldom higher than 2 t/ha. In the Philippines, the average commercial yield of fresh ginger is 6–7 t/ha.

Handling after harvest To prepare dried ginger, fresh rhizomes are washed and soil particles, roots and shoots are removed. Rhizomes are then killed by immersion in boiling water for ten minutes, or by peeling, scraping or slicing, and then dried. Rhizomes with the peel either carefully scraped off ('uncoated' or 'white' ginger) or retained ('coated' or 'black' ginger) are usually sun-dried for several days to yield the dried ginger of commerce. Uncoated ginger is sometimes treated with lime to improve its white colour and reduce insect attack. Dried rhizomes can be pulverized to produce ground ginger. In Australia, mechanical washing and drying are practised.

Ginger oil and oleoresin can be obtained from fresh or dried rhizomes. Ginger oil is obtained by steam distillation, oleoresin by extraction with organic solvents such as acetone, alcohol or ether. Both coated and uncoated ginger can be used for oil distillation and oleoresin extraction, but coated rhizomes are preferred. Oil yields from coated rhizomes are higher than from uncoated ones, as the epidermal tissue is rich in oil-containing cells. The presence of pungent compounds responsible for the taste of ginger oil can be substantially reduced by poor post-harvest handling or improper distillation.

Ginger rhizomes are often heavily contaminated with microorganisms that can be treated with ethylene oxide or gamma irradiation to avoid health problems. In most importing countries, dried gin-

ger has to meet strict quality and cleanliness criteria, commonly based on the American Spice Trade Association (ASTA) specifications.
Rhizomes to be used as planting material can be stored in many ways. A simple method is to leave a part of the field unharvested, cut the foliage, cover the field with mulch and dig up the rhizomes when needed. Other methods are pit storage, used e.g. in India, where mature rhizomes are treated with a fungicide, shade-dried and placed in pits, which are then covered, and storage in smoke houses. Cold storage is not recommended, because rhizome viability is gradually reduced and may become zero after short periods below 0°C.

Genetic resources There are many locally important ginger cultivars. More than 400 ginger accessions are maintained at the Indian Institute for Spices Research in Calicut, Kerala, India, and new collections are added from time to time. In Indonesia, 45 ginger accessions collected from all over the country are being maintained at the Research Institute for Spices and Medicinal Crops in Bogor.

Breeding Breeding of ginger has been severely hampered by poor flowering and seed set. Moreover, cultivars are rather uniform because of vegetative propagation. Hence most of the crop improvement programmes are confined to the evaluation and selection of the naturally occurring clonal variation and the introduction of cultivars from abroad. In India, work is also being done on in vitro selection for resistance to rhizome rot and bacterial wilt.

Prospects Ginger is a popular spice, and its consumption will probably increase. However, further increases in yield and production are hampered by the major diseases (rhizome rot and bacterial wilt) for which more effective control measures need to be developed. Improving seed set is important to facilitate breeding work. Locally, as in the Philippines, the current high price of fresh ginger on the local market may provide an incentive for farmers to venture into ginger production. However, it is often difficult to obtain large quantities of planting material, and to overcome disease and post-harvest problems.

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3 Minor spices

Alpinia globosa (Lour.) Horan.

ZINGIBERACEAE

Synonyms *Amomum globosum* Lour.

Vernacular names Round Chinese cardamom (En). Vietnam: s[ej] (northern), m[ef] tr[ef] (southern).

Distribution Southern China and Vietnam.

Uses The seeds are used as a condiment, but they are more popular as a medicine (taken as a decoction) against disorders of the intestines such as colic, stomach-ache, dysentery.

Observations Erect, perennial herb, up to 1.3 m tall. Leaves ovate-oblong, 60 cm × 12 cm, margin finely dentate-ciliate, apex acuminate, glabrous. Inflorescence terminal, spike-like, each bract with 4 flowers; flower 3 cm wide, white-reddish. Fruit a globose capsule, up to 1 cm in diameter, with brittle, whitish pericarp. Seeds 5–7, three-angled, compressed, slightly lobed at top, greyish, aromatic. *A. globosa* flowers in June in Vietnam and may also be of interest to other countries in South-East Asia.

Selected sources 65, 83.

Amomum acre Valeton

ZINGIBERACEAE

Vernacular names Indonesia: panasa, panasan, pane (southern Sulawesi).

Distribution Indonesia (southern Sulawesi).

Uses The fruits and inner part of petioles are cut into small pieces, pickled in vinegar and subsequently added to food as a pungent condiment. The seed-coat and very young stem are sometimes directly used as a pungent condiment.

Observations Fruit ellipsoidal, 3 cm × 2 cm, pale yellow-white, somewhat angular and with short thin spines. *A. acre* grows in mountainous areas. It is poorly known; only the fruit has been described. According to Rumphius 2 different forms are distinguished: 'rombo' and 'kautopi'. *A. acre* fruits resemble those of *Etlingera rosea* Burtt & Smith, which are smaller and bear more spines.

Selected sources 40, 94.

Amomum aromaticum Roxb.

ZINGIBERACEAE

Synonyms *Geocallis fasciculata* Horan.

Vernacular names Bengal or Nepal cardamom (En). Vietnam: th[ar]o qu[ar].

Distribution Tropical eastern Himalayas (Bangladesh, India (Assam), Nepal), wild and cultivated. Possibly cultivated also in Vietnam.

Uses Seed used as a spice and medicinally, in the same way as other cardamoms.

Observations Herb with rhizome from which leafy shoots and separate inflorescences appear. Leafy stem about 1 m tall. Leaf oblong-lanceolate, 15–30 cm × 5–10 cm, glabrous. Inflorescence a short- peduncled, small globose spike; flower with pale yellow labellum that is twice as long as the corolla segments, and anthers with a large, petaloid, 3-lobed connectivum. Fruit an oblongoid-trigonal capsule, about 2.5 cm long. *A. aromaticum* flowers in the dry season and fruits in September. The seed contains cineol. It is possibly of interest for South-East Asia.

Selected sources 12, 43, 60, 81.

Amomum ochreum Ridley

ZINGIBERACEAE

Vernacular names Malaysia: tepus batu (Peninsular).

Distribution Peninsular Malaysia.

Uses The seeds are used as a substitute for true cardamom but they are reputed to be insipid.

Observations Herb with underground rhizome emitting leafy shoots at 5–12 cm intervals and separate inflorescences. Leafy shoot 1–5 m tall, basal half covered with sheaths only; ligule unlobed, about 7 mm long; petiole 1–3 cm long; blade oblong, 40–52 cm × 8–10 cm, base rounded, apex with a point 5 cm or longer. Inflorescence spike-like, 5 cm long at flowering, 10 cm when fruiting; peduncle 8–20 cm long; flower with obovate, 3-lobed labellum, about 3 cm × 3 cm, orange-yellow, with red veins and spots; anther appendage transversely oblong, about 1 cm × 3 mm, faintly red-spotted. Fruit globose, 4.5 cm in diameter, with few blunt fleshy spines. Seed irregular, about 1 cm long, covered with a thin aril. *A. ochreum* occurs rather commonly in the hills of Peninsular Malaysia at moderate altitudes.

Selected sources 12, 42, 79.

Amomum subulatum Roxb.

ZINGIBERACEAE

Synonyms *Cardamomum subulatum* (Roxb.) Kuntze.

Vernacular names Bengal or Nepal cardamom, winged cardamom, greater cardamom (En).

Distribution Eastern Himalayas, Nepal. In Nepal and India also cultivated.

Uses Seed used as a substitute for cardamom and applied to sweeten food. Seed and its oil are also used medicinally.

Observations Rhizomatous herb with leafy shoots about 1 m tall and separate inflorescences. Leaves sessile on the sheaths, narrow-lanceolate, 30–60 cm × 7.5–10 cm. Inflorescence a dense globose spike, 5–7.5 cm in diameter, on a short peduncle; flower with yellow-white, emarginate labellum, much longer than corolla segments; stamens with very short filament and entire anther appendage. Fruit a globose capsule, about 2.5 cm in diameter, red-brown, densely covered with soft, irregularly toothed wing-like outgrowths. In the area of distribution *A. subulatum* occurs in the lower mountains, often along watercourses. Flowering is in March–April, fruiting in the rainy season. Seed contains cineol. Possibly also of interest for South-East Asia.

Selected sources 12, 14, 43, 60, 81, 83.

Amomum testaceum Ridley

ZINGIBERACEAE

Vernacular names Malaysia: ka tepus (Peninsular). Thailand: krawan (southern), pla ko (peninsular). Vietnam: b[aj]ch d[aaj]u kh[aas]u.

Distribution Southern Thailand, Peninsular Malaysia, Borneo (Sabah). Possibly also sometimes cultivated in the same areas and in Vietnam.

Uses The seed is aromatic and is occasionally used like true cardamom.

Observations Rhizomatous herb with leafy shoots 2–3 m tall and separate inflorescences. Leaves oblong, up to 60 cm × 10 cm, base narrowly cuneate resembling a winged petiole, apex shortly caudate. Inflorescence an oblongoid spike, up to 15 cm × 3 cm, on a peduncle 6–15(–50) cm long; bracts papery with narrow longitudinal grooves; labellum obovate, up to 2 cm × 1.5 cm, white with a broad dull yellow patch towards the apex and a paler yellow median band flanked by purple lines that extend to the base; stamen with 8 mm long filament and a 3-lobed anther appendage. Fruit a globose capsule, 1.5 cm in diameter, smooth or slightly ribbed, pinkish, slightly hairy. Seed brown with a thin white aril. *A. testaceum* is common on limestone throughout Peninsular Malaysia.

Selected sources 12, 42, 79, 86.

Amomum xanthophlebium Baker

ZINGIBERACEAE

Synonyms *Amomum stenoglossum* Baker.

Vernacular names Malaysia: tepus, bunga tantan, bunga tanjong (Peninsular).

Distribution Peninsular Malaysia and Borneo.

Uses Flowers are used as a flavouring in curries, in the same way as sambal.

Observations Rhizomatous herb with leafy shoots up to 5 m tall and separate inflorescences. Leaves oblong-lanceolate, up to 80 cm × 12 cm, sheathed and short-petiolate, apex shortly pointed. Peduncle 10–15(–40) cm long; inflorescence an ellipsoidal spike, 12–24 cm × 8–9 cm; bracts variable, 5–7 cm × 2–4 cm, deep red, with slightly raised longitudinal veins; bracteoles 3.5–5.5 cm long, not tubular, 3-lobed; calyx 2–3.5 cm long; corolla tube as long as calyx, lobes crimson, dorsal one up to 2.5 cm × 2 cm, lateral lobes oblong, about 8 mm wide; labellum obovate, 3.7 cm × 3.2 cm, edges crinkled, white suffused with red, with red stripes and spots and yellow stripes towards the apex; anther connective 3-lobed, middle lobe up to 4 mm × 3 mm; filament 1 cm long, pink. Fruit obovoid, 2 cm × 1.5 cm, smooth, appressed silky hairy. *A. xanthophlebium* occurs from lowland forest up to 1300 m altitude.

Selected sources 12, 42, 79, 86.

Archidendron fagifolium (Blume ex Miquel) Nielsen

LEGUMINOSAE

Synonyms *Pithecellobium angulatum* auct., non Benth., *P. fagifolium* Blume ex Miquel, *P. mindanaense* Merrill. Note: *Pithecellobium* is often written as *Pithecolobium*.

Vernacular names Indonesia: jengkolan, jering goleng (Javanese), ki ca-ang (Sundanese). Philippines: kulikul (Sulu), lalatan (Subanun), tomanag (Bagobo).

Distribution Sumatra (var. *fagifolium*), Java, Borneo (var. *borneense* Nielsen) and the Philippines (var. *mindanaense* (Merrill) Nielsen).

Uses Although the smell of the seed is rather offensive, the seeds are used to add flavour to food just like jengkol (*Archidendron jiringa* (Jack) Nielsen).

Observations Shrub or tree, up to 16 m tall. Leaves bipinnately compound; pinnae 1–3 pairs; leaflets 2–5 pairs per pinna, ovate-elliptical to trapezoid or lanceolate, 2–15 cm × 1–7 cm, glabrous to puberulous; glands present on rachis and pinna. Inflorescence consisting of pedunculate glomerules aggregated into a narrow panicle; panicle up to 35 cm long; glomerules composed of about 3 subsessile flowers; corolla white to greenish-white, funnel-shaped, 4–6 mm long, 5-lobed. Fruit a legume, 11–20 cm × 1–2 cm, curved into a flattened half or full circle, light yellow outside, orange within. Seed compressed ellipsoidal, 8 mm × 4 mm, glossy black. Var. *fagifolium* is up to 6 m tall, its leaflets are glabrous on the underside, its glands are raised, the rachis gland is circular to elliptical and the pinna gland circular; it occurs in rain forest and forest margins, on volcanic soils, limestone or clay, up to 1000 m altitude; it flowers and fruits throughout the year. Var. *borneense* is up to 16 m tall, its leaflets are puberulous on the major veins, its rachis and pinna glands are linear to slit-like and not raised; it occurs in primary rain forest, swampy forest, up to 600 m altitude, and flowers and fruits May–December. Var. *mindanaense* is up to 8 m tall, its leaflets are puberulous on the major veins, its rachis and pinna glands are circular and usually raised; it occurs on ridges in rain forest, up to 1150 m altitude.

Selected sources 7, 26, 40, 61.

Ardisia squamulosa Presl

MYRSINACEAE

Synonyms *Ardisia boissieri* A. DC., *A. drupacea* (Blanco) Merrill, *A. humilis* auct., non Vahl.

Vernacular names Philippines: tagpo (Tagalog), babagion (Cebu Bisaya), butau (Bicol).

Distribution Possibly endemic in and rather common throughout the Philippines.

Uses The flowers and fruits are cooked as a flavouring with fish. The leaves are used to soothe and heal wounds.

Observations Small tree, up to 10 m tall and 15 cm in stem diameter. Leaves alternate, oblanceolate, 6–15 cm × 2–6 cm, entire, slender, pointed at both ends. Inflorescence a few-flowered terminal or lateral umbel-like raceme; pedicel 3 cm long; flowers 4–5-merous, about 1 cm long, white or pink, fragrant. Fruit a globose, 1-seeded drupe, up to 1 cm in diameter, dark blue to purple. *A. squamulosa* occurs commonly in primary forest, up to 1000 m altitude. The chemical composition of the fresh fruit is approximately: water 29%, protein 15%, fat 2%, carbohydrates 22%, fibre 27% and ash 5%. Propagation is possible by seed.

Selected sources 10, 31, 61.

Barringtonia scortechinii King

LECYTHIDACEAE

Vernacular names Malaysia: putat gajah, putat tuba, putat hutan (Peninsular). Borneo: tempalang, langsat burung.

Distribution Peninsular Thailand, Peninsular Malaysia, Sumatra and Borneo.

Uses The fruit can be used as a flavouring in food. Pounded seeds or bark are used as a fish poison in Malaysia (they contain saponins). The wood is used as timber (putat).

Observations Spreading tree, usually 7–20 m tall, occasionally up to 40 m; bole 3–40 cm in diameter, up to 20 m tall, sometimes with buttresses 2 m × 1 m × 5 cm; bark scaly, finely longitudinally fissured, brown or red, peeling off in small flakes. Leaves subcoriaceous, glabrous, glossy bright green; petiole up to 5 cm long; blade obovate to elliptical, 8–21 cm × 5–8 cm. Inflorescence a pendulous spike, up to 70 cm long and with up to 65 flowers; calyx tubular with 3–4 lobes; petals 4, elliptical, 1.5 cm × 1 cm, greenish-white to pink-red; stamens in 4–5 whorls, numerous, at base united in a staminal tube, inner whorl staminodial. Fruit an ovoid, 1-seeded berry, 10–12 cm × 3–5 cm with 8 ridges, green with a reddish tinge; immature fruits tetragonous with distinct wings on the edges which gradually disappear. Seed ovoid, 5–6 cm × 2 cm, yellow-white. *B. scortechinii* occurs in primary and secondary forest in Borneo in low undulating country up to 1400 m altitude, in Peninsular Malaysia in swampy forest and near rivers in hillside forest. Flowering and fruiting year-round.

Selected sources 12, 21, 69, 101.

Borago officinalis L.

BORAGINACEAE

Vernacular names Borage, beebread, talewort (En). Bourrache, borrage (Fr).

Distribution Native to the north-eastern Mediterranean. Escaped from cultivation in the rest of the Mediterranean and large parts of Europe, Asia and America. Cultivated in almost all of Europe and North America, India, China and New Zealand. In Java cultivated in mountain regions and in the Philippines grown on several farms in Cavite province.

Uses The leaves and flowers are used fresh as a herb or garnish in salads, or cooked as a vegetable and in soups. Dried leaves may be used for flavouring and to make a tea. The seeds are used as a source of oil containing unsaturated fatty acids. Borage is credited with sudorific, emollient and diuretic properties and is an excellent bee-feeding plant. Borage, especially the flowers, is in demand by international hotels and food establishments in the Philippines.

Observations Erect, annual, hispid herb, 0.2–1.2 m tall. Stem thick, angular, hollow. Leaves alternate, simple; lower petioles up to 8 cm long; blade ovate-elliptical to oblong, 3–24 cm × 2–12 cm, sparsely bristly, veins prominent beneath. Inflorescence a corymb with many-flowered cincinnate partial inflorescences; pedicel up to 2 cm long, initially erect and nodding at the apex, later elongate and patent-deflexed; flowers bisexual, 5-merous; calyx deeply divided, with narrow lobes as long as corolla or shorter, much enlarged after anthesis; corolla stellate, blue, rarely white or pink, 1.5–3.5 cm across, corolla tube short, lobes acute, throat with protruding scales; filaments with an appendage; anthers connivent, much exserted, longer than filaments; ovary deeply 4-partite; style long. Fruit consisting of 4 nutlets; nutlet oblong, 0.5–1 cm long, ribbed-tuberculate, the hollow base having an appendage. In Java *B. officinalis* flowers throughout the year. The seeds contain 28–35% fatty acids, including gamma-linolenic acid (18–25% of total fatty acids), which has been reported to be beneficial in the treatment of hypertension, high cholesterol levels, eczema and other disorders. It also contains erucic acid, which may be harmful in large doses.

Selected sources 7, 11, 33, 38, 45, 60, 72, 77, 78, 84, 100.

Capsicum pubescens Ruiz & Pavón

SOLANACEAE

Synonyms *Capsicum guatemalense* Bitter.

Vernacular names Apple chilli, rocoto, chilli manzana (En). Indonesia: cabe gondol, cabe bendot, cabe Dieng (Java).

Distribution *C. pubescens* is only known in cultivation and is most common in the Andes of Colombia, Ecuador, Bolivia and Peru, where it is known as rocoto or locoto. It is now also grown in the highlands of Costa Rica, Guatemala and southern Mexico, but less abundantly than in South America. In Indonesia it is cultivated in West and Central Java at higher altitudes.

Uses The fruits are used as a spice like those of other *Capsicum* species and are said to be mildly to strongly pungent.

Observations Herb or climbing shrub up to 3 m tall. Stem striate, branched, with purple nodes. Leaves alternate, ovate, rugose, margin entire, sometimes ciliate. Flowers borne singly and axillary; calyx up to 6-lobed, lobes up to 1 mm long; corolla campanulate to rotate, blue or purple, with a white eye; stigma green. Fruit a berry, pendent to erect, yellow to red, orange or brown, very variable in shape, size and pungency. In South America *C. pubescens* grows at 1500–3300 m altitude. In Indonesia it is cultivated at altitudes above 1400 m, in scattered small plots between tea and cinchona plantations. It was the most common pepper of the Incas and it can be distinguished from other cultivated *Capsicum* species by its flowers being blue or purple instead of white or greenish, and its seeds being black in contrast to the pale yellow, smoother seeds of the other species. In many parts of the lowland tropics the fruit set of *C. pubescens* is not satisfactory.

Selected sources 34, 39, 45, 60, 71, 75, 77.

Cinnamomum culitlawan (L.) Kosterm.

LAURACEAE

Synonyms *Cinnamomum culilaban* (L.) J.S. Presl, *C. culilawan* (Roxb.) J.S. Presl, *Laurus culitlawan* L.

Vernacular names Indonesia: kulitlawang, kayu teja (Indonesian), salakat (Ambon).

Distribution Indonesia (Moluccas: Ambon and adjacent islands, but apparently very rare). It is said to have been also occasionally planted elsewhere (e.g. in Malaysia and India), but this is difficult to verify because the name 'culitlawan' has been used for several other *Cinnamomum* species as well.

Uses The bark smells of cloves (this is the meaning of 'kulitlawang') and is used as a spice and medicinally. The bark and its oil (lawang oil) are used as a constipating agent and as a medicine against cholera. The oil is a source of eugenol used e.g. for synthesis of vanillin. The root bark also has a fennel (*Foeniculum vulgare* Miller) flavour and has been used as a substitute for sassafras bark (*Sassafras albidum* (Nutt.) Nees). The wood is not suitable for timber but is good for fuel.

Observations Tree with slender branchlets. Leaves opposite; petiole up to 1 cm long; blade lanceolate-oblong to ovate-elliptical, 9–12 cm × 2.5–4.5 cm, coriaceous, glabrous. Inflorescence an axillary panicle, 6 cm long, few-flowered; flowers densely pilose. There is much confusion around *C. culitlawan*; only 2 poor flowering specimens and several sterile specimens are known from herbaria. Much of the information in the literature refers to other species.

Selected sources 12, 18, 40, 52.

Cinnamomum deschampsii Gamble

LAURACEAE

Vernacular names Malaysia: kayu manis.

Distribution The origin of *C. deschampsii* is unknown. It has been collected in Peninsular Malaysia (Pinang) and in Singapore but it is doubtfully native there.

Uses The bark is thick, very aromatic and with a very pleasant flavour, resembling Chinese cassia (*Cinnamomum cassia* J.S. Presl).

Observations Bushy tree, stem about 1.5 m tall, and 30 cm in diameter. Leaves coriaceous; petiole 0.5 cm long; blade oblong to elliptical-ovate, 7.5–15 cm × 5–7 cm. Inflorescence a lax spreading panicle with silky flowers. Fruit an ellipsoidal one-seeded berry, about 1 cm long. *C. deschampsii* occurs in the lowlands, in fields and along roads.

Selected sources 12, 79.

Cinnamomum puberulum Ridley

LAURACEAE

Vernacular names Malaysia: teja, medang kemangi.

Distribution Peninsular Malaysia (Kedah, Pahang; a rare endemic).

Uses The bark is used as a spice, e.g. to flavour curries.

Observations Tree, up to 15 m tall; bole 40 cm in diameter. Young twigs pale yellow hairy, older twigs glabrous, blackish. Leaves alternate, tri-veined; petiole up to 1.5 cm long; blade elliptical to oblong, 6.5–13 cm × 2.5–3.5 cm, leathery, lower surface adpressed hairy and slightly glaucous. Inflorescence an axillary or terminal racemose panicle, 6 cm long; flowers yellow haired. Fruit a cylindrical one-seeded berry, 1 cm × 0.6 cm. *C. puberulum* occurs in lowland and mountain forest.

Selected sources 12, 79, 101.

Cinnamomum rhynchophyllum Miquel

LAURACEAE

Synonyms *Cinnamomum lampongum* Miquel.

Vernacular names Indonesia: kayu lawang (Indonesian), kayu salangan (Lampung), modang sanggar (Batak). Malaysia: teja.

Distribution Peninsular Malaysia (rare), Sumatra and Borneo.

Uses The bark smells like cloves and nutmeg and is used as a spice and medicinally to cure intestinal problems.

Observations Tree up to 20 m tall; bole 30 cm in diameter. Leaves subopposite, tri-veined; petiole up to 1.5 cm long; blade elliptical to oblong, 7–23 cm × 2–8 cm, apex with 1–2 cm long acumen, leathery, hairy and slightly glaucous below, secondary veins with few lateral veins running towards margin and joining to form looped intramarginal vein. Inflorescence a terminal or axillary hairy panicle, up to 15 cm long, with yellow flowers. Fruit an ovoid-truncate, one-seeded berry, about 1 cm in diameter. *C. rhynchophyllum* occurs in lowland and hill forests, up to 500 m altitude.

Flowers May–November.
Selected sources 12, 18, 51, 101.

Citrus amblycarpa (Hassk.) Ochse

RUTACEAE

Synonyms *Citrus limonellus* Hassk. var. *amblycarpa* Hassk., *C. nobilis* Lour. var. *amblycarpa* (Hassk.) Ochse & De Vries.

Vernacular names Indonesia: jeruk limau (Java), jeruk limo (Java), jeruk sambal (Java).

Distribution Exclusively known from cultivation in Java (Indonesia).

Uses The juice of immature fruits is very fragrant and is used as a condiment to enhance the taste of several dishes (e.g. sambal, soto and bahmie). The leaves are also used as a condiment, e.g. to improve the taste of meat sauce as a substitute for the leaves of *Citrus hystrix* DC., but also to perfume washing water.

Observations Shrub or low tree, up to 7 m tall, with almost spineless branches. Leaves alternate, unifoliolate; petiole 1 cm long; blade ovate-oblong to lanceolate, 4–8 cm × 2–4 cm, margin shallowly crenate, glabrous, densely pellucid dotted, fragrant when bruised. Flowers solitary in leaf axils or in a terminal 3–5-flowered raceme, white, 2 cm in diameter, fragrant; calyx 1 mm long, with 4–5 segments; petals 3–5, up to 1 cm long; stamens 16–20, forming a tube at base. Fruit a depressed globose berry, 1.5–3.5 cm in diameter, shiny dark green when immature, turning yellow-green at maturity, peel bullate, not very thin; pulp yellow-green, sour, fragrant. Seed long, pear-shaped, up to 1 cm × 0.5 cm. *C. amblycarpa* is cultivated in Java from sea-level up to 350 m altitude. Flowering is in March–April. The fruits are on sale in most markets.

Selected sources 7, 40, 66.

Claoxylon indicum (Reinw. ex Blume) Hassk.

EUPHORBIACEAE

Synonyms *Claoxylon polot* Merrill, *Erytrochilus indicus* Reinw. ex Blume.

Vernacular names Indonesia: bleketupuk (Javanese), talingkup (Sundanese), katerbik (Madurese). Malaysia: sitampu, lampin budak, laping budak. Cambodia: chhë: tô:ch. Thailand: khang namphung (northern), ngun phung khao (northern), phakwan baiyai (south-east), kha ka ai (peninsular). Vietnam: l[ooj]c m[aj]i.

Distribution From India throughout continental South-East Asia and southern China, Malaysia and Indonesia.

Uses Young leaves are used to prepare a spicy sauce or are eaten steamed, as a vegetable. In Indonesia the leaves are sometimes used to feed fish in ponds. Medicinally the leaves are used as a laxative, and are pounded together with pieces of bark and applied externally to the chest, against asthma. In China a decoction of the leaves is taken to treat various diseases. The tree cannot be used for firewood, as it produces a suffocating smoke.

Observations Shrub or small tree, up to 20 m tall, usually tomentellous throughout, often with a purplish tinge. Leaves alternate; petiole up to 16 cm long; blade ovate to elliptical, 9–27 cm × 5–20 cm, densely studded with fine pellucid dots, margin coarsely dentate. Male inflorescence an axillary, spiciform raceme, up to 40 cm long, with flowers in fascicles 6–13 together, calyx 3–4-partite, stamens 15–25; female inflorescence axillary, shorter and denser than the male one, up to 12 cm long, calyx 3–5-partite, styles 3–4. Fruit a 3–4-angular, depressed capsule with 6–8 longitudinal furrows, 5–6 mm × 7–8 mm, with soft, short, grey hairs and distinctly raised margins of sutures. Seed ovoid to subreniform. *C. indicum* occurs in evergreen mixed forest, often in humid locations on humus-rich soils but also on sandy coasts, up to 850 m altitude. The tree is easily propagated from cuttings.

Selected sources 3, 4, 12, 21, 40, 43, 66, 101.

Colocasia gigantea (Blume ex Hassk.) J.D. Hooker

ARACEAE

Synonyms *Caladium giganteum* Blume ex Hassk., *Colocasia indica* Hassk., non Kunth, *Leucocasia gigantea* (Blume ex Hassk.) Schott.

Vernacular names Indonesia: rombang (Javanese), lumpuy (Sundanese), kamumu (Minangkabau). Thailand: khun (central), bon (south-west), ok dip (peninsular). Vietnam: d[oj]c m[uf]ng, m[oon] to.

Distribution From India throughout South-East Asia to Australia. Is occasionally also cultivated in South-East Asia.

Uses The fruits smell like *Alpinia malaccensis* (Burm.f.) Roscoe and are used as a flavouring; they are also eaten as a snack. The petioles are eaten as a vegetable.

Observations Erect, fleshy, latex-producing herb, up to 2 m tall, with a tuberous subterranean rhizome. Leaves peltate, with a bilobed base, pinnately veined; petiole up to 1.5 m long, light green, white-pruinose; blade ovate in outline, 25–120 cm × 17–35 cm, basal lobes pointing downwards, connate up to half their length, anterior lobe much longer than the basal ones and having 4–6 primary veins. Inflorescence a spadix; peduncle up to 55 cm long; spathe oblong, 5–15 cm × 4–8 cm, white, 1.5–2 times as long as the tubular part of the spadix; tubular part 3–8 cm long; female portion of spadix 4–8 cm long, fertile part 2–3.5 cm long; male part 2–9.5 cm long; sterile appendage of spadix 3–6 mm long. Fruit an oblongoid berry, about 1 cm long. *C. gigantea* produces hydrocyanic acid. It occurs in lower mountainous regions, in shady and moist sites, up to 1000 m altitude.

Selected sources 7, 12, 40, 60.

Cyrtandra pendula Blume

GESNERIACEAE

Vernacular names Malaysia: asam batu, meroyan panas.

Distribution Peninsular Malaysia, Indonesia (Java, Sumatra).

Uses The sourish leaves can be used for flavouring. In Peninsular Malaysia a decoction of the whole plant is used by women suffering from puerperal fever.

Observations Creeping or ascending herb, up to 15 cm tall with brown-pilose, subquadrangular stem. Leaves opposite but in a same pair very unequal (1 normal and the other small or stipule-like), crowded at the top of the stem; petiole 7–27 cm long, densely pubescent; blade of normal leaf ovate to elliptical-oblong, 13–20 cm × 7–12 cm, margin crenate, dentate or serrate, glabrous above, densely pubescent on the veins beneath. Inflorescence an axillary, few-flowered umbel, up to 18 cm tall; peduncle red-brown pubescent, very variable in length, up to 28 cm long; bracts 1.5 cm long, lobed at apex; corolla white, 5-lobed, up to 4 cm long, densely villous outside; filaments 2, 7–12 mm long, with scattered long hairs; staminodes 3; style in upper part somewhat pilose bearing a bilobed stigma. Fruit a berry. *C. pendula* occurs in forest vegetation. Based on the length of the peduncle 3 varieties have been distinguished: var. *blumeana* Clarke (peduncle 3.5–7 cm long), var. *pendula* (peduncle 10–28 cm long), and var. *subsessilis* Bakh.f. (peduncle 0.5 cm long).

Selected sources 7, 12.

Dioscoreophyllum cumminsii (Stapf) Diels

MENISPERMACEAE

Synonyms *Dioscoreophyllum lobatum* Diels, *Rhophalandria cumminsii* Stapf, *R. lobatum* C.H. Wright.

Vernacular names West African serendipity berry, Guinea potato (En). Patate du Golfe de Guineé (Fr).

Distribution Originating from tropical Africa (West, Central and southern); occasionally cultivated (e.g. in Ghana), also elsewhere.

Uses The fruits are edible and used to sweeten food; they contain a sweet-tasting protein (monellin) with a sweetening power of more than 3000 times that of sugar. The fruits are stable and can be stored for weeks at room temperature without losing their sweetness. The tubers can be eaten like potatoes. In Gabon the pungent peel of the roots is used to cure wounds, the softened stem devoid of hairs is applied as a plaster on swollen limbs and the viscid sap of the stem is applied to extract abscesses and spines and as a wash against venereal diseases; the root is considered as a sexual stimulant.

Observations Herbaceous to woody, dioecious liana with tuberous rhizome and hairy stems. Tubers about 2 cm in diameter, whitish. Leaves alternate; petiole 6–15 cm long; blade entire or lobed, in outline ovate-triangular, 9–20 cm long and wide, sagittate-cordate at base, acuminate at apex, glabrescent, palmately veined. Inflorescence an axillary raceme, male one up to 30 cm long, female one to 10 cm long; flowers without petals, yellow-green; male flowers with 6–8 sepals in 2 whorls and 3–6 stamens fused into a synandrium; female flowers with 6 sepals and 3–6 carpels with thickened recurved stigmas. Fruit a small, subovoid drupe, up to 3.5 cm long on a peduncle 1 cm long; exocarp smooth, shiny yellow-red, endocarp crustaceous. Seed 1.5–3 cm long. *D. cumminsii* occurs in primary and secondary densely closed vegetation, often in old plantations. Several varieties have been distinguished, mainly based on leaf form and hairiness. Propagation is possible by seed and by tubers. Germination of seed is inhibited by light; pretreating the seed with 0.1–0.5% gibberellic acid solution accelerates germination. *D. cumminsii* is potentially useful for South-East Asia as a source of an intense natural sweetener for the food industry and for low-calorie diets for diabetics and dieters. Other potential sources of natural sweeteners are: *Synsepalum dulcificum*

(Schum. & Thonner) Baillon (miraculous berry, containing miraculin) and *Thaumatococcus daniellii* (Bennet) Benth. (katemfe, containing thaumatin).

Selected sources 1, 28, 41, 46, 60, 89, 97.

Dipteryx odorata (Aublet) Willd.

LEGUMINOSAE

Synonyms *Baryosma tonga* Gaertner, *Coumarouna odorata* Aublet, *Dipteryx tetraphylla* Spruce ex Benth.

Vernacular names Tonka bean (En). Coumarou (Fr).

Distribution Indigenous to South America, especially along the tributaries of the Orinoco in Brazil, Colombia, the Guianas and Venezuela. Occasionally introduced and sometimes cultivated elsewhere.

Uses After the seeds (beans) have been soaked for several days in strong rum or alcohol (45–65%) and then dried they become pliable, show a heavy crystalline coumarin deposit on the testa and have an odour of new-mown hay. The cured beans contain about 8% water, 2–3% coumarin and 25% of tonka butter. The bean or its extract is used to perfume and flavour food, tobacco, soap and liqueurs. It is also used as a substitute for vanilla and as a fixing agent for dyes and perfumes. Medicinally the seeds are used as a tonic or narcotic and to cure diarrhoea, cough and schistosomiasis. The brown, close-grained timber is very hard, tough and durable and resistant to marine borers but difficult to work. It is a very suitable wood where resistance to pressure is required. The trees are also used for shade in cocoa. The bark of the tree yields a kino very similar to eucalyptus kino and containing about 40% of tannin.

Observations Tree, up to 40 m tall and trunk up to 1 m in diameter. Root system with a vigorous taproot to only 1 m depth, deeper-growing anchor roots and a dense surface mass of feeding roots. Leaves alternate, pinnately compound, leathery, glossy green; rachis flattened and winged; leaflets 3–6, opposite or alternate, elliptical but unequal-sided, up to 15 cm × 8 cm. Inflorescence a panicle with rose-violet flowers; calyx tube 4 mm long, 2 posterior sepals petaloid; corolla 10–12 mm long. Fruit drupaceous, ellipsoidal, 7–10 cm × 3–6 cm, indehiscent, pale yellow-brown; mesocarp pulpy; endocarp hard, enclosing a single seed. Seed usually wrinkled, 3–5 cm × 1–2 cm, dull mahogany, weighing about 3 g. In the wild *D. odorata* occurs in tropical forest, often along river banks. It requires an annual rainfall of 1500–2750 mm and is grown up to 350 m altitude. It prefers humus-rich soils poor in calcium. Propagation is usually by seed, but is possible by cuttings as well. Initial spacing is 3 m × 3 m, thinning after 10 years. When about 2 m tall the trees are topped to induce branching. Normally flowering and fruiting starts 7–10 years after planting, but good crops are only obtained every 2–3 years. Pollination is by insects. Diseases and pests are never serious; only bats pick the fruits to eat the pulpy flesh. Yield of dried beans per tree is normally 0.5–1 kg annually, but up to 25 kg can be obtained. Two commercial types are recognized: the Angostura-Venezuelan type and the Brazilian or Para type. The main producer of tonka beans from wild trees is Venezuela, followed by Brazil and Colombia. Production has decreased because of competition from synthetic coumarin and vanillin. To a lesser extent, seeds of other *Dipteryx* species are used similarly as *D. odorata*. As a source of natural flavour, *D. odorata* is possibly of interest for South-East Asia. Experiments in the early 1900s in Indonesia and Singapore were promising.

Selected sources 12, 25, 40, 60, 74.

Dysoxylum alliaceum (Blume) Blume

MELIACEAE

Synonyms *Dysoxylum costulatum* (Miquel) Miquel, *D. euphlebium* Merrill, *D. thyrsoideum* Hiern.

Vernacular names Indonesia: kayu bawang (Moluccas), ki bawang (Sundanese), pela (Javanese). Malaysia: beka-beka bukit, kasai tembaga, kulim burong (Peninsular). Philippines: kalimutain, kuling-babui (Tagalog), paluahan (Bisaya). Thailand: ta suea khao (peninsular). Vietnam: ch[awj]c kh[ees].

Distribution From the Andaman Islands and peninsular Thailand throughout the Malesian Archipelago towards northern Australia and the Solomon Islands. Possibly occurring also in South Vietnam.

Uses All parts smell strongly of onions. Fresh young leaves are cooked with fish or other food to impart an onion flavour. The seeds in particular are used together with some juice of ginger and lemon or lime, to prepare a sauce very similar to garlic sauce, which is served with fish and other food. In the past, dried seeds that were blackened from being dried in smoke, were taken on ships as a garlic substitute. The wood is white and light; it is used on a small scale for interior construction but is not insect-resistant.

Observations Tree up to 38 m tall, all parts smelling strongly of onion; trunk up to 80 cm in diameter, fluted to 4 m at base with buttresses up to 60 cm tall and projecting 1 m from the trunk. Leaves paripinnate, 3–6(–8)-jugate, up to 60(–120) cm long, subcoriaceous; petiole 5–15 cm long; petiolule 0.5–2 cm long; leaflet elliptical, ovate or subfalcate, 7.5–25 cm × 2.5–7.5 cm. Inflorescence a pyramidal thyrse, up to 40 cm long, branchlets bearing cymules of 1–3 sweetly scented flowers; pedicel up to 4 mm long; flowers 4–5-merous; calyx shallowly cupular, 3 mm in diameter, margin 4-toothed; petals 4–5, linear, 5–8 mm long, white or pinkish; staminal tube glabrous to puberulous, bearing 8 or 10 anthers; pistil with 3-locular ovary and terete style. Infructescence up to 25 cm long; fruit a subglobose capsule, up to 7.5 cm in diameter, sometimes lobed and constricted between the seeds, red. Seeds 1–4 per capsule, oblong-globose, red. *D. alliaceum* occurs in rain forest, also on limestone, often in *Agathis* forest on peat overlying sand, up to 1800 m altitude. It is a very polymorphic species, closely related to *D. excelsum* Blume which occurs in the same area but whose parts never have an onion smell.

Selected sources 7, 12, 26, 40, 101.

Embelia philippinensis A. DC.

MYRSINACEAE

Synonyms *Rhamnus lando* Llanos, *Ribesoides philippense* O. Kuntze, *Samara philippinensis* Vidal.

Vernacular names Philippines: lando (Tagalog), dikai (Laguna), pongpong (Bontok).

Distribution In the Philippines from northern Luzon to southern Mindanao and in Borneo.

Uses The acid leaves are used in the Philippines as a flavouring for fish, meat and vegetables or to give a sour taste to soup. The fruits are eaten and have a sweet-sour taste. Fresh mature stems are used for temporary tying purposes.

Observations Woody vine with spiny older stems, up to 4 m long and 1.5 cm in diameter. Leaves alternate, elliptical, 7–14 cm × 3–4 cm, acuminate, leathery, smooth, shiny dark green with prominent veins. Inflorescence compound with numerous small whitish flowers. Fruit a globose berry, up to 0.5 cm in diameter, red when ripe. *E. philippinensis* occurs in open or partially shaded secondary dipterocarp forest up to moderate altitudes and is often common. Propagation is by seed and by stem cuttings.

Selected sources 10, 12, 31, 61.

Eruca sativa Miller

CRUCIFERAE

Synonyms *Brassica eruca* L., *Eruca foetida* Moench, *E. vesicaria* (L.) Cav. subsp. *sativa* (Miller) Thellung.

Vernacular names Garden rocket, roman rocket, rocket salad (En). Roquette (Fr).

Distribution The origin of *E. sativa* is not known but it occurs wild and cultivated in the Mediterranean, North and North-East Africa, the Balkans, and East and Central Asia. It is also cultivated in India and America. In South-East Asia it is cultivated on several farms in Cavite province, the Philippines.

Uses The leaves, seedlings and seeds of *E. sativa* are used in salads and as a condiment in the preparation of sauces and mustard. It is also used medicinally. In Asia *E. sativa* is cultivated for oil production; the seed oil is used as an edible oil, lubricant, fuel and for medicinal purposes. Immature green plants and the press cake are used to feed cattle and other animals. Garden rocket is in demand by international hotels and restaurants in the Philippines.

Observations Erect, annual, branching, glaucous, glabrous or sub-hispid herb, 5–60(–100) cm tall. Leaves alternate, lyrate-pinnatifid, variously toothed, rarely obovate and subentire. Inflorescence racemose; sepals 4, long elliptical, 7–12 mm long, often tipped with hairs; petals 4, 14–24 mm long, pale yellow or white, veins visible; stamens 6, free. Fruit a silique, 1–4.5 cm long, turgid, beaked, erect. Seeds numerous, 2-seriate, globose, 1–2 mm in diameter. *E. sativa* is self-sterile. The seeds contain 30–35% oil. *E. sativa* can be grown on poor soils with low rainfall.

Selected sources 9, 38, 43, 45, 49, 60, 77, 78, 92.

Etlingera rosea Burtt & Smith

ZINGIBERACEAE

Synonyms *Amomum roseum* K. Schumann, non Roxb., *Donacodes roseus* Teijsm. & Binn., nom. nud., *Geanthus roseus* Loesen., nom. illegit., non Valeton.

Vernacular names Indonesia: galoba papua, potmepini, gitipi tana (Moluccas).

Distribution Indonesia (Moluccas, Sulawesi).

Uses The aril around the seed has a pleasant taste and is eaten directly or used as a condiment, e.g. for fish.

Observations Perennial herb, about 5 m tall. Leaves subsessile, ligule rounded, up to 7 mm long; blade linear to lanceolate, 50–55 cm × 6–6.5 cm, glabrous to ciliate. Inflorescence spike-like, subglobose, 5 cm in diameter, near to the soil surface on separate peduncle about 6 cm long; outer bracts elliptical, up to 2.5 cm long; pedicel 2 mm long; bracteole tubular, bilobed, appressed pilose; calyx tubular, 2 cm long, ending in 3 teeth; corolla tubular, tube about 2 cm long, ending in 3 lobes 12 mm long; labellum 17 mm long; filament 3 mm long, anther 4 mm long. Fruit capsular, subglobose although slightly compressed triangular, 1 cm in diameter, red, easily dehiscing into 3 parts, exocarp with short spines. Seed with pleasant-tasting aril.

Selected sources 15, 16, 17, 83.

Etlingera solaris (Blume) R.M. Smith

ZINGIBERACEAE

Synonyms *Elettaria solaris* Blume, *Nicolaia solaris* (Blume) Horan., *Phaeomeria solaris* (Blume) K. Schumann.

Vernacular names Indonesia: honje warak, honje laka (Sundanese).

Distribution Indonesia (Java).

Uses The fruits are edible and used as a sour condiment.

Observations Robust, perennial herb, up to 5 m tall, with stout rhizome. Leaves distichous, finely veined; sheath densely floccose-pubescent, with prominent longitudinal stripes, faintly ribbed transversally; ligule densely sericeous, elongate, 3–5 cm long; petiole about 1 cm long, glabrous; blade lanceolate, 50–80 cm × 13–20 cm, base unequal, margin ciliate, apex short acuminate. Inflorescence head-like, globose, 5–12 cm in diameter, arising laterally from rhizome near base of leafy shoot; peduncle partly subterranean, ascending, up to 36 cm long, with large scales; involucral bracts ovate, largest outer ones up to 9 cm × 3 cm, dirty red or yellow-green, densely sericeous pubescent; flower bracts linear-lanceolate, 5–6 cm long, becoming gradually smaller towards the apex of the rachis; bracteole tubular but deeply cleft, 3-dentate, 4 cm long; calyx tubular, 5 cm long, red; corolla lobes slightly protruding from calyx, 3 cm long, scarlet; labellum 2 cm long, red with yellow margins or orange with a red blotch. Fruit obovoid, 4–5 cm long, crowned by persistent bracts, angular, juicy, red. Seed 3–4 mm long. *E. solaris* grows in mountain forest, at 800–1650 m altitude and is very variable.

Selected sources 7, 17, 40, 83.

Etlingera walang (Blume) R.M. Smith

ZINGIBERACEAE

Synonyms *Achasma walang* (Blume) Valeton, *Amomum walang* (Blume) Valeton, *Donacodes walang* Blume.

Vernacular names Indonesia: walang (Sundanese).

Distribution Indonesia (West Java, probably only known from cultivation there, sometimes escaping).

Uses The leaves are used as a condiment. The crushed leaves have an unpleasant odour which is like that of the rice bug *Leptocorisa acuta* ('walang sangit'). Historically more important is the practice in western Java of burning leaves on rice fields in order to repel that pest of rice.

Observations Perennial herb, 1.5–2 m tall, with slender rhizome and root system. Leaves distichous; petiole about 1 cm long; blade lanceolate, 30–50 cm × 5–6 cm, glabrous. Inflorescence head-like, ovoid-cylindrical, 5–7 cm × 2–3 cm; peduncle subterranean, up to 8 cm long, covered with scales 5 cm long; bracts narrowly lanceolate, outer ones up to 8 cm × 1 cm, inner ones smaller; bracteole tubular, very thin, 5 cm long; calyx tubular, 7 cm long, 3-dentate; corolla tubular, with 3 red lobes; labellum yellow, 5 cm long; filament short, anther about 1 cm long; style 5–6 cm long, stigma faintly 2-horned. Fruit unknown.

Selected sources 17, 40, 93.

Eupatorium chinense L.

COMPOSITAE

Synonyms *Buphthalmum oleraceum* Lour., *Eupatorium japonicum* Thunb. ex Murray.

Vernacular names Indonesia: teklan gede (Sundanese). Philippines: apanang-gubat (Tagalog). Vietnam: t[oor] ma, y[ee]n b[aj]ch.

Distribution Indo-China, China, Taiwan, Korea, Japan and the Philippines. Introduced and also cultivated elsewhere, e.g. in Indonesia.

Uses In Indo-China the leaves are used for seasoning food. In Indonesia and elsewhere the fragrant leaves are used to perfume hair and clothes. In Indo-China it is often planted as an ornamental hedge. In China the whole plant is used medicinally as a diuretic and anthelmintic.

Observations Small rhizomatous shrub, up to 2 m tall. Leaves opposite, oblong-lanceolate, 8–13 cm long, usually trilobed, serrate, glossy green; petiole 0.5–1 cm long. Inflorescence a head, numerous fragrant flower heads arranged into a terminal corymb; involucral bracts 7–8 mm long; corolla 4–6 mm long, purplish; pappus 5–6 mm long. Fruit an achene, about 3 mm long. *E. chinense* occurs in moist grassland along rivers. Propagation is mainly by pieces of rhizome. *E. chinense* is poorly known and needs better investigation.

Selected sources 12, 22, 40, 48.

Ferula assa-foetida L.

UMBELLIFERAE

Synonyms *Ferula rubicaulis* Boissier, *F. pseudalliacea* Rech.f., *Narthex polakii* Stapf & Wettst.

Vernacular names The gum: asafoetida (En), hing (En, India). Laos: maha hing.

Distribution Endemic to western and south-western Iran. Occasionally cultivated elsewhere.

Uses The gum extracted from the stem and the root used to be an important trade commodity used as a condiment in food since it has a very persistent garlic-like odour. Medicinally it is used to cure hysteria and as a vermifuge. In the United States the regulatory status 'generally recognized as safe' has been accorded to asafoetida fluid extract (GRAS 2106), asafoetida gum (GRAS 2107) and asafoetida oil (GRAS 2108).

Observations Perennial, glabrous herb, up to 2 m tall and stem up to 7.5 cm in diameter at the base. When wounded the plant exudes a white, sticky sap, which soon turns red-yellow. Upper leaf sheath about 9 cm × 4 cm; basal leaves 3–4-ternate-pinnate, 3–3.5 cm × 1.5–2.5 cm; ultimate segments up to 2.5 cm × 2 cm, simple to pinnatisect. Inflorescence a globose panicle, composed of umbels; flowers 20–25 per umbellule; petals 5, yellow, about 1.5 mm long. Fruiting umbels with 10–50 rays, rays 3–5 cm long; mericarp 11–14 mm × 7–9 mm, with 2 mm wide wings. *F. assa-foetida* grows in dry, stony locations, up to 100 m altitude. To collect the gum the stem is removed and a collection trench dug around the root. Incisions are made in the root and the whole is covered to prevent undue desiccation. Every 3–4 days the gum is collected and the tapping process repeated. The gum consists of a mixture of about 30% resin, 25–50% gum and 6–9% essential oil. Two other *Ferula* species produce a similar gum, originate from neighbouring areas and are often confused with *F. assa-foetida*: *F. foetida* (Bunge) Regel and *F. narthex* Boissier. It is unclear whether these species are of interest for South-East Asia.

Selected sources 19, 38.

Ficus virgata Reinw. ex Blume

MORACEAE

Synonyms *Ficus decaisneana* Miquel, *F. trymatocarpa* Miquel (often written: *F. trematocarpa*), *F. philippinensis* Miquel.

Vernacular names Indonesia: daun ulang-ulang (Moluccas), lumaput (Sulawesi), nunok (Ambon). Philippines: diakit (Bisaya), kauis (Igorot), liuliu (Ifugao).

Distribution From the Ryukyu Islands and Taiwan to Micronesia, the Philippines, Sulawesi, Lesser Sunda Islands, Moluccas, New Guinea, east to the Solomon Islands, New Caledonia and Vanuatu, south to northern Australia.

Uses On Ambon (Indonesia) young leaves, no older than 3 days, are eaten fresh as an appetizer and to lessen the pungency and bitterness of sauces and thus prevent stomach-ache.

Observations Tree up to 10 m tall, often epiphytic. Leaves distichous to alternate, coriaceous, glabrous; petiole 1–1.5 cm long; blade elliptical to oblong, 10–20 cm × 4–7 cm, lateral veins 10–12 pairs. Inflorescence and infructescence a globular, axillary fig, 1 cm in diameter, solitary or paired, finely scabrid, orange-yellow to red-brown; peduncle and pedicel each up to 5 mm long; perianth lobes 3–4; male flower with 1 stamen; female flower with lateral or subterminal style and dilated stigma. *F. virgata* occurs in rain forest at low elevations. Three varieties have been distinguished. It can be propagated by cuttings. Closely related to *F. tinctoria* G. Forster with similar distribution but with much smaller figs.

Selected sources 20, 27, 40, 56, 61.

Globba marantina L.

ZINGIBERACEAE

Vernacular names Indonesia: kapulaga ambon, halia utan, bonelau (Moluccas). Philippines: barak (Tagalog), bangliu (Iloko), luyan-luyaan (Pangasinan). Vietnam: l[oo] ba l[uf]n.

Distribution Probably originating from the Moluccas, now widely distributed from peninsular Thailand and the Philippines to New Guinea and the Solomon Islands. Possibly occurring also in Vietnam.

Uses In the Moluccas the somewhat spicy bulbils are eaten fresh or dried, as a seasoning. They are also used in the same way as cardamom because of their pleasant, not pungent taste, and to stimulate appetite.

Observations Perennial herb, up to 50 cm tall, with tuberous roots. Leafy shoot with 8–15 leaves; sheath subglabrous, ligule 2 mm long and fringed with hairs, petiole of upper leaves distinct and 5 mm long; blade lanceolate, 15 cm × 4–5 cm, with short hairs below. Inflorescence compact, 1–4 cm long, hardly exserted beyond the leaf sheath; peduncle 1–3 cm long; sterile bracts 8–15, imbricating, green, lower ones large, up to 1.5–2.5 cm × 2 cm, upper ones smaller, usually each one bearing an axillary bulbil; bulbil narrowly ovoid to conical, 1 cm long, warty, consisting of a small shoot and a swollen root; rachis (seldom produced) 2–12 mm long, bearing 1–4 cincinni 2–3 mm apart; cincinni bearing up to 6 flowers; bracts similar to sterile bracts; bracteole about 1 cm long; flowers subsessile, dark yellow; calyx 9 mm long, 3-lobed, 2 long acute lobes, 1 short and blunt one; corolla tubular, 3-lobed, lobes 5–7 mm long, dorsal lobe hooded, lateral lobes concave; labellum 12 mm × 8 mm, orange, with a round, deeper orange spot; filament 2 cm long, anther 2.5 mm long. Fruits have never been observed. *G. marantina* rarely flowers but produces bulbils abundantly, which serve for propagation. When it dies back seasonally, the rhizomes and bulbils remain dormant for about 5 months (October–March in Peninsular Malaysia), after which they germinate simultaneously. *G. marantina* favours open dry habitats and the bulbils can survive long adverse conditions. In Malaysia it is found in dry forested areas and on sandbanks, in Indonesia (Moluccas) it occurs in valleys, on banks and in sago plantations.

Selected sources 7, 12, 40, 42, 57, 58.

Hyptis suaveolens (L.) Poiteau

LABIATAE

Synonyms *Ballota suaveolens* L., *Marrubium indicum* Thunb., non Burm.f., *Schaueria graveolens* Hassk.

Vernacular names Bush tea-bush (En). Indonesia: lampesan (Javanese), jukut bau (Sundanese), mang-kamang (Madurese). Malaysia: malbar hutan, selaseh hutan, pokok kemangi. Philippines: amotan (Bicol), suob-kabayo (Tagalog), loko-loko (Bisaya). Thailand: kara, maeng lak kha (peninsular). Vietnam: [es] th[ow]m, t[is]a t[oo] d[aj]i.

Distribution Native of tropical America but now distributed and naturalized pantropically, including South-East Asia. Occasionally cultivated in Mexico and India.

Uses The shoot tips are used as a food flavouring and the roots as an appetizer. Sometimes the whole plant is used as forage for cattle. Medicinally it has many applications: to promote lactation in women, as a stimulant, a sudorific, an antiseptic for wounds, to cure catarrh, skin complaints, and rheumatic pains. The leaves are also used to repel bedbugs. The essential oil in the leaves (0.025%) has been used as an adulterant of patchouli oil.

Observations Strongly aromatic, almost fetid herb, up to 2 m tall with 4-angled, much branched, hirsute stem. Leaves decussate, firmly herbaceous; petiole 0.5–3 cm long; blade ovate to broadly obovate, 3–5 cm × 2–4 cm, gland-dotted, margin irregularly serrulate, densely pubescent beneath. Inflorescence a verticillate, 2–5-flowered cyme, arranged racemosely towards the end of branches in the axil of smaller leaves; peduncle up to 1 cm long; calyx campanulate, 5 mm long, in fruit up to 10 mm, strongly 5-ribbed, with 5 setaceous teeth; corolla tubular, 6–8 mm long, blue to violet, limb bilabiate, upper lip 2-lobed, lower lip 3-lobed; stamens 4, included in corolla; stigma shortly bifid. Fruit usually consisting of 2 nutlets; nutlet narrowly oblongoid, up to 4 mm × 3 mm, faintly rugose, brown. *H. suaveolens* occurs in dry open localities, along streams and roadsides, as a weed in plantations and fields, from sea-level up to 1300 m altitude, in seasonal and per-humid conditions. Flowering and fruiting is year-round. In the dry season it sheds its leaves. The pericarp of the nutlet swells to a gelatinous mass when soaked in water.

Selected sources 7, 10, 12, 26, 40, 56, 60.

Limnophila rugosa (Roth) Merrill

SCROPHULARIACEAE

Synonyms *Herpestis rugosa* Roth, *Limnophila roxburghii* auct., non G. Don.

Vernacular names Indonesia: hades (Sundanese), selaseh ayer (Moluccas), selaseh banyu (Palembang). Philippines: kalaoo (Bicol), tala (Tagalog), tara-tara (Iloko). Thailand: kachom (central), om kop (northern). Vietnam: h[oof]i n[uw][ows]c, qu[ees] d[aas]t.

Distribution From India, southern China and Ryukyu Islands throughout South-East Asia to Fiji and Samoa.

Uses The leaves and tender stems smell of anise and are eaten as a condiment raw or cooked. The herb is also used to perfume hair. A decoction and a steam-bath serve to cure itching eyes. A decoction of a mixture of *L. rugosa* and *Ocimum basilicum* L. is drunk against mild gonorrhoea and impotence.

Observations Erect, semi-aquatic, fragrant, annual herb, up to 50 cm tall; stem simple or branched, glabrous to hirsute, rooting from the lower nodes. Leaves decussate; petiole 0.5–3 cm long; blade ovate-lanceolate to ovate-elliptical, 2–12 cm × 1–5 cm, base decurrent into petiole, margin crenate, scabrid above, hirsute or scabrid on major veins beneath, densely punctate. Flowers usually solitary, axillary, but axillary pedunculate clusters with up to 7 sessile flowers occur too, the clusters subtended by 2 small leaves; peduncle up to 3.5 cm long; calyx tubular, irregularly but deeply 5-lobed, 6–11 mm long; corolla tubular, 5-lobed, bilabiate, up to 16 mm long, blue, with a yellow spot in the throat, pilose externally; stamens 4, didynamous, inside the corolla; pistil with filiform style and bilobed stigma. Fruit a capsule, broadly compressed ovoid, up to 6.5 mm × 3 mm, septicidally 4-valved, pale brown. Seed small, irregularly angular, numerous, shiny black. *L. rugosa* occurs in wet locations along streams, pools and rice fields, from sea-level up to 1500 m altitude.

Selected sources 10, 12, 29, 40, 66, 70, 87.

Melissa officinalis L.

LABIATAE

Synonyms *Melissa altissima* J.E. Smith, *M. inodora* Bornm., non Hassk.

Vernacular names Lemon balm, balm, bee balm (En). Mélisse, citronelle (Fr).

Distribution *M. officinalis* is native from the eastern Mediterranean, through the Crimea, the Caucasus and northern Iran to Central Asia. It has been introduced and naturalized in Europe (up to 60°N) and America and is also cultivated in temperate climates of North Africa and Asia. In South-East Asia *M. officinalis* is occasionally cultivated in the mountains of Java and on several farms in Cavite province, the Philippines.

Uses *M. officinalis* is grown as a culinary herb, medicinal plant, essential-oil plant and bee-feeding plant. The leaves are used to flavour salads, soups, vinegars and liqueurs and to make a tea. Lemon balm is in demand by international hotels in the Philippines. An essential oil is obtained from the leaves and used in the medicine and perfume industries. In the United States the regulatory status 'generally recognized as safe' has been accorded to lemon balm (GRAS 2111), lemon balm oleoresin (GRAS 2112) and lemon balm oil (GRAS 2113). It is also used medicinally, mainly to stimulate digestion, calm the nerves, promote menstruation, and relieve headache and toothache.

Observations Several-stemmed perennial herb, 60-90 cm tall, lemon-scented when bruised, with a subterranean rhizome. Stem obtusely quadrangular, furrowed, hairy. Leaves decussately opposite; petiole up to 3.5 cm long; blade ovate to elliptical, 2–8 cm × 1–5 cm, base cuneate-truncate or cordate, margin crenate-serrate, apex rather acute, hairy on both sides. Inflorescence an axillary verticillaster, 2–12-flowered; bracteoles ovate-oblong, about 1.5 mm long, hairy; calyx campanulate, funnel-shaped, 5–9 mm long, hairy, 13-veined, bilabiate, upper lip 3-dentate, lower lip bifid; corolla white or pale violet, much longer than the calyx, tube 8–12 mm, infundibuliform, limb bilabiate, upper lip erect, emarginate, lower lip expanded, 3-fid; stamens 4, didynamous, inserted deeply in tube; anthers 2-celled; disk equal-sided. Fruit composed of 4 obovoid, glabrous nutlets.

Propagation is possible by seed and by cuttings. Important compounds in the essential oil of *M. officinalis* are neral, geranial, geraniol, citronellal and citronellol, but the compounds may differ per cultivar. The essential-oil concentration in the leaves is usually very low, 0.02–0.05%; rarely, up to 1% occurs. The oil is very expensive and is often adulterated.

Selected sources 7, 11, 24, 26, 35, 45, 55, 60, 62, 73, 77, 78, 82, 84.

Monodora myristica (Gaertner) Dunal

ANNONACEAE

Synonyms *Annona myristica* Gaertner, *Monodora grandiflora* Bentham, *Xylopia undulata* Pal. de Beauv.

Vernacular names African nutmeg, calabash nutmeg, calabar nutmeg (En). Fausse noix muscade, muscadier de calabash (Fr).

Distribution Originating from Africa, from Liberia to Cameroons, Uganda and Angola. It is occasionally cultivated in those areas and elsewhere.

Uses The aromatic seeds are ground and used as a condiment in food, imparting a flavour resembling that of nutmeg. The seeds are a popular spice and for sale all over West Africa. Medicinally the seeds are used as a stimulant, stomachic, insect repellent, and to cure headache and sores. The seeds are also made into necklaces worn by women for their scent. They contain 5–9% of a colourless essential oil. The tree is also grown as an ornamental for its conspicuous, attractive and scented flowers. The white or greyish wood is hard but easy to work and suitable for carpentry, turnery and walking sticks. The bark is used to treat haemorrhoids, stomach-ache, febrile pains and eye diseases.

Observations Tree, up to 35 m tall; trunk clear, up to 2 m in girth, branches horizontal; bark thin and smooth, slash white. Leaves drooping, thick, alternate; petiole thick, about 1 cm long; blade obovate, oblong or elliptical, up to 45 cm × 20 cm, lateral veins up to 20 pairs, secondary veins running parallel. Flowers singular, appearing at the base of young shoots when new leaves appear; pedicel up to 20 cm long, bearing a leaf-like bract at about one third from top; flower large, pendent, fragrant; calyx over 2.5 cm long, edges wavy, crisped, red-spotted; petals 6, outer 3 up to 10 cm long, with crisped margins, spotted red, yellow and green; inner 3 petals subtriangular, forming a white-yellow cone at the centre and spotted red outside and green inside. Fruit a globose berry, up to 20 cm in diameter, suspended on a long stalk, green, with numerous seeds embedded in whitish sweet-smelling pulp. Seed oblongoid, about 1.5 cm long, pale brown. *M. myristica* occurs in evergreen and deciduous forest. Flowers are protogynous and insect-pollinated. It may be an interesting multipurpose tree for the wetter parts of South-East Asia. It was introduced into Indonesia (Bogor Botanical Garden) in 1897; now several cloned trees are present and flower regularly but fail to set fruit, possibly because of a self-incompatibility factor. Seeds of other *Monodora* species have similar uses.

Selected sources 12, 13, 47, 54, 60, 97.

Myristica cinnamomea King

MYRISTICACEAE

Vernacular names Malaysia: pendarah, mendarah, pala bukit. Singapore: maiang pahong.

Distribution Peninsular Malaysia, Singapore, Sumatra, Borneo and the Philippines.

Uses The seed is aromatic and is used in the same way as nutmeg.

Observations Dioecious tree, 20–25 m tall, stem diameter 20 cm, bark dark brown to grey; twigs slender, finely scurfy. Leaves thinly leathery; petiole 1.5 cm long; blade oblong-lanceolate, 15–20 cm × 6–7 cm, silvery-brown beneath. Inflorescence a short cyme, up to 1 cm long; flowers about 6 mm long. Fruit ovoid, 7–9 cm × 5 cm, rusty-brown scurfy; pericarp thick. Seed with thin, red, laciniate aril. *M. cinnamomea* occurs in lowland and low hills, rarely up to 1000 m altitude.

Selected sources 12, 44, 101.

Myristica womersleyi J. Sinclair

MYRISTICACEAE

Distribution North-eastern New Guinea.

Uses The seed is said to be intensely aromatic and a possible source of spice and oil. It is also used as a bait in possum traps.

Observations Tree, up to 27 m tall with tomentose, rust-coloured twigs. Leaves oblong, 14–20 cm × 5.5–9 cm, brown-haired beneath; petiole up to 1.3 cm long. Flowers not yet known. Fruit globose, 6–9 cm in diameter, brown-haired, on a stalk 0.5 cm long. Seed globose, 5 cm in diameter, strongly aromatic; aril divided into numerous narrow segments. *M. womersleyi* is common but restricted to the eastern highlands of north-eastern New Guinea (Michael and Piora Mountains) at altitudes 800–2300 m.

Selected sources 32.

Ocimum tenuiflorum L.

LABIATAE

Synonyms *Ocimum brachiatum* Hassk., *O. flexuosum* Blanco, *O. sanctum* L.

Vernacular names Holy basil, sacred basil (En). Basilic sacré, basilic des moines (Fr). Indonesia: ruku-ruku (Sumatra), kemangi utan (Moluccas), lampes (Javanese, Sundanese). Malaysia: oku, ruku ruku, sulasi. Philippines: loko-loko (Tagalog), kamangi (Bicol), bidai (Ilocano). Cambodia: mrèah prëu. Laos: saph'au. Thailand: kaphrao (central), kom ko dong, im-khim-lam (northern). Vietnam: h[uw][ow]ng nhu t[is]a, [es] t[is]a, [es] d[or].

Distribution Native to tropical Asia, but occurring pantropically cultivated and sometimes also naturalized.

Uses In Hinduism holy basil is the most sacred plant and has been cultivated for over 3000 years in courtyards and temple gardens. It is a symbol of fidelity and of pure devine love. In South-East Asia holy basil is occasionally used as a condiment in salads, fruit dishes and meat, fish and chicken but more often as a medicine because all aboveground parts are said to possess antibacterial, antifebrile and demulcent properties. In Indonesia a decoction of the leaves is used to treat colds in children, to heal wounds and to promote lactation in women. In the Philippines it is used against gonorrhoea and in Malaysia against rheumatism.

Observations An aromatic, erect, much branched herb, 30–60(–100) cm tall with stem woody at base and an indumentum of patent hairs. Leaves decussately opposite; petiole 0.5–2.5 cm long; blade broadly elliptical, 1.5–6 cm × 1–2.5 cm, margin remotely serrate, pubescent. Inflorescence racemose, 8–10 cm long, consisting of opposite 3-flowered cymes appearing as verticils, lax; flowers 3 mm long, pink or white. Fruit consisting of 4 nutlets, surrounded by the persistent calyx on a spreading pedicel 3–4 mm long. The essential-oil composition (up to 0.8% fresh-weight basis) varies strongly between populations but usually contains eugenol (40–70%, mainly as methyleugenol), caryophyllene (27%) and methylchavicol (10%). In South-East Asia *O. tenuiflorum* is a common weed of waste places in settled areas, often in great quantities, but also planted in kitchen gardens and on cemetries, in sunny dry locations, up to 600 m altitude, flowering year-round. Many forms have been described and cultivation is similar to sweet basil.

Selected sources 26, 64, 68, 84.

Pandanus krauelianus K. Schumann

PANDANACEAE

Distribution Papua New Guinea.

Uses The edible fruit contains an oil and is used cooked, to flavour food.

Observations Leaves oblong, 2 m × 3–3.5 cm, with short spines at the margin and the main vein, acuminate at apex. Fruit a syncarp of drupes, cylindrical, 20–30 cm × 5–8 cm, yellow when mature; drupe clavate-obpyramidal or prismatic, 1.5–2.5 cm × 3–5 mm. *P. krauelianus* grows in mountainous areas along rivers.

Selected sources 12, 98.

Persicaria hydropiper (L.) Spach

POLYGONACEAE

Synonyms *Polygonum flaccidum* Meisner, *P. gracile* R. Br., *P. hydropiper* L.

Vernacular names Water pepper (En). Indonesia: si tuba sawah (Sumatra), cacabean (Sundanese). Malaysia: daun senahun, rumput tuboh, tube seluwang. Philippines: agagat, tuba (Bontok), buding (Igorot). Thailand: phak phai nam, pha chi mi (northern). Vietnam: ngh[eer] r[aw]m, ngh[eer] n[uw][ows]c.

Distribution Europe, northern Africa, Asia, Australia and North America.

Uses Young leaves and shoots have a strong peppery taste and are used to flavour food. Medicinally the whole plant is used as a diuretic and emmenagogue. In Indonesia the gland-dotted leaves are used as a fish poison.

Observations Annual ascending herb, up to 80 cm tall. Stem much branched, rooting at the basal nodes; nodes enlarged and with a red ring at base. Leaves alternate, glandular; petiole 2–5 mm long, sheathing at base and with a prominent, tubular, ciliate ocrea 1.5 cm long; blade lanceolate, 2–8 cm × 0.5–2 cm. Inflorescence spiciform or racemose, up to 17 cm long, terminal or axillary, with funnel-form bracts; pedicel longer than bract; perianth 4–5-merous, greenish-white to pink; stamens 5; style 2-cleft. Fruit an achene, 2–3-sided, 2–3 mm long, brown-black. *P. hydropiper* occurs in open waste places, fields and in sunny, wet locations, from sea-level up to 1500 m altitude. Two subspecies are distinguished: subsp. *hydropiper* (in temperate climates, all parts larger, fruits mostly 2-sided) and subsp. *microcarpum* Danser (in tropical climates, all parts smaller, fruits usually 3-sided).

Selected sources 12, 23, 40, 56, 60.

Persicaria pubescens (Blume) Hara

POLYGONACEAE

Synonyms *Polygonum leptostachyum* de Bruyn, *P. pubescens* Blume, *P. roettleri* Merrill, non Roth.

Vernacular names Indonesia: siok-siok-rangan (Batak, Sumatra), tuboh lalap, tuboh perpancej (Sumatra). Malaysia: kelima paya, kesuma, tebok selydang. Vietnam: ngh[eer] l[oo]ng ng[aws]n.

Distribution From India throughout continental South-East Asia to Taiwan and Japan, and in Sumatra and Java.

Uses The leaves are used as a seasoning for food. Medicinally, a decoction with onion is used as a styptic. When used with a young pineapple to procure abortion it mitigates the violent action of the pineapple.

Observations Annual to perennial ascending herb, up to 1.7 m tall; stem much branched, often reddish, strigose and glandular, with nodes enlarged. Leaves alternate, glandular; petiole up to 1 cm long, with a sheathing base and a prominent, tubular, ciliate ocrea 1–1.5 cm long; blade ovate-lanceolate to lanceolate, 5–15 cm x 1.5–2.5 cm. Inflorescence a panicle with spike-like branches, terminal or axillary, up to 18 cm long; bracts funnel-shaped; perianth segments 5, white to red; stamens 8; style 3-cleft. Fruit an achene, 2–3 mm long, trigonous, blackish-brown. *P. pubescens* occurs more often than *P. hydropiper* in wet locations in mountainous regions, up to 2200 m altitude, but is less common. It also flowers and fruits less abundantly and is sometimes perennial.

Selected sources 12, 23, 56.

Pimpinella pruatjan Molkenb.

UMBELLIFERAE

Synonyms *Pimpinella alpina* Koord.-Schum., non Host.

Vernacular names Indonesia: purwaceng (Javanese), antanan gunung (Sundanese).

Distribution Indonesia (Java, from Mount Pangrango in West Java to Mount Argapura in East Java).

Uses In traditional Javanese medicine the aromatic roots are primarily used as an aphrodisiac, but they are also esteemed for their general restorative properties.

Observations Perennial, aromatic herb up to 50 cm tall, with a thick root of 15 cm length and numerous ascending flowering stems bearing only poorly developed leaves. Stem terete, striate, usually ascending, sometimes spreading, puberulous when young, glabrous later. Leaves mostly in radical rosettes, sheathing; sheath 3 cm long; petiole up to 10 cm long; blade imparipinnate with (1–)5(–11) leaflets; leaflet subsessile, cordate-orbicular, 1–2.5 cm long, crenate-dentate; upper leaves smaller, with shorter petioles and less densely incised leaflets. Inflorescence a terminal or leaf-opposed umbel; peduncle 1–7 cm long; involucre 3–many-foliolate; primary rays 4–9, 7–25 mm long, hairy; secondary rays 4–8 per umbellule, 1–4 mm long; involucel 4–many-foliolate; petals about 1 mm long and wide, white, tips inflexed. Fruit a schizocarp; mericarp about 2 mm × 1 mm, warty-scaly.
P. pruatjan is found in sunny or slightly shaded locations, in grasslands, in *Casuarina* forests, along pathways and stream banks, sometimes on steep slopes at 1800–3300 m altitude. It is considered an endangered species in Indonesia, where it is conserved ex situ through in vitro culture.

Selected sources 7, 26, 40, 96.

Piper aduncum L.

PIPERACEAE

Synonyms *Artanthe adunca* (L.) Miquel, *Piper angustifolium* Ruiz & Pavón, *P. elongatum* Vahl.

Vernacular names Spanish elder (En). Indonesia: seuseureuhan (Sundanese).

Distribution Widespread in Central and South America, from Mexico to Brazil and in the West Indies. It has naturalized in many regions in Malesia.

Uses *P. aduncum* is the American substitute for Indian long pepper (*P. longum* L.). It is the 'matico' of the European pharmacy: its leaves serve as a mild aromatic tonic, stimulant and internal styptic. The oil contains asarone and coneol. In Malesia it is also used medicinally.

Observations Monoecious shrubby tree, 2–8 m tall. Leaf blade oblong-elliptical to lanceolate, 12–20 cm × 3–9 cm, length/width ratio 3/1, upper surface scabrous. Inflorescence often bisexual, as long as the leaves, arching; floral bracts rounded subtriangular, 0.4–0.7 mm wide, densely yellow-white ciliate; male flower 2–3-staminate; female flower sessile, stigmas 3-fid. Fruit a berry, obovoid, 0.8–1 mm in diameter. *P. aduncum* grows in open or disturbed areas, roadsides, forest edges and along streams, up to 1500 m altitude.

Selected sources 7, 90, 99.

Piper caninum Blume

PIPERACEAE

Synonyms *Piper banksii* Miquel, *P. lauterbachii* C. DC., *P. macrocarpum* C. DC.

Vernacular names Indonesia: mrican. Malaysia: sireh hutan, lada hantu, chambai. Philippines: buyo-buyo (Bicol), detid (Igorot), tampadan (Manobo). Vietnam: ti[ee]u ch[os].

Distribution Widely distributed in Malesia through New Guinea to the Solomon Islands and Australia; occasionally also cultivated. Perhaps occurring also in Vietnam.

Uses The Besisi people in Malaysia use the fruit as a favourite flavouring. Leaves are chewed as a substitute for betel. It is also chewed to treat hoarseness. After childbirth the leaves are applied to wash the mother. Fruits are used as an adulterant for cubebs, but they are smaller and smell of anise.

Observations Dioecious climber with pilose twigs and petioles. Leaf blade ovate, 14 cm × 7 cm, length/width ratio 2/1. Female inflorescence up to as long as the leaves, flowers with 4-fid stigmas; male inflorescence often longer than the leaves. Infructescence often longer than the leaves. Fruit a berry, ovoid to globose, 4 mm × 3 mm, red. *P. caninum* is a slender lowland climber of mixed forest and in village thickets, very common in Java. A strongly pubescent form in Java has been described as *P. lowong* Blume, but is not a different species. *P. lanatum* Roxb. is used similarly to *P. caninum* and is probably the same species.

Selected sources 7, 50, 99.

Piper lolot C. DC.

PIPERACEAE

Vernacular names Lolot pepper (En). Poivre lolot (Fr). Cambodia: chaphlu:. Laos: 'i: lë:d. Vietnam: l[as] l[oos]t, t[aas]t b[as]t.

Distribution Indo-China.

Uses The leaves are used as a condiment. Medicinally the whole plant possesses anti-inflammatory and anodyne properties, e.g. used to cure skin diseases, rheumatism, headache, diarrhoea and toothache. For medicinal use whole plants, preferably in flower, are dried and stored.

Observations Perennial creeper, ascending up to 40 cm; stem swollen at the nodes. Leaves broadly cordate with amplexicaul petiole and 5–7 main veins. Inflorescence an erect, axillary spike of unisexual flowers. Fruit a single-seeded berry. *P. lolot* is found in humid locations in forests and along streambanks. It flowers and fruits from August to October. All parts contain an essential oil.

Selected sources 22, 64.

Piper sarmentosum Roxb. ex Hunter

PIPERACEAE

Synonyms *Chavica sarmentosa* (Roxb. ex Hunter) Miq.

Vernacular names Indonesia: karuk (Sundanese), cabean (Javanese), sirih tanah (Moluccas). Malaysia: chabai, kadok batu. Philippines: patai-butu (Sulu). Cambodia: mörech ansai. Thailand: cha phlu (central), nom wa (peninsular), phlu ling (northern). Vietnam: ti[ee]u l[oos]t, tat ph[aws]t.

Distribution From India to southern China and from the Philippines southward to the Moluccas.

Uses The dried infructescence is occasionally used as a spice and as a medicine. In Thailand the whole plant is used as an expectorant, the leaf as a carminative.

Observations Erect or ascending, often stoloniferous herb or shrublet, up to 1 m tall. Leaves with 2–8 cm long petiole; lower leaves ovate-cordate, 7–15 cm × 5–10 cm, 5–7-veined; highest leaves obliquely oblong, 7–11 cm × 3–5 cm, 3-veined. Inflorescence an erect spike, 1–2 cm long; bracts circular, white, about 1 cm in diameter; stamens short; stigmas 3–4. Fruit a berry, connate to each other and adnate to bract but with free apex. *P. sarmentosum* grows in thickets up to 600 m altitude, preferably in shady circumstances. In the past *P. sarmentosum* has been confused with *P. longum* L., which does not occur in Malesia.

Selected sources 7, 50.

Quararibea funebris (La Llave) Vischer

BOMBACACEAE

Synonyms *Lexarza funebris* La Llave, *Myrodia funebris* (La Llave) Bentham.

Vernacular names Flor de cacao, rosita de cacao, madre de cacao (Sp).

Distribution From central Mexico to northwestern Costa Rica. Occasionally cultivated there and elsewhere.

Uses The dried flowers provide a highly pungent spice, rather suggestive of fenugreek (*Trigo-*

nella foenum-graecum L.) in odour. In Mexico this spice is used to flavour 'pozonque' or 'tejate', a thick, frothy, aromatic beverage made with chocolate, finely ground maize meal and water. The Aztecs called the flowers 'cacahoaxochitl' rivalling the biting capsicum peppers in pungency. The spice never became popular outside Mexico, although the spicy odour is very persistent and strong. The tree provides a good quality wood and the flowers and fruits are used in local medicine to control fevers and to alleviate menstruation pains. It also has ornamental value.

Observations Tree, up to 25 m tall; trunk up to 30 cm in diameter, smooth and slightly fluted; branches verticillate, diverging horizontally from trunk with upper half drooping. Leaves alternate, simple, entire; petiole 7–27 mm long; blade obovate to elliptical, 8–40 cm × 3–13 cm. Flowers solitary or few together; pedicel 1–1.5 cm long; calyx infundibuliform, irregularly lobed, 1–2 cm long, persistent and accrescent (up to 2.5 cm length) in fruit; petals 5, spatulate, 1.5–4 cm long, white when fresh, sepia-brown when dried, moderately to densely pubescent; staminal column cylindrical, 1.5–3.5 cm long; style filiform, 1.5–3.5 cm long, stigma capitate. Fruit drupaceous, broadly ellipsoidal to slightly obovoid, 2–3 cm × 1.5 cm, 1–2-seeded; exocarp green but densely brown haired. Major constituents isolated from the flowers are the odour principle 3-hydroxy-4,5-dimethyl-2(5H)-furanone, the alkaloid funebrine, the aminolactone 3-amino-4,5-dimethyl-2(5H)-furanone and the amino acid 2S, 3S, 4R-4-hydroxyisoleucine. *Q. funebris* occurs in moist to wet primary lowland and highland forest, up to 1600 m altitude. After sowing it takes 5–6 years before the tree starts flowering. In Oaxaca, Mexico, it flowers all year long but most abundant in the rainy season. In South-East Asia it is potentially of interest as a spice, as ornamental and for its wood.

Selected sources 5, 60, 76, 80.

Renanthera moluccana Blume

ORCHIDACEAE

Vernacular names Indonesia: anggrek merah, bunga karang (Moluccas).

Distribution Indonesia (Ambon, Buru), Papua New Guinea.

Uses The young leaves are sour in taste, with a slight suggestion of capers (*Capparis* spp.) and can be used as a flavouring, alone or together with other foodacids. The rather fibrous leaves are conserved in salt or acid.

Observations Epiphytic herb with aerial roots perforating the leaf sheath; stem woody, 9–10 mm in diameter, internodes 2–4 cm long. Leaves with tubular sheath, 2–2.5 cm long, sometimes overlapping; blade elliptical, 6.5–13 cm × 2.5–4 cm, herbaceous, emarginate. Inflorescence an axillary panicle, up to 0.5 m long, with up to 5 branches and numerous flowers that open more or less simultaneously; flowers coral red, paler inside; lip 3-lobed; pollinia 4. Fruit an angular ellipsoidal capsule, about 4 cm long and 5 mm in diameter. *R. moluccana* often occurs along the edges of fresh lagoons, from sea-level up to 800 m altitude.

Selected sources 12, 40, 59.

Rhaphidophora lobbii Schott

ARACEAE

Vernacular names Malaysia: akar asam tebing paya.

Distribution Peninsular Malaysia and Borneo.

Uses The leaves are used as a flavouring in curries.

Observations Climbing herb with 4-angled stem 4–5 m long. Leaves thinly coriaceous, entire; petiole 2–7 cm long, thickened at base; blade oblong-lanceolate, 20–22 cm × 5–7 cm, veins in 12 or more distinct pairs. Inflorescence a spadix; peduncle 2.5 cm long; spathe cylindrical-cuspidate, 2.5 cm long, yellow, thick; spadix about 2.5 cm long; perianth none; stamens 3–6, filaments linear; stigma discoid. Fruit a berry containing 6 seeds. *R. lobbii* occurs on low trees and shrubs in jungle swamps.

Selected sources 12, 79.

Spondias acida Blume

ANACARDIACEAE

Synonyms *Poupartia dulcis* Blume.

Vernacular names Indonesia: dondongan (Javanese).

Distribution Peninsular Malaysia, Java, Borneo.

Uses The acid fruits can be used as a flavouring for food.

Observations Large tree, up to 50 m tall with a bole up to 36 m and a diameter up to 1 m; buttresses 2–2.5 m tall, spreading out 3 m, rather thin. Leaves aggregated at the apices of twigs, imparipinnate, appearing after the fruit matures;

rachis about 30 cm long; leaflets opposite, broadly elliptical, up to 10 cm × 5 cm, very asymmetrical, abruptly acuminate, coriaceous, with 15–20 pairs of veins. Inflorescence an axillary panicle, up to 30 cm long; pedicel 2–3 mm long; flowers 5-merous, white, small; stamens 10; ovary 5-locular, styles 5. Fruit an ellipsoidal drupe, 2–2.5 cm × 1.5–2 cm, deep orange, glossy or dull; mesocarp succulent, orange; endocarp enveloped by a fibrous cocoon with 5 longitudinal distinct fibres. *S. acida* occurs in tropical lowland rain forest, often on limestone formations; fruiting is abundant every year, but the tree is rather rare. Easily propagated from cuttings. *S. acida* has been confused with *S. pinnata* (Koenig ex L.f.) Kurz, *S. malayana* Kosterm. and *S. novoguineensis* Kosterm.

Selected sources 53.

Spondias malayana Kosterm.

ANACARDIACEAE

Synonyms *Poupartia pinnata* Blanco, *Spondias pinnata* auct., non (Koenig ex L.f.) Kurz, *S. wirtgenii* Hasskarl.

Vernacular names Indonesia: kloncing (Javanese), kadongdong (Balinese), liwas (Minahasa). Malaysia: amra. Philippines: libas (Tagalog). Cambodia: puën si: phlaè, mkak préi.

Distribution Scattered in Malesia, in Java especially in the drier eastern part, not in New Guinea.

Uses Young leaves, inflorescences and fruits are sometimes used as an acid flavouring for food. The root is applied externally to regulate menstruation. The leaves are mixed with other substances, to treat coughs. In Bali a lotion from the leaves with the bark and leaves of an *Eugenia* sp. and a young coconut may be used on ulcers. The leaves with henna, lemon juice and lime may be applied for herpes and with salt for scurf. A decoction of the wood is drunk against gonorrhoea and the bark, cooked with sour milk, is taken against dysentery. The timber is very soft and not durable; it can be used to make matches and temporary poles.

Observations Tree, 20(–40) m tall, glabrous; trunk straight, cylindrical, smooth but with large deep longitudinal cracks, diameter 30–35(–150) cm, but without buttresses. Leaves spirally arranged, aggregate, 15–35 cm long, (3–) 5–6(–8)-jugate, chartaceous; petiolules 4–10 mm long; leaflets opposite to subopposite, elongate oblong, 2.5–5 cm × 5–13 cm, almost asymmetrical, conspicuously abruptly acuminate, veins 16–25 ending in a marginal vein close to the margin. Inflorescence a stiff, axillary panicle, up to 24 cm long, branched from the base, branches up to 10 cm long; flowers in dense glomerules, subsessile, 4 mm in diameter; calyx small; petals 5, 1.5–2.5 mm long, fleshy; stamens up to 1.5 mm long with broad filaments; styles 5, short, knobbly. Fruit a broadly ellipsoidal drupe, 3–5 cm × 2.5–3.5 cm, orange-yellow, pulp juicy, yellow-orange, 3–4 mm thick; endocarp a smooth white stone with a capsule of dense fibres, 5-celled. Seed usually 1–2. *S. malayana* prefers areas with a pronounced dry season, usually on infertile soils in dry deciduous forest, up to 600 m altitude; also at the inland of mangrove vegetation where the trees are small and stunted. In the dry season the trees bear numerous pendulous bundles of fruits; new flushes and flowers appear simultaneously. *S. malayana*, *S. acida* Blume and *S. novoguineensis* Kosterm. belong to a complex that was formerly wrongly identified as *S. pinnata* (Koenig ex L.f.) Kurz in Malesia. Branch cuttings of *S. malayana* root easily.

Selected sources 10, 12, 26, 40, 53, 66.

Spondias novoguineensis Kosterm.

ANACARDIACEAE

Synonyms *Spondias pinnata* auct., non (Koenig ex L.f.) Kurz.

Vernacular names Indonesia: ngaulo (Ternate), uritchu (Ambon), kanuris (Biak). Papua New Guinea: bali (New Britain)

Distribution Indonesia (Moluccas: Ambon, Aru Islands, Ternate, Seram), New Guinea and the Solomon Islands.

Uses The acid fruit can be used as a flavouring for food.

Observations Tree, up to 40 m tall; bole branchless for up to 25 m, diameter up to 120 cm, with very large buttresses, up to 1.5 m tall and spreading 2 m out. Leaves aggregate at the end of twigs, up to 40 cm long; leaflets subopposite, 9–10 pairs, pari- or imparipinnate, oblong, 4–15 cm × 1.5–2.5 cm, sharply acuminate, obscurely reticulate with 20–30 parallel pairs of veins that join up into a marginal vein. Inflorescence a panicle, up to 20 cm long; flowers 5-merous; petals white to cream; stamens 10; styles 4–5. Fruit an ellipsoidal drupe, 3 cm × 4 cm, dirty orange, pulp greenish-white; endocarp bony, consisting of a smooth capsule of interwoven, longitudinal fibres. *S. novogui-*

neensis occurs in lowland tropical rain forest and flowers when leafless. It has been confused with *S. pinnata* (Koenig ex L.f.) Kurz, *S. acida* Blume and *S. malayana* Kosterm.

Selected sources 53.

Spondias pinnata (Koenig ex L.f.) Kurz

ANACARDIACEAE

Synonyms *Mangifera pinnata* Koenig ex L.f., *Spondias amara* Lamk, *S. mangifera* Willd.

Vernacular names Amra, amna, ambra (En, India). Burma (Myanmar): gwe, pwe-baung. Cambodia: mokak. Laos: ko:k, ku:k. Thailand: ma-kok. Vietnam: c[os]c chua, c[os]c r[uwf]ng.

Distribution India, the Himalayas, Burma (Myanmar) and perhaps introduced and naturalized in Thailand, Indo-China, Andaman Islands and Sri Lanka.

Uses The leaves are used for flavouring. The fruit is eaten as a vegetable when green and as a fruit when ripe but it has a watery, almost odourless acid taste. It can be made into chutneys, stews, pickles and jams. The wood is soft and deteriorates quickly in the open. Timber can be used for packing cases, floats, canoes, matches and non-ornamental plywood. It is fairly good for unbleached wood pulp. As fuel it is of poor quality. Medicinally the fruit is used as an astringent, antiscorbutic and against bilious dyspepsia. The juice is applied against earache.

Observations Tree up to 27 m tall and with trunk diameter up to 50 cm but usually much smaller. Leaves 30–60 cm long, imparipinnate; leaflets 5–11, broadly elliptical, 6–10 cm × 2.5–6 cm, base rounded, apex acuminate, with 20–25 pairs of close parallel veins, all joining an intramarginal vein. Inflorescence a large terminal panicle, with greenish-white, polygamous flowers. Fruit an ovoid drupe, 4–7 cm long, smooth, yellowish-green mottled with yellow and black, fleshy; stone surrounded by a capsule of intertwined fibres. Seed oblong-elliptical; only one of the three ovules develops. *S. pinnata* occurs in dry areas in deciduous forest, up to 1500 m altitude, but is nowhere very common. It loses its leaves for a considerable period, after which it flowers and the new shoots appear. *S. pinnata* occurs at the periphery of Malesia; in Malesia it has been confused with *S. acida* Blume, *S. malayana* Kosterm. and *S. novoguineensis* Kosterm.

Selected sources 53.

Synsepalum dulcificum (Schum. & Thonner) Baillon

SAPOTACEAE

Synonyms *Bumelia dulcifica* Schum. & Thonner, *Pouteria dulcifica* (Schum. & Thonner) Baehni, *Richardella dulcifica* (Schum. & Thonner) Baehni.

Vernacular names Miraculous berry, miraculous fruit, sweet berry (En). Fruit miraculeux (Fr).

Distribution Africa, from Ghana to the Congo area. Occasionally cultivated, also outside its area of natural distribution.

Uses The sweet-acid pulp around the seeds is eaten. The taste of sweetness remains for about 2 hours in the mouth, 'sweetening' sour and bitter substances eaten in that time. It has a greater effect in sweetening acidity than in countering bitterness. It is also used for sweetening palm-wine. The twigs are used as chewsticks and the wood as firewood.

Observations Shrub or small tree, up to 4.5 m tall. Leaves alternate, simple, entire, clustered near ends of branchlets; petiole very short; blade obovate-oblanceolate, 5–10 cm × 1.5–4 cm, glabrous below, with about 8 pairs of lateral veins. Flowers solitary, in small, axillary, subsessile clusters; calyx tubular, 4–5-lobed, ribbed; corolla tubular, tube as long as calyx, lobes 4–5, brown; stamens 4–5; pistil with simple style and inconspicuous stigma. Fruit a one-seeded, ellipsoidal berry, 1.5–1.8 cm long, dark red; pulp whitish-pink. Seed large with a hard, shiny testa. *S. dulcificum* prefers damp localities, e.g. along rivers. It is often grown around dwellings. Propagation is by seed but it is slow-growing. The active principle is a basic glycoprotein (miraculin) with a high molecular weight (44 000) which is difficult to stabilize. The purified protein is potentially an interesting sweetening agent. It may potentially be of interest for South-East Asia as source of a natural sweetening agent. Other potential sources of natural sweeteners are: *Dioscoreophyllum cumminsii* (Stapf) Diels (serendipity berry, containing monellin) and *Thaumatococcus daniellii* (Bennet) Benth. (katemfe, containing thaumatin).

Selected sources 6, 46, 47, 60.

Thaumatococcus daniellii (Bennet) Benth.

MARANTACEAE

Synonyms *Donax daniellii* (Bennet) Roberty, *Monostiche daniellii* (Bennet) Horan., *Phrynium daniellii* Bennet.

Vernacular names Katemfe, katamfe, miraculous fruit (En). Fruit miraculeux (Fr).

Distribution West Africa, from Sierra Leone to Congo. Occasionally cultivated, also outside its natural area of distribution.

Uses The aril of the seed contains a sweet-tasting protein (thaumatin) that can be used as a substitute for sugar, also in low caloric diets and drinks. Because of the persistent sweet aftertaste, it also 'sweetens' normally bitter or sour substances. Sometimes it is especially cultivated for its leaves (e.g. in Nigeria), which are used for roofing and packing.

Observations Rhizomatous herb with short stem bearing a single leaf. Petiole 2–3 m tall; blade ovate, very large, 60 cm × 40 cm or larger. Inflorescence a raceme, 10 cm long, subsessile; flowers whitish-pinkish, about 2 cm long. Fruit a triangular capsule, about 3 cm in diameter, 3-loculed. Seed 3-sided, irregularly pyramidal surrounded by a whitish aril, which is transparent and jelly like, swelling considerably in water. *T. daniellii* occurs in lowland tropical rain forest. Propagation is mainly by rhizome cuttings and shade is necessary for good growth. Planting distance is about 1 m × 1 m. In Africa first flowering starts 3 months after planting but flowering is more abundant after about 1 year. Good fruits develop only in plants that are 2 years old or older. Young fruits mature in 13 weeks. Thaumatin is the sweetest of known natural and synthetic substances, 2000–3000 times sweeter than sucrose. *T. daniellii* might be an interesting source of a natural sweetener for South-East Asia. Other potential sources of natural sweeteners are: *Dioscoreophyllum cumminsii* (Stapf) Diels (serendipity berry, containing monellin) and *Synsepalum dulcificum* (Schum. & Thonner) Baillon (miraculous berry, containing miraculin).

Selected sources 2, 12, 13, 30, 60, 63, 67, 97.

Toddalia asiatica (L.) Lamk

RUTACEAE

Synonyms *Paullinia asiatica* L., *Toddalia aculeata* (Smith) Persoon.

Vernacular names Lopez root (En). Indonesia: areuy beleketebek (Sundanese), duri kengkeng (Javanese), rabet kingking (Madurese). Malaysia: akar kucing. Philippines: dauag (Tagalog), subit (Igorot), kaboat (Bisaya). Laos: ngu: haux, pè:m pa:x. Vietnam: x[is]t xa, cam n[us]i.

Distribution From India, southern China and Taiwan throughout South-East Asia. Also in Mauritius and Madagascar.

Uses All parts of the plant are used to flavour food, as a tonic for the stomach and to prevent fever. An infusion of the leaves is used against asthma. The leaves contain a valuable low-grade perfume oil (0.08%).

Observations Woody liana, 2–20 m long; stem scrambling by the sharp, recurved prickles. Leaves alternate or spiralled, trifoliolate; petiole up to 2 cm long; leaflets sessile, ovate to oblong-lanceolate, 3–10 cm × 1–2.5 cm, margins shallowly crenulate. Inflorescence paniculate, up to 7.5 cm long; pedicel 3–6 mm long; flowers 3–5 mm long, 5-merous, unisexual, creamy-white, usually 3–10 together in cymes or lax umbels on the lateral rachises; male flower with 5 stamens; female flower with a short gynophore and a capitate stigma. Fruit a subglobose drupe, 5–7 mm in diameter, 3–5-grooved, glandular, orange. Seeds up to 7, somewhat compressed. *T. asiatica* occurs in humid forest, from sea-level up to 2300 m altitude.

Selected sources 7, 10, 40, 56.

Urophyllum arboreum (Reinw. ex Blume) Korth.

RUBIACEAE

Vernacular names Indonesia: ki cengkeh (Sundanese).

Distribution Indonesia (West Java).

Uses The bruised leaves smell strongly of cloves and are used as a spice and medicinally in Java. The wood can be used in house building and lasts 4–5 years when exposed.

Observations Dioecious treelet, up to 8 m tall and 10–15 cm in stem diameter. Leaves opposite, subglabrous; blade lanceolate, 10–15 cm × 2–5 cm, caudate-acuminate, when bruised smelling strongly of cloves. Inflorescence with 2 or more superposed whorls of flowers; pedicel about 1 cm long; flowers unisexual; male flower with 5-toothed to almost entire calyx 3.5 mm long, corolla tube 1.5 mm long, 5 lobes 3.5 mm long, stamens 5 with subsessile anthers 0.5 mm long; female flower with campanulate calyx, corolla with lobes up to 4 mm long, pistil with 1 mm style and 5 stigmatic branches. Fruit a 5-celled berry, globose, 5–7 mm in diameter. *U. arboreum* occurs in forest at 200–1200 m altitude. It is closely related and has been considered as conspecific to the wider occurring *U. glabrum* Wallich, whose bruised leaves, however, do not smell of cloves and do not contain eugenol.

Selected sources 7, 12, 40.

Vanilla abundiflora J.J. Smith

ORCHIDACEAE

Distribution Borneo.

Uses The fruits can be used like those of *V. planifolia* H.C. Andrews but their fragrance is less strong.

Observations Succulent herb with stem 10–20 m long. Leaf blade elliptical, up to 25 cm × 9 cm. Inflorescence a dense raceme with numerous large, white flowers. Fruit compressed-cylindrical, up to 25 cm × 2 cm, yellow-brown. *V. abundiflora* occurs in moderately dense forest on swampy land, which is occasionally flooded.

Selected sources 40, 85.

Weinmannia fraxinea Smith ex D. Don

CUNONIACEAE

Synonyms *Pterophylla fraxinea* D. Don, *Weinmannia sundana* Heyne (non Blume, nec Miquel).

Vernacular names Indonesia: kulit papeda, aeru, taeru (Moluccas).

Distribution Indonesia (Moluccas: Ambon, Bacan, Haruku, Seram). Occasionally cultivated elsewhere (e.g. in Java, Bogor Botanical Garden).

Uses In Indonesia (Moluccas) the bark is used to flavour food and to colour it red (e.g. sago). For daily use the bark can be conserved dried. The pale yellow wood is easy to work; it is used for house construction.

Observations Dioecious tree, 11 m or taller, with trunk diameter 60–120 cm. Leaves opposite or whorled, pinnately compound; stipules persistent, reniform, up to 2 cm × 2.5 cm; leaflets 5 or 7, narrowly elliptical, 7–12 cm × 2–3 cm, asymmetrical at base, margin crenate-serrate, glabrous. Inflorescence a pseudoraceme, up to 12 cm long, usually in pairs at apex of branchlets; pedicel about 2 mm long; flowers small, 4-merous, male one with 8 stamens, female one with 2 styles. Fruit a pubescent, ellipsoidal capsule, 6–7 mm long, containing 6–8 seeds. Seed 3 mm long, long haired. *W. fraxinea* occurs in forest vegetation, from sea-level up to 1100 m altitude.

Selected sources 8, 12, 40.

Zanthoxylum armatum DC.

RUTACEAE

Synonyms *Zanthoxylum alatum* Roxb., *Z. planispinum* Sieb. & Zucc.

Vernacular names Wild Chinese pepper (En). Philippines: chi-it, sibit-paklauit (Igorot). Laos: ma:d. Thailand: mak kak (northern). Vietnam: d[aws]ng cay, s[er]n gai.

Distribution From Pakistan and northern India east to Japan and Taiwan, south only in the Philippines and Lesser Sunda Islands. Occasionally cultivated there and also outside its natural area of distribution.

Uses Various parts of the plant are used to season food, especially in Thailand, China and India. The pungent bark is used to clean teeth and as an insect repellent. Leaves, bark and fruits are used in India to cure fever, dyspepsia, diarrhoea, smallpox and cholera.

Observations Deciduous or evergreen, dioecious, scandent or erect shrub or small tree up to 6 m tall. Leaves alternate, trifoliolate or imparipinnate, 5–23 cm long, rachis winged; leaflets 1–5 pairs, opposite, ovate to lanceolate, 1.5–13 cm × 0.5–5 cm, margins entire to glandular crenate. Inflorescence paniculate, axillary or terminal, 1–7 cm long; flowers about 2 mm long, perianth segments 6–7, green-yellow, undifferentiated; male flower with 4–6 stamens; female flower with 1–3-carpellate ovary and 1–3 stigmas. Fruit a subglobose follicle, 4–5 mm in diameter, single or 2–3 together, reddish; each follicle 2-valved and 1-seeded. Seed shiny black. *Z. armatum* occurs in rain forest, thickets and, at higher elevations, often on open slopes and rock ledges; in Malesia up to 1750 m, in continental Asia up to 2400 m altitude.

Selected sources 12, 36, 56.

Zanthoxylum avicennae (Lamk) DC.

RUTACEAE

Synonyms *Fagara avicennae* Lamk, *Zanthoxylum diversifolium* Warburg, *Z. tidorense* Miquel.

Vernacular names Indonesia: karangeang (Javanese), adas kastela (Moluccas), samirin (Seram). Philippines: bagatambal (Bisaya), bungi (Tagalog), kangai (Pampango). Vietnam: mu[oof]ng tr[oof]ng, ho[af]ng m[oj]c d[af]i, s[er]n.

Distribution From Thailand east to China (Fukien Province) and south to Indonesia (Java, Lesser Sunda Islands, Sulawesi, Moluccas), Malaysia (Sabah) and the Philippines.

Uses In Java the leaves and fruits are used to flavour food; the leaves smell like coriander, the seeds like anise. The hard, dense, heavy reddish wood is used to make small tool handles. In the Philippines and Indo-China the stem and bark are used medicinally as a tonic and to treat snake bites.

Observations Erect or scandent, dioecious, evergreen shrub or small tree, up to 15 m tall, with pseudostipula, straight or recurved prickles on the branches. Leaves alternate, imparipinnate, 5–30 cm long; rachis narrowly winged; leaflets 2–11 pairs, subopposite, ovate to elliptical-lanceolate, 1–8 cm × 1–3 cm, pellucid dotted, subleathery, margins subentire to glandular crenate. Inflorescence cymose, terminal or axillary, 5–21 cm long, upper branches usually whorled; flowers up to 3 mm long, 5-merous, perianth differentiated, white to green-yellow; male flower with 5 stamens; female flower with 2-carpellate gynoecium. Fruit a subglobose follicle, 4.5 mm in diameter, single or more usually in pairs. *Z. avicennae* occurs in dry forest, thickets and on open slopes at altitudes up to 1650 m. Plants from dry, open and mountainous locations tend to become dwarfed or scandent with much reduced leaves and inflorescences.

Selected sources 10, 36, 37, 40, 88.

Zingiber chrysostachys Ridley

ZINGIBERACEAE

Vernacular names Malaysia: lempui.

Distribution Peninsular Malaysia.

Uses The pungent rhizomes are possibly a substitute for *Zingiber zerumbet* (L.) J.E. Smith. A decoction of the leaves is administered against fever.

Observations Rhizomatous perennial herb with leafy shoots up to 60(–100) cm tall. Leaves lanceolate, 12–17 cm × 4–5.5 cm. Inflorescence spiciform on a separate scape arising from the rhizome; scape 7–10 cm long; spike cylindrical, up to 10 cm × 4 cm; bracts suborbicular, 2–3 cm in diameter, bright yellow; bracteoles 2.5 cm long; calyx 1.5 cm long, corolla 4.5 cm long, pale yellow; labellum with obovate midlobe, 1.2 cm long, crimson with irregular white margins, side lobes ovate, 8 mm × 5 mm, white; anther appendage mottled pink to red. *Z. chrysostachys* occurs in evergreen forest and in dry bamboo forest on limestone hills, 200–1400 m altitude.

Selected sources 12, 42, 79, 91.

Zingiber griffithii Baker

ZINGIBERACEAE

Vernacular names Malaysia: tepus merah, tepus kechil, tepus huma.

Distribution Peninsular Malaysia, Singapore, peninsular Thailand.

Uses The rhizomes are pungent. The whole plant may be used for poulticing the body, e.g. to alleviate fever.

Observations Rhizomatous, perennial herb with leafy shoots, up to 1.2 m tall. Leaves broadly lanceolate to ovate, 15–25 cm × 5–8 cm, beneath with very fine silky hairs, veins raised when dry. Inflorescence spiciform on a separate scape 4–15 cm long; bracts elliptical, up to 2.5–4 cm × 1.5–2.5 cm, pink to red; bracteoles absent; spike fusiform to cylindrical, 10–15 cm × 1.5–3.5 cm; calyx 2.5 cm long; corolla 5 cm long, white to pale yellow, dorsal lobe 2 cm × 1 cm; labellum with triangular midlobe 17 mm × 6 mm, white to pale yellow, lateral staminodes very small. Fruit a glabrous capsule, about 2 cm long. Seed maroon. *Z. griffithii* occurs in lowland evergreen forest or in secondary forest in damp, shady locations on soils rich in humus.

Selected sources 12, 42, 79, 91.

Zingiber ottensii Valeton

ZINGIBERACEAE

Vernacular names Indonesia: panglai hideung (Sundanese), bunglai hantu (eastern Sumatra). Peninsular Malaysia: lampoyang hitam, kunyit hitam, berseh hitam. Thailand: phlai dam (northern), puu loei dam (northern), phlai muang (Bangkok).

Distribution Indonesia (Java, Sumatra), Peninsular Malaysia, Thailand.

Uses The rhizomes are pungent. In traditional medicine they are pounded into a poultice and used by women after childbirth, or are added to a mixture to make a sedative lotion or a tonic. A popular plant, cultivated in home gardens.

Observations Rhizomatous, perennial herb with leafy shoots up to 1.5 m tall. Rhizome purplish inside and with a very pungent smell. Leaves elliptical, 35–40 cm × 6–8 cm. Inflorescence spiciform and on separate scape 25–40 cm long; bracts obovate, 4 cm long, convex with incurved tips, bright red; bracteoles linear, 3 cm long; spike ellipsoidal to cylindrical, 10–12 cm × 4 cm; calyx 2.3 cm long, white; corolla 5.7 cm long, cream to yellow; labellum 5.5 cm long, pale yellow with red-brown markings, or faintly pink densely interspersed with large and small pale yellow spots; midlobe almost circular and 2 cm in diameter. Fruit a red cylindrical capsule. *Z. ottensii* is only known from cultivation and can easily be distinguished by its purplish rhizome flesh.

Selected sources 12, 40, 42, 79, 91, 95.

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P.C.M. Jansen,
with contributions from:
K.N. Tyas (*Globba marantina*)
X.Y. Wolff (*Globba marantina*)
M. Brink (*Borago officinalis, Capsicum pubescens, Eruca sativa, Melissa officinalis*)

4 Spice plants with other primary use

List of species in other commodity groups (parenthesis), which are used also as a spice. Synonyms in the indented lines.

Abelmoschus moschatus Medikus (essential-oil plants)
    Hibiscus abelmoschus L.
Achillea millefolium L. (medicinal and poisonous plants)
Acorus calamus L. (medicinal and poisonous plants)
    Acorus asiaticus Nakai
    Acorus terrestris Spreng.
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)
Aglaia odoratissima Blume (essential-oil plants)
    Aglaia affinis Merrill
    Aglaia diepenhorstii Miquel
    Aglaia heterophylla Merrill
Allium ampeloprasum L. cv. group Leek (vegetables)
    Allium ampeloprasum L. var. *porrum* (L.) J. Gay
    Allium porrum L.
Allium cepa L. cv. group Aggregatum (vegetables)
    Allium ascalonicum auct. non Strand
    Allium cepa L. var. *aggregatum* G. Don
    Allium cepa L. var. *ascalonicum* Backer
    Allium cepa L. var. *solanina* Alef.
Allium cepa L. cv. group Common Onion (vegetables)
    Allium cepa L. var. *cepa*
Allium chinense G. Don (vegetables)
    Allium bakeri Regel
    Allium schoenoprasum auct. non L.
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 malaccensis (Burm.f.) Roscoe (essential-oil plants)

Catimbium malaccense (Burm.f.) Holttum
Languas malaccensis Merrill
Maranta malaccensis Burm.f.
Alpinia zerumbet (Pers.) Burtt & Smith (essential-oil plants)
Alpinia speciosa (Wendl.) K. Schum.
Catimbium speciosum (Wendl.) Holttum
Costus zerumbet Pers.
Zerumbet speciosum Wendl.
Amomum dealbatum Roxb. (edible fruits and nuts)
Amomum maximum Roxb. sensu Backer & Ochse
Amomum krervanh Pierre ex Gagnepain (medicinal and poisonous plants)
Amomum lappaceum Ridley (edible fruits and nuts)
Amomum uliginosum J.G. König ex Retz. (medicinal and poisonous plants)
Amomum villosum Loureiro (medicinal and poisonous plants)
Amomum echinosphaera K. Schumann ex Gagnepain
Amomum xanthioides Wallich ex Baker (medicinal and poisonous plants)
Amomum villosum Loureiro var. *xanthioides* (Wallich ex Baker) T.L. Wu & S.J. Chen
Ancistrocladus tectorius (Loureiro) Merrill (medicinal and poisonous plants)
Antidesma bunius (L.) Sprengel (edible fruits and nuts)
Antidesma dallachyanum Baillon
Antidesma rumphii Tulasne
Stilago bunius L.
Apium graveolens L. (vegetables)
Apium dulce Miller
Apium lusitanicum Miller
Apium rapaceum Miller
Archidendron jiringa (Jack) I.C. Nielsen (vegetables)
Pithecellobium jiringa (Jack) Prain
Pithecellobium lobatum Benth.
Zygia jiringa (Jack) Kosterm.
Archidendron microcarpum (Benth.) I.C. Nielsen (timber trees)
Abarema microcarpa (Benth.) Kosterm.
Pithecellobium microcarpum Benth.
Artemisia vulgaris L. (medicinal and poisonous plants)
Astronia papetaria Blume (timber trees)
Backhousia citriodora F. v. Mueller (essential-oil plants)
Blumea lanceolaria (Roxburgh) Druce (medicinal and poisonous plants)
Blumea conspicua Hayata
Blumea laxiflora Elmer
Blumea myriocephala DC.
Brassica juncea (L.) Czernjaew (vegetables/vegetable oils and fats)
Brassica integrifolia (West) Rupr.
Sinapis juncea L.
Sinapis timoriana DC.
Bruguiera gymnorhiza (L.) Savigny (dye and tannin-producing plants)
Bruguiera conjugata Merr.
Bruguiera cylindrica (non Blume) Hance
Bruguiera rheedii Blume

Camellia sasanqua Thunberg ex Murray (vegetable oils and fats)
Canavalia ensiformis (L.) DC. (forages)
  Canavalia gladiata (Jacq.) DC. var. *ensiformis* (L.) Benth.
  Dolichos ensiformis L.
Canavalia gladiata (Jacq.) DC. (vegetables)
  Canavalia ensiformis auct. non (L.) DC.
  Canavalia ensiformis (L.) DC. var. *gladiata* (Jacq.) Kuntze
  Dolichos gladiatus Jacq.
Capsicum annuum L. (vegetables)
Capsicum frutescens L. (vegetables)
Chenopodium ambrosioides L. (medicinal and poisonous plants)
Chloranthus spicatus (Thunb.) Makino (essential-oil plants)
  Chloranthus inconspicuus Swartz
  Chloranthus indicus Wight
  Chloranthus obtusofolius Miquel
Cinchona officinalis L. (medicinal and poisonous plants)
  Cinchona calisaya Wedd.
  Cinchona ledgeriana Moens ex Trimen
Cinchona pubescens Vahl (medicinal and poisonous plants)
  Cinchona cordifolia Mutis
  Cinchona succirubra Pav. ex Klotzsch
Cinnamomum iners Reinw. ex Blume (timber trees)
  Cinnamomum eucalyptoides T. Nees
  Cinnamomum nitidum Blume
  Cinnamomum paraneuron Miq.
Cinnamomum mercadoi S. Vidal (timber trees)
Cinnamomum mollissimum Hook.f. (timber trees)
Cinnamomum porrectum (Roxb.) Kosterm. (timber trees)
  Cinnamomum glanduliferum C. Nees
  Cinnamomum parthenoxylon (Jack) C. Nees
  Cinnamomum sumatranum (Miq.) Meissner
Cinnamomum sintoc Blume (timber trees)
  Cinnamomum calophyllum Reinw. ex C. Nees
  Cinnamomum camphoratum Blume
  Cinnamomum cinereum Gamble
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 bergamia Risso & Poiteau (essential-oil plants)
  Citrus aurantium L. subsp. *bergamia* (Risso & Poiteau) Engler
  Citrus aurantium L. var. *bergamia* (Risso & Poiteau) Wight & Arnott
Citrus hystrix DC. (edible fruits and nuts)
Citrus limon (L.) Burm. f. (edible fruits and nuts)
Citrus medica L. (edible fruits and nuts)
  Citrus aurantium L. var. *medica* Wight & Arnott

Citrus crassa Hasskarl
Citrus reticulata Blanco (edible fruits and nuts)
Citrus chrysocarpa Lushington
Citrus deliciosa Tenore
Citrus nobilis Andrews et auct., non Lour.
Citrus sinensis (L.) Osbeck (edible fruits and nuts)
Citrus aurantium L. var. *sinensis* L.
Clausena anisum-olens (Blanco) Merrill (essential-oil plants)
Clausena laxiflora Quis. & Merrill
Clausena sanki (Perr.) Molino
Cookia anisum-olens Blanco
Cleome gynandra L. (vegetables)
Cleome pentaphylla L.
Gynandropsis gynandra (L.) Briq.
Gynandropsis pentaphylla (L.) DC.
Crocus sativus L. (dye and tannin-producing plants)
Cryptocarya massoy (Oken) Kosterm. (medicinal and poisonous plants)
Cryptotaenia canadensis (L.) DC. (vegetables)
Cryptotaenia japonica Hassk.
Curcuma zedoaria (Christmann) Roscoe (plants yielding non-seed carbohydrates)
Amomum latifolium Lamk
Amomum zedoaria Christmann
Curcuma pallida Lour.
Curcuma zerumbet Roxb.
Cymbopogon citratus (DC.) Stapf (essential-oil plants)
Andropogon ceriferus Hackel
Andropogon citratus DC.
Andropogon nardus (L.) Rendle var. *ceriferus* Hackel
Dendrobium salaccense (Blume) Lindley (essential-oil plants)
Grastidium salaccense Blume
Dendrobium gemellum Ridley
Dendrobium intermedium Teijsm. & Binnend.
Dysoxylum alliaceum (Blume) Blume (timber trees)
Dysoxylum euphlebium Merr.
Dysoxylum klemmei Merr.
Dysoxylum thyrsoideum Hiern.
Elettariopsis sumatrana Valeton (medicinal and poisonous plants)
Embelia ribes Burm.f. (medicinal and poisonous plants)
Embelia garciniifolia Wallich ex Miq.
Enydra fluctuans Loureiro (vegetables)
Enydra longifolia (Blume) DC.
Enydra paludosa (Reinw.) DC.
Etlingera gracilis (Valeton) R.M. Smith (edible fruits and nuts)
Excoecaria indica (Willd.) Muell. Arg. (dye and tannin-producing plants)
Sapium indicum Willd.
Stillingia diversifolia Miq.
Stillingia indica (Willd.) Baillon
Fortunella polyandra (Ridley) Tanaka (ornamental plants)

Garcinia cowa Roxburgh (vegetables)
Garcinia sizygiifolia Pierre (edible fruits and nuts)
Hemerocallis minor Miller (ornamental plants)
Hibiscus acetosella Welwitsch ex Hiern (vegetables)
    Hibiscus eetveldianus De Wild. & Th. Durand
Homalomena griffithii (Schott) Hook.f. (medicinal and poisonous plants)
Houttuynia cordata Thunberg (vegetables)
Illicium anisatum L. (medicinal and poisonous plants)
Jasminum grandiflorum L. (essential-oil plants)
    Jasminum floribundum R. Br. ex Fresen.
    Jasminum officinale L. var. *grandiflorum* (L.) Stokes
    Jasminum officinale L. forma *grandiflorum* (L.) Kobuski
Jasminum sambac (L.) Aiton (medicinal and poisonous plants)
    Nyctanthes sambac L.
Kaempferia galanga L. (medicinal and poisonous plants)
Kaempferia rotunda L. (medicinal and poisonous plants)
    Kaempferia longa Jacq.
Lavandula angustifolia Miller (essential-oil plants)
    Lavandula officinalis Chaix
    Lavandula spica L.
    Lavandula vera DC.
Lavandula latifolia Medikus (essential-oil plants)
    Lavandula spica auct., non L.
Lavandula stoechas L. (essential-oil plants)
Lavandula ×intermedia Emeric. ex Loisel. (essential-oil plants)
    Lavandula ×burnati Briquet
Leucas lavandulifolia J.E. Smith (medicinal and poisonous plants)
Leucas zeylanica (L.) R. Br. (medicinal and poisonous plants)
Litsea cubeba (Lour.) Persoon (essential-oil plants)
    Laurus cubeba Lour.
    Litsea citrata Blume
    Tetranthera polyantha Wallich ex Nees var. *citrata* Meissner
Litsea pipericarpa (Miquel) Kosterm. (essential-oil plants)
    Lindera pipericarpa (Miquel) Boerl.
    Polyadenia pepericarpa Miquel
Lycium chinense Miller (vegetables)
    Lycium rhombifolium (Moench) Dippel
Lycopersicon esculentum Miller (vegetables)
    Lycopersicon lycopersicum (L.) Karsten
    Solanum lycopersicum L.
Mallotus floribundus (Blume) Muell. Arg. (timber trees)
    Mallotus anamiticus O. Kuntze
Melicope lunu-ankenda (Gaertn.) T.G. Hartley (timber trees)
    Euodia aromatica Blume
    Euodia lunu-ankenda (Gaertn.) Merr.
    Euodia roxburghiana (Cham.) Benth.
Mentha arvensis L. (medicinal and poisonous plants)
Mentha ×cordifolia Opiz ex Fresen (medicinal and poisonous plants)
Mentha ×piperita L. (medicinal and poisonous plants)

Mentha pulegium L. (medicinal and poisonous plants)
Momordica charantia L. (vegetables)
    Momordica chinensis Spreng.
    Momordica elegans Salisb.
    Momordica indica L.
Momordica cochinchinensis (Lour) Spreng. (vegetables)
    Momordica meloniflora Hand.-Mazz.
    Momordica mixta Roxb.
    Muricia cochinchinensis Lour.
Moringa oleifera Lamk (vegetables)
    Guilandina moringa L.
    Moringa polygona DC.
    Moringa pterygosperma Gaertner
Murraya koenigii (L.) Spreng. (timber trees)
    Bergera koenigii L.
    Chalcas koenigii (L.) Kurz
    Murraya foetidissima Teijsm. & Binnend.
Myristica elliptica Wallich ex Hook.f. & Thomson (timber trees)
    Myristica calocarpa Miquel
    Myristica sycocarpa Miquel
Nigella damascena L. (essential-oil plants)
    Nigella coerulea Lamk
    Nigella pygmaea Persoon
Ocimum americanum L. (vegetables)
    Ocimum africanum Lour.
    Ocimum brachiatum Blume
    Ocimum canum Sims
Ocimum gratissimum L. (essential-oil plants)
    Ocimum suave Willd.
    Ocimum viride Willd.
    Ocimum viridiflorum Roth
Oenanthe javanica (Blume) DC. (vegetables)
    Oenanthe stolonifera DC.
    Sium javanicum Blume
Ottelia alismoides (L.) Persoon (auxiliary plants)
    Ottelia condorensis Gagnep.
    Ottelia japonica Miquel
    Ottelia javanica Miquel
Oxalis corniculata L. (medicinal and poisonous plants)
    Oxalis javanica Blume
    Oxalis repens Thunb.
Pandanus conoideus Lamk (edible fruits and nuts)
    Pandanus butyrophorus Kurz
Pangium edule Reinw. (medicinal and poisonous plants)
Papaver somniferum L. (medicinal and poisonous plants)
Paraserianthes lophanta (Willd.) Nielsen (auxiliary plants)
    Acacia montana Jungh.
    Albizia montana (Jungh.) Benth.
Parkia harbesonii Elmer (vegetables)

Parkia intermedia Hassk. ex Hoeven & de Vries (vegetables)
Parkia leiophylla Kurz (vegetables)
Parkia sherfeseei Merrill (vegetables)
Parkia speciosa Hassk. (vegetables)
  Parkia macrocarpa Miquel
Parkia sumatrana Miquel (vegetables)
  Parkia dongnaiensis Pierre
  Parkia insignis Kurz
  Parkia streptocarpa Hance
Parkia timoriana (DC.) Merrill (vegetables)
  Parkia roxburghii G. Don
Peperomia pellucida (L.) Kunth (medicinal and poisonous plants)
  Piper exiguum Blume
  Piper pellucidum L.
Phyllanthus acidus (L.) Skeels (medicinal and poisonous plants)
  Cicca acida (L.) Merr.
  Phyllanthus acidissimus (Blanco) Muell. Arg.
  Phyllanthus distichus (L.) Muell. Arg.
Phymatosorus longissima (Blume) Pichi-Serm. (cryptogams)
  Phymatodes longissima (Blume) J. Sm.
Pimenta racemosa (Miller) J.W. Moore (essential-oil plants)
  Caryophyllus racemosus Miller
  Myrtus acris Swartz
  Pimenta acris (Swartz) Kostel.
Piper porphyrophyllum N.E. Br. (ornamental plants)
Pistacia lentiscus L. (plants producing exudates)
Plectranthus amboinicus (Loureiro) Sprengel (medicinal and poisonous plants)
  Coleus amboinicus Lour.
  Coleus aromaticus Benth.
  Coleus carnosa Hassk.
Plectranthus barbatus Andrews (medicinal and poisonous plants)
  Coleus barbatus (Andrews) Benth.
  Coleus forskohlii (Willd.) Briq. non Vahl
Polyscias verticillata Stone (vegetables)
Pothomorphe subpeltata (Willd.) Miquel (medicinal and poisonous plants)
Pothomorphe umbellata (L.) Miquel (medicinal and poisonous plants)
Psidium guajava L. (edible fruits and nuts)
  Psidium aromaticum Blanco
Rorippa nasturtium-aquaticum (L.) Hayek (vegetables)
  Nasturtium officinale R. Br.
  Rorippa officinalis (R. Br.) P. Royen
  Sisymbrium nasturtium-aquaticum L.
Rosa L. cv. group Damascena (essential-oil plants)
  Rosa damascena Miller
  Rosa damascena Miller var. *trigintipetala* (Dieck) Koehne
  Rosa gallica L. var. *damascena* Voss
Scorodocarpus borneensis (Baillon) Becc. (timber trees)
  Ximenia borneensis Baillon
Sesamum orientale L. (vegetable oils and fats)

Sesamum indicum L.
Tamarindus indica L. (edible fruits and nuts)
Tamarindus occidentalis Gaertn.
Tamarindus officinalis Hook.
Taraxacum officinale Weber ex F.H. Wigg. (vegetables)
Tetrastigma harmandii Planchon (edible fruits and nuts)
Tetrastigma loheri Gagnepain (edible fruits and nuts)
Tetrastigma philippinense Merrill
Trachyspermum ammi (L.) Sprague ex Turrill (medicinal and poisonous plants)
Trichosanthes tricuspidata Lour. (medicinal and poisonous plants)
Trichosanthes tricuspis Miq.
Tropaeolum majus L. (ornamental plants)
Wollastonia biflora (L.) DC. (medicinal and poisonous plants)
Wollastonia moluccana (Blume) DC. (medicinal and poisonous plants)
Ximenia americana L. (edible fruits and nuts)
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

Composition of spice-oil samples

Alpinia galanga (L.) Willd.
Galanga root oil (from Indonesia)

47.3% 1,8-cineole
11.5% β-pinene
7.1% α-pinene
6.2% α-thujene
6.0% terpinen-4-ol
4.7% α-terpineol
4.3% limonene
2.1% γ-terpinene
1.8% geranyl acetate
1.4% myrcene
1.1% α-terpinene
1.1% terpinolene
0.9% sabinene
0.8% linalool
0.4% borneol
0.4% bornyl acetate
0.4% trans-p-mentha-2,8-dien-1-ol
0.3% camphene
0.3% para-cymene
0.3% β-phellandrene
0.3% α-fenchol
0.1% geranial
0.1% α-phellandrene
0.1% (E)-β-ocimene
0.1% α-fenchene
0.1% cis-p-menth-2-en-1-ol
trace tricyclene
trace δ-3-carene
trace (Z)-β-ocimene
trace citronellol
trace geraniol
trace neral
trace β-thujone
trace trans-sabinene hydrate
99.3% total
Source: Scheffer et al., 1981.

Alpinia galanga (L.) Willd.
Galanga root oil (from Malaysia)

18.2% (E)-β-farnesene
16.2% β-bisabolene
10.7% α-bergamotene
10.2% α-pinene
5.5% 1,8-cineole
5.1% geranyl acetate
2.5% bornyl acetate
2.5% caryophyllene oxide
1.9% ar-curcumene
1.9% pentadecane
1.6% β-pinene
1.6% limonene
1.6% citronellyl acetate
1.6% β-sesquiphellandrene
1.5% eugenyl acetate
1.0% chavicyl acetate
0.9% caryophyllene
0.8% para-cymene
0.8% β-santalene
0.7% myrcene
0.7% copaene (unknown isomer)
0.6% α-humulene
0.5% camphene
0.3% terpinen-4-ol
0.2% α-terpineol
0.2% chavicol
trace sabinene
trace α-terpinene
trace terpinolene
trace linalool
trace borneol
trace p-cymen-8-ol
trace tridecane
89.4% total
Source: de Pooter et al., 1985.

Alpinia galanga (L.) Willd.
Galanga leaf oil (from United States)

52.3% myrcene
17.1% (Z)-β-ocimene
9.0% α-pinene
4.1% borneol
3.5% β-caryophyllene
3.0% β-bisabolene

1.7% β-pinene
1.4% bornyl acetate
1.3% (E)-β-farnesene
1.0% caryophyllene oxide
0.5% limonene
0.1% 1,8-cineole
95.2% total
Source: Charles et al., 1992.

Anethum graveolens L.
Dill seed oil (from Europe)

45.0% carvone
35.0% limonene
7.0% α-phellandrene
2.0% cis-dihydrocarvone
1.5% trans-dihydrocarvone
0.5% α-pinene
0.5% para-cymene
0.2% myrcene
0.2% iso-dihydrocarveol
0.2% neodihydroisocarveol
0.1% camphene
0.1% sabinene
0.1% β-pinene
0.1% δ-3-carene
0.1% (E)-anethole
0.1% cis-carveol
0.1% trans-carveol
0.1% dihydrocarveol
0.1% neodihydrocarveol
93.0% total
Source: Lawrence, 1980.

Anethum graveolens L.
Dill seed oil (from India)

45.0% limonene
23.1% carvone
20.7% dill apiole
5.2% cis-dihydrocarvone
4.2% trans-dihydrocarvone
0.1% myrcene
0.1% α-phellandrene
0.1% para-cymene
0.1% (Z)-β-ocimene
0.1% β-caryophyllene
0.1% α,p-dimethylstyrene
0.1% α-pinene
0.1% β-pinene
0.1% α-terpinene
0.1% γ-terpinene
0.1% linalool
0.1% borneol
0.1% terpinen-4-ol
0.1% α-terpineol
0.1% thymol
0.1% nerolidol (unknown isomer)
0.1% elemol
0.1% (E)-anethole
0.1% cis-carveol
0.1% β-eudesmol
0.1% dodecane
0.1% pentadecane
0.1% heptadecane
0.1% myristicin
0.1% elemicin
0.1% viridiflorol
0.1% neoisodihydrocarveol
0.1% decane
0.1% tridecane
0.1% tetradecane
0.1% hexadecane
0.1% octadecane
0.1% nonadecene/nonadecane
100.2% total
Source: Lawrence, 1980.

Anethum graveolens L.
Dillweed oil (from United States)

32.1% limonene
27.7% carvone
27.2% α-phellandrene
5.0% dill ether
3.4% β-phellandrene
1.6% para-cymene
1.0% α-pinene
1.0% cis-dihydrocarvone
0.4% γ-terpinene
0.3% trans-dihydrocarvone
0.2% cis-carvyl acetate
0.1% terpinolene
100.0% total
Source: Lawrence, 1996.

Anthriscus cerefolium (L.) G.F. Hoffmann
Chervil oil (from France)

75.0% methyl chavicol
20.0% 1-allyl-2,4-dimethoxybenzene
0.1% α-pinene
0.1% β-pinene
0.1% limonene
0.1% dodecanal
0.1% nerol
0.1% geraniol
0.1% neral

0.1% geranial
0.1% geranyl acetate
0.1% β-caryophyllene
0.1% eugenol
0.1% p-methoxyphenylacetone
0.1% bisabolene (unknown isomer)
0.1% β-ionone
0.1% (Z)-3-hexenol
0.1% undecane
0.1% zingiberene
0.1% 1-hexanol
0.1% chavicol
0.1% benzyl alcohol
0.1% β-gurjunene
0.1% geranyl propionate
0.1% 2-phenylethanol
0.1% 3-nonanol
0.1% 1-nonen-3-ol
0.1% 2-hexenal
0.1% 3-hexenal
0.1% (E,E)-2,4-hexadienal
0.1% 5-methylhex-4-enone-3
0.1% nonanone-3
0.1% (E)-3-hexenyl acetate
0.1% nonenyl-3 acetate
0.1% neryl propionate
0.1% 2,5-dimethoxy-allylbenzene (tent.)
0.1% allyl-3,5-dimethoxybenzene
0.1% chavibetol
0.1% 1-nonenyl-3 acetate
0.1% γ-dodecalactone
0.1% p-methoxy-phenylpropan-1-one
98.9% total
Source: Rigaud & Sarris, 1982.

Armoracia rusticana P.G. Gaertner, B. Meyer & J. Scherbius
Horseradish root extract

50.0% allyl isothiocyanate
44.0% 2-phenylethyl isothiocyanate
2.3% 4-pentenyl isothiocyanate
2.1% allyl thiocyanate
1.5% 2-butyl isothiocyanate
trace 3-butenyl isothiocyanate
trace 3-(methylthio)propyl isothiocyanate
99.9% total
Source: Gilbert & Nursten, 1972.

Artemisia dracunculus L.
French tarragon oil

77.0% methyl chavicol
9.0% (E)-β-ocimene
8.1% (Z)-β-ocimene
2.5% limonene
0.9% γ-terpinene
0.5% eugenol
0.5% methyl eugenol
0.2% nerol
0.2% elemicin
0.1% β-pinene
0.1% myrcene
0.1% para-cymene
0.1% linalool
0.1% terpinen-4-ol
0.1% geraniol
0.1% α-pinene
0.1% camphene
0.1% sabinene
0.1% α-terpinene
0.1% terpinolene
0.1% 1,8-cineole
99.8% total
Source: Werker et al., 1994.

Artemisia dracunculus L.
French tarragon oil (from United States)

80.0% methyl chavicol
7.0% (E)-β-ocimene
6.6% (Z)-β-ocimene
2.5% limonene
0.6% α-pinene
0.5% methyl eugenol
0.5% γ-terpinene
0.3% eugenol
0.1% myrcene
0.1% methyl isoeugenol
0.1% β-pinene
0.1% sabinene
0.1% linalool
0.1% elemicin
trace camphene
trace terpinolene
trace geraniol
trace nerol
trace trans-alloocimene
trace terpinen-4-ol
trace 1,2-cineole
trace trans-isoelemicin
trace α-thujene
trace α-phellandrene

trace α-terpinene
trace para-cymene
trace citronellyl acetate
trace cis-alloocimene
98.8% total
Source: Tucker & Maciarello, 1987.

Carum carvi L.
Caraway oil (from Israel)

49.0% carvone
48.0% limonene
0.4% myrcene
0.3% trans-carveol
0.3% trans-dihydrocarvone
0.2% dihydrocarveol
0.1% cis-dihydrocarvone
0.1% cis-carveol
0.1% β-caryophyllene
0.1% linalool
0.1% α-pinene
0.1% sabinene
0.1% β-phellandrene
trace α-terpinene
trace β-pinene
trace camphene
trace para-cymene
trace terpinolene
98.8% total
Source: Putievsky et al., 1994.

Carum carvi L.
Caraway oil (from France)

50.1% carvone
45.4% limonene
1.4% dihydrocarveol
1.0% dihydrocarvone
0.3% myrcene
0.3% trans-carveol
0.2% para-cymene
0.2% p-mentha-1,3-dien-7-al
0.1% γ-terpinene
0.1% sabinene
trace α-pinene
99.1% total
Source: Bourrel et al., 1995.

Cinnamomum burmanni (C. Nees & T. Nees) C. Nees ex Blume
Indonesian cassia bark oil (from China)

51.4% 1,8-cineole
12.5% α-terpineol
9.0% camphor
8.5% terpinen-4-ol
1.8% borneol
1.6% α-pinene
1.6% β-caryophyllene
1.0% para-cymene
0.5% β-eudesmol
0.5% camphene
0.4% elemol
0.4% myristicin
0.4% β-pinene
0.3% α-humulene
0.1% bornyl acetate
89.7% total
Source: Ji Xiao-duo et al., 1991.

Cinnamomum burmanni (C. Nees & T. Nees) C. Nees ex Blume
Indonesian cassia leaf oil (from China)

28.5% 1,8-cineole
16.5% borneol
6.4% α-terpineol
6.1% para-cymene
5.8% spathulenol
4.1% terpinen-4-ol
3.1% bornyl acetate
2.9% β-caryophyllene
1.9% α-pinene
1.7% β-pinene
1.5% cinnamyl acetate
1.2% myristicin
0.6% elemol
0.4% α-humulene
0.4% linalool
0.2% camphene
0.1% β-eudesmol
81.4% total
Source: Ji Xiao-duo et al., 1991.

Cinnamomum cassia J.S. Presl
Chinese cassia leaf oil (from China)

74.1% cinnamic aldehyde
10.5% 2-methoxycinnamaldehyde
6.6% cinnamyl acetate
1.2% coumarin
1.1% benzaldehyde
0.7% 2-phenylethyl acetate
0.6% 2-phenylethanol
0.6% 2-methoxybenzaldehyde
0.2% 2-methylbenzofuran
0.2% 3-phenylpropanal
0.2% salicylaldehyde

0.2% cinnamyl alcohol
0.2% nerolidol (unknown isomer)
0.1% acetophenone
0.1% α-pinene
96.5% total
Source: Zhu et al., 1993.

Cinnamomum cassia J.S. Presl
Chinese cassia leaf oil (from Australia)

77.2% cinnamic aldehyde
15.3% coumarin
3.6% cinnamyl acetate
1.2% benzaldehyde
0.8% 4-ethylguaiacol
0.4% ethyl cinnamate
0.2% 2-phenylethyl acetate
0.2% 2-phenylethanol
0.1% α-terpineol
0.1% eugenyl acetate
0.1% benzyl benzoate
0.1% terpinen-4-ol
0.1% nonanal
trace 1-hexanol
trace chavicol
trace camphene
trace 1,8-cineole
trace cinnamyl alcohol
trace cuminaldehyde
trace eugenol
trace farnesol (unknown isomer)
trace geranial
trace guaiacol
trace α-humulene
trace isoeugenol
trace linalool
trace methyl benzoate
trace 3-phenylpropanal
trace α-pinene
trace β-pinene
trace terpinolene
trace 2-vinylphenol
99.4% total
Source: Senanayake, 1977.

Cinnamomum cassia J.S. Presl
Chinese cassia bark oil (from China)

65.5% (E)-cinnamic aldehyde
8.7% coumarin
3.6% cinnamyl acetate
2.7% 2-methoxycinnamaldehyde
0.9% benzaldehyde
0.7% 2-methoxybenzaldehyde
0.6% benzyl benzoate
0.2% cinnamyl alcohol
0.2% 2-phenylethyl acetate
0.2% eugenyl acetate
0.1% (Z)-cinnamic aldehyde
0.1% 2-phenylethyl benzoate
0.1% 3-phenylpropanal
trace caryophyllene oxide
trace α-pinene
trace camphene
trace β-pinene
trace myrcene
trace α-phellandrene
trace δ-3-carene
trace α-terpinene
trace para-cymene
trace limonene
trace β-phellandrene
trace (Z)-β-ocimene
trace (E)-β-ocimene
trace γ-terpinene
trace terpinolene
trace linalool
trace borneol
trace terpinen-4-ol
trace α-terpineol
trace nerol
trace geraniol
trace linalyl acetate
trace bornyl acetate
trace β-caryophyllene
trace α-humulene
trace α-muurolene
trace δ-cadinene
trace α-copaene
trace p-cymen-8-ol
trace isoamyl isovalerate
trace spathulenol
trace eugenol
trace carvacrol
trace β-elemene
trace methyl eugenol
trace benzoic acid
trace isocaryophyllene
trace γ-muurolene
trace aromadendrene
trace anisaldehyde
trace α-cadinol
trace guaiacol
trace ar-curcumene
trace (E)-β-farnesene
trace safrole
trace acetic acid
trace vanillin

trace chavicol
trace 10-epi-α-cadinol
trace methyl cinnamate
trace calamenene
trace benzyl alcohol
trace trans-linalool oxide (5) (furanoid)
trace cis-linalool oxide (5) (furanoid)
trace α,p-dimethylstyrene
trace ethyl cinnamate
trace 2-phenylethanol
trace salicylaldehyde
trace acetophenone
trace carvotanacetone
trace palustrol
trace α-elemene
trace styrene
trace menthene
trace butyl 2-methylbutyrate
trace (Z)-isoeugenol
trace α-himachalene
trace 3-phenylpropyl acetate
trace isoamyl benzoate
trace 2-phenylethyl formate
trace 2-vinylbenzaldehyde
trace 4-vinylbenzaldehyde
trace p-tolyl propyl ether
trace 4-tolylacetaldehyde
trace (E)-2-methoxycinnamaldehyde
trace dimethoxycinnamaldehyde
trace dimethoxy allyl phenol
trace 3-phenylpropanoic acid
trace o-methoxycinnamic alcohol
trace (E)-cinnamic acid
84.4% total
Source: Vernin et al., 1990.

Cinnamomum cassia J.S. Presl
Chinese cassia bark oil (from Australia)

87.0% cinnamic aldehyde
4.7% benzaldehyde
2.5% 2-phenylethanol
2.0% 3-phenylpropanal
0.7% 1,8-cineole
0.5% 4-ethylguaiacol
0.5% guaiacol
0.4% ethyl cinnamate
0.4% cuminaldehyde
0.3% chavicol
0.3% coumarin
0.1% benzyl benzoate
0.1% linalool
0.1% cinnamyl acetate
0.1% nonanal
0.1% eugenol
0.1% α-pinene
trace eugenyl acetate
trace terpinen-4-ol
trace camphene
trace cinnamyl alcohol
trace farnesol (unknown isomer)
trace fenchone
trace geranial
trace geraniol
trace 1-hexanol
trace 3-hexenol-1
trace α-humulene
trace isoeugenol
trace methyl benzoate
trace methyl cinnamate
trace 2-phenylethyl acetate
trace β-pinene
trace sabinene
trace safrole
trace β-selinene
trace α-terpinene
trace α-terpineol
trace terpinolene
100.0% total
Source: Senanayake, 1977.

Cinnamomum loureirii C. Nees
Vietnamese cassia bark oil

92.5% (E)-cinnamic aldehyde
0.8% 3-phenylpropanal
0.6% (Z)-cinnamic aldehyde
0.6% coumarin
0.3% benzaldehyde
0.3% eugenol
0.1% β-caryophyllene
0.1% benzyl benzoate
0.1% camphor
0.1% 1,8-cineole
0.1% linalool
0.1% β-phellandrene
0.1% salicylaldehyde
0.1% α-terpineol
95.6% total
Source: Lawrence, 1995.

Cinnamomum verum J.S. Presl
Cinnamon bark oil

70.0% (E)-cinnamic aldehyde
8.0% eugenol
5.5% cinnamyl acetate
2.3% β-caryophyllene

1.6% linalool
1.4% α-terpineol
1.1% benzaldehyde
0.8% 3-phenylpropanal
0.8% terpinen-4-ol
0.8% camphor
0.5% benzyl benzoate
0.5% 1,8-cineole
0.5% α-copaene
0.5% coumarin
0.5% 2-methoxycinnamaldehyde
0.5% β-phellandrene
95.2% total
Source: Lawrence & Shu, 1993.

Cinnamomum verum J.S. Presl
Cinnamon bark oil

89.0% (E)-cinnamic aldehyde
2.5% β-caryophyllene
2.4% eugenol
2.2% (Z)-cinnamic aldehyde
1.4% linalool
0.7% (E)-2-methoxycinnamaldehyde
0.7% benzyl benzoate
0.1% benzaldehyde
0.1% caryophyllene oxide
0.1% (E)-cinnamic alcohol
0.1% cinnamyl acetate
0.1% para-cymene
0.1% limonene
0.1% β-phellandrene
0.1% 3-phenylpropanal
0.1% α-pinene
0.1% β-pinene
0.1% α-terpineol
0.1% α-ylangene
100.0% total
Source: Jayatilaka et al., 1995.

Cinnamomum verum J.S. Presl
Cinnamon bark oil

46.5% (E)-cinnamic aldehyde
8.2% limonene
6.2% β-caryophyllene
4.2% para-cymene
3.6% eugenol
3.5% α-pinene
3.0% linalool
2.9% δ-3-carene
2.6% (E)-cinnamyl acetate
2.6% camphor
1.8% benzyl benzoate
1.6% camphene
1.4% α-copaene
1.0% β-pinene
1.0% β-phellandrene
0.9% α-humulene
0.8% 2-methoxycinnamaldehyde
0.5% benzaldehyde
0.3% eugenyl acetate
0.1% myrcene
0.1% α-terpineol
92.8% total
Source: Bouzid et al., 1997.

Cinnamomum verum J.S. Presl
Cinnamon leaf oil (from India)

84.5% eugenol
3.7% linalool
2.5% cinnamyl acetate
2.3% β-caryophyllene
1.5% (E)-cinnamic aldehyde
1.0% α-phellandrene
0.5% α-pinene
0.5% α-humulene
0.4% 1,8-cineole
0.3% para-cymene
0.3% β-elemene
0.2% methyl chavicol
0.2% safrole
0.2% β-pinene
0.2% camphene
0.1% α-terpineol
0.1% eugenyl acetate
0.1% myrcene
0.1% (E,E)-farnesol
0.1% borneol
0.1% terpinolene
0.1% caryophyllene oxide
0.1% camphor
0.1% γ-cadinene
0.1% α-thujene
0.1% δ-3-carene
0.1% (E)-β-ocimene
0.1% γ-terpinene
trace terpinen-4-ol
trace α-terpinene
trace sabinene
trace β-phellandrene
trace (Z)-β-ocimene
trace nerol
trace citronellal
trace β-selinene
trace (Z,E)-α-farnesene
trace cuminaldehyde

trace trans-linalool oxide (5) (furanoid)
trace cis-linalool oxide (5) (furanoid)
trace 2-phenylethanol
trace 2-phenylethyl benzoate
trace 2-phenylethyl propionate
trace (E)-methyl isoeugenol
trace (Z)-cinnamic aldehyde
trace (E)-cinnamic alcohol
99.6% total
Source: Maallavarapu et al., 1995.

Coriandrum sativum L.
Coriander fruit oil

63.8% linalool
5.5% camphor
4.9% para-cymene
4.6% γ-terpinene
3.3% α-pinene
2.4% limonene
1.8% geraniol
1.2% myrcene
1.1% δ-3-carene
1.0% geranyl acetate
1.0% β-pinene
1.0% α-terpineol
0.8% trans-linalool oxide (5) (furanoid)
0.7% anethole
0.6% camphene
0.6% cis-linalool oxide (5) (furanoid)
0.6% terpinen-4-ol
0.5% carvone
0.1% borneol
0.1% citronellol
0.1% eugenol
0.1% 6-methyl-5-hepten-2-one
0.1% neral
0.1% neryl acetate
0.1% sabinene
0.1% α-terpinene
trace carvacrol
trace β-caryophyllene
trace caryophyllene oxide
trace 1,8-cineole
trace p-cymen-8-ol
trace geranial
trace (Z)-3-hexenyl butyrate
trace α-humulene
trace menthol
trace α-thujene
trace thymol
96.3% total
Source: Anitescu et al., 1997.

Coriandrum sativum L.
Coriander leaf oil

15.6% (E)-2-dodecenal
12.7% (E)-2-tetradecenal
12.1% (E)-2-decenal
9.3% decanal
8.2% (E)-2-decenol
5.3% (E)-2-undecenal
5.0% dodecanal
4.8% 2-pentadecenal
2.8% phytol
2.5% (E)-2-tridecenal
2.3% undecanal
2.3% undecenal (unknown isomer)
2.1% 1-decanol
1.7% tetradecanal
1.5% 1-eicosanol
1.4% tridecanal
1.4% 1-docosanol
1.0% dodecenal (unknown isomer)
0.9% 2-hexadecenal
0.7% tetradecenal (unknown isomer)
0.7% decenal (unknown isomer)
0.6% 2-dodecenol
0.5% octanal
0.5% pentadecanal
0.5% 9-decenal
0.4% 1-tetracosanol
0.4% nonane
0.3% nonanal
0.2% 2-undecenol
0.2% pentadecenal (unknown isomer)
0.2% 4-decenal
0.1% germacrene B
0.1% tridecenal (unknown isomer)
0.1% 1-dodecanol
0.1% trans-5-methyltetrahydrofurfurylal
0.1% 1-undecanol
0.1% methyl octadecanoate
0.1% hexadecanal
trace 2-tridecen-1-ol
trace undecane
trace limonene
trace phenylacetaldehyde
trace hexadecenal (unknown isomer)
98.5% total
Source: Potter, 1996.

Cuminum cyminum L.
Cumin oil (from Egypt)

21.0% β-pinene
21.0% cuminaldehyde

20.0% γ-terpinene
11.0% p-mentha-1,3-dien-7-al
9.7% para-cymene
8.9% p-mentha-1,4-dien-7-al
1.4% α-phellandrene
1.1% myrcene
1.0% α-pinene
0.7% limonene
0.5% terpinen-4-ol
0.5% carotol
0.4% β-farnesene
0.3% β-phellandrene
0.3% α-terpineol
0.3% β-caryophyllene
0.2% α-thujene
0.2% 1,8-cineole
0.2% cumin alcohol
0.1% α-terpinene
0.1% terpinolene
98.9% total
Source: Analytical Methods Committee, 1993.

Cuminum cyminum L.
Cumin oil (from India)

30.0% γ-terpinene
25.5% cuminaldehyde
16.0% para-cymene
9.1% p-mentha-1,3-dien-7-al
8.9% β-pinene
2.7% p-mentha-1,4-dien-7-al
0.6% α-pinene
0.6% p-menth-3-en-7-al
0.3% sabinene
0.3% myrcene
0.3% α-phellandrene
0.3% limonene
0.3% β-phellandrene
0.2% (Z)-β-farnesene
0.2% cumin alcohol
0.1% α-terpinene
0.1% terpinen-4-ol
0.1% isocaryophyllene
0.1% p-isopropylphenol
0.1% α-terpineol
0.1% trans-α-bergamotene
0.1% terpinolene
0.1% bornyl acetate
0.1% cis-sabinene hydrate
trace linalool
trace thymol
trace camphene
trace δ-3-carene
trace trans-sabinene hydrate
96.2% total
Source: Baser et al., 1992.

Curcuma longa L.
Turmeric oil (from Indonesia)

29.5% turmerone
24.7% ar-turmerone
20.0% turmerol
2.5% β-curcumene
2.4% α-atlantone
2.4% β-sesquiphellandrene
1.4% ar-curcumene
1.4% ar-dihydroturmerone
1.1% (6S,1R)-6-(1,5-dimethylhex-4-enyl)-3-methylcyclohex-2-enone
0.9% ar-turmerol
0.9% 2-(1,5-dimethylhex-4-enyl)-4-methylphenol
0.6% curcuphenol
0.3% β-bisabolol
0.2% β-caryophyllene
0.2% β-farnesene
trace α-phellandrene
trace para-cymene
trace limonene
trace 1,8-cineole
trace camphor
trace β-elemene
trace germacrone
trace α-zingiberene
88.6% total
Source: Zwaving & Bos, 1992.

Elettaria cardamomum (L.) Maton
Cardamom oil (from India)

38.8% 1,8-cineole
24.6% α-terpinyl acetate
6.2% β-pinene
5.7% linalool
4.2% sabinene
4.0% limonene
3.4% α-terpineol
2.3% α-pinene
2.0% terpinen-4-ol
1.0% linalyl acetate
0.8% geranyl acetate
0.2% geraniol
trace nerolidol (unknown isomer)
93.2% total
Source: Gopalakrishnan, 1994.

Elettaria cardamomum (L.) Maton
Cardamom oil (from India)

49.0% α-terpinyl acetate
24.7% 1,8-cineole
5.8% linalool
4.6% linalyl acetate
2.7% α-terpineol
2.5% geraniol
1.9% terpinen-4-ol
1.4% sabinene
1.2% myrcene
1.2% nerolidol (unknown isomer)
0.9% limonene
0.9% nerol
0.4% β-caryophyllene
0.4% α-pinene
97.6% total
Source: Variyar & Bandyopadhyay, 1995.

Eryngium foetidum L.
Fitweed leaf oil (from Malaysia)

59.7% (E)-2-dodecenal
9.6% 2,3,6-trimethylbenzaldehyde
6.7% dodecanal
4.6% (E)-2-tridecenal
3.5% 2-formyl-1,1,5-trimethylcyclohexa-2,4-dien-6-ol
2.1% 2-formyl-1,1,5-trimethylcyclohexa-2,5-dien-4-ol (ferulol)
1.8% 2,3,4-trimethylbenzaldehyde
1.7% decanal
1.3% 2-methylcrotonic acid
0.7% tetradecanal
0.6% phenylacetaldehyde
0.4% (E)-2-undecenal
0.4% 3,4-dimethylbenzaldehyde
0.4% 2-formyl-1,1,5-trimethylcyclohexa-2,4-dien-6-one
0.2% γ-decalactone
0.1% (E)-2-decenal
0.1% hexanal
0.1% 3,5,5-trimethyl-3-cyclohexen-1-one
0.1% (Z)-3-hexenol
0.1% nonanal
0.1% 1,2,4-trimethylbenzene
0.1% 2-octanone
0.1% 3,5,5-trimethyl-2-cyclohexen-1-one (isophorone)
0.1% 2,6,6-trimethyl-1,3-cyclohexadien-1-carboxaldehyde (safranal)
0.1% terpinen-4-ol
trace octanal
trace (E)-2-heptenal
trace hexanol
trace benzaldehyde
trace heptanal
trace p-cymene
trace 1-octen-3-ol
trace (E,E)-2,4-heptadienal
trace 2-octylfuran
trace (E)-2-nonenal
trace 1,2,3-trimethylbenzene
trace (E,E)-2,4-dodecadienal
trace vanillin
94.8% total
Source: Wong et al., 1994.

Etlingera elatior (Jack) R.M. Smith
Torch ginger flowering-shoot oil

33.2% 1-dodecanol
17.2% dodecanal
13.7% α-pinene
7.4% dodecanoic acid
3.7% dodecyl acetate
3.3% 1-decanol
2.8% tetradecanol
2.8% 2-undecanone
2.8% decanal
1.4% 10-undecenal
1.2% verbenone
1.2% (Z)-9-tetradecen-1-ol
1.1% β-caryophyllene
0.6% limonene
0.5% nerolidol (unknown isomer)
0.4% 2-nonanol
0.3% decanoic acid
0.3% tetradecyl acetate
0.3% 2-tridecanone
0.3% β-phellandrene
0.3% 1-undecanol
0.2% 2-nonanone
0.2% furfuryl alcohol
0.2% α-terpineol
0.2% terpinolene
0.2% (Z)-5-tetradecen-1-ol
0.1% furfural
0.1% tetradecanoic acid
0.1% δ-3-carene
0.1% linalool
0.1% toluene
0.1% undecane
0.1% para-cymene
0.1% α,p-dimethylstyrene
0.1% α-humulene
0.1% myrcene

0.1% hexadecane
0.1% 9-decen-1-ol
0.1% decyl acetate
trace p-cymen-8-ol
trace 3-methylbutanol
trace octenyl acetate (unknown isomer)
trace β-pinene
trace tetradecane
trace (Z)-5-tetradecenyl acetate
96.9% total
Source: Wong et al., 1993.

Foeniculum vulgare Miller
Sweet-fennel oil (from Italy)

87.1% (E)-anethole
4.7% limonene
3.5% (Z)-anethole
2.1% fenchone
0.4% 1,8-cineole
0.3% α-pinene
0.2% myrcene
0.1% para-cymene
trace camphor
trace camphene
trace linalool
trace menthol
trace menthone
trace (E)-β-ocimene
trace (Z)-β-ocimene
trace α-phellandrene
trace β-pinene
trace sabinene
trace terpinen-4-ol
98.4% total
Source: Piccaglia & Marotti, 1993.

Foeniculum vulgare Miller
Bitter-fennel oil (from Italy)

81.9% (E)-anethole
10.2% fenchone
4.9% limonene
1.7% (Z)-anethole
0.4% α-pinene
0.2% camphor
0.2% myrcene
0.1% menthol
0.1% para-cymene
0.1% sabinene
0.1% (Z)-β-ocimene
trace camphene
trace 1,8-cineole
trace linalool
trace menthone
trace (E)-β-ocimene
trace α-phellandrene
trace β-pinene
trace terpinen-4-ol
99.8% total
Source: Piccaglia & Marotti, 1993.

Illicium verum Hook.f.
Star anise oil (from Vietnam)

79.9% (E)-anethole
10.4% limonene
2.1% α-pinene
1.7% β-phellandrene
1.0% linalool
0.9% δ-3-carene
0.6% methyl chavicol
0.5% α-phellandrene
0.4% myrcene
0.4% β-caryophyllene
0.4% anisaldehyde
0.2% sabinene
0.2% α-terpineol
0.2% β-pinene
0.2% para-cymene
0.2% α-terpinene
0.2% terpinolene
0.1% γ-terpinene
0.1% (Z)-anethole
99.7% total
Source: Formacek & Kubeczka, 1982.

Illicium verum Hook.f.
Star anise oil (from China)

71.6% (E)-anethole
14.6% foeniculin
5.0% methyl chavicol
1.4% limonene
0.6% linalool
0.6% nerolidol (unknown isomer)
0.5% anisaldehyde
0.5% (E,E)-α-farnesene
0.4% β-caryophyllene
0.4% (Z)-β-ocimene
0.2% myrcene
0.2% cinnamyl acetate
0.2% α-phellandrene
0.2% α-terpineol
0.1% para-cymene
0.1% α-terpinene
0.1% (E)-β-ocimene
trace camphene

trace α-pinene
trace sabinene
trace β-pinene
trace δ-3-carene
trace γ-terpinene
trace terpinolene
trace α-copaene
trace (Z)-anethole
trace methyl anisate
96.7% total
Source: Cu et al., 1990.

Laurus nobilis L.
Laurel leaf oil (from Spain)

43.0% 1,8-cineole
9.3% linalool
8.5% sabinene
7.5% α-terpinyl acetate
6.5% α-pinene
4.5% α-terpineol
4.2% β-pinene
3.0% terpinen-4-ol
2.3% methyl eugenol
1.7% limonene
1.7% myrcene
1.0% eugenol
1.0% γ-terpinene
0.7% β-caryophyllene
0.7% α-terpinene
0.6% bornyl acetate
0.6% camphene
0.6% para-cymene
0.5% borneol
0.3% α-humulene
0.3% linalyl acetate
0.3% terpinolene
0.2% eugenyl acetate
0.2% α-fenchene
0.2% α-phellandrene
0.1% geranyl acetate
0.1% neryl acetate
0.1% β-phellandrene
0.1% caryophyllene oxide
0.1% α,p-dimethylstyrene
0.1% sabinene hydrate
0.1% α-thujene
99.9% total
Source: Boelens & Sindreu, 1986.

Laurus nobilis L.
Laurel fruit oil (from India)

28.4% 1,8-cineole
10.1% α-phellandrene
9.3% α-pinene
5.9% α-terpineol
4.9% sabinene
3.8% α-thujene
3.3% α-humulene
2.3% linalool
2.2% camphor
2.2% γ-gurjunene
1.9% β-pinene
1.4% myristicin
1.4% terpinen-4-ol
1.2% methyl eugenol
0.9% allo-aromadendrene
0.7% geranial
0.6% neral
0.1% δ-cadinene
80.4% total
Source: Nigam et al., 1992.

Lippia graveolens Kunth
Mexican oregano oil (from United States)

50.0% thymol
12.0% carvacrol
8.5% para-cymene
4.0% 1,8-cineole
3.5% γ-terpinene
3.0% terpinen-4-ol
1.8% terpinen-4-yl acetate
1.7% myrcene
1.2% δ-3-carene
1.1% α-terpinene
1.0% borneol
1.0% linalool
1.0% trans-p-menth-2-en-1-ol
1.0% α-pinene
0.9% α-terpineol
0.8% β-bisabolene
0.6% limonene
0.6% β-phellandrene
0.5% β-caryophyllene
0.5% ledene
0.5% methyl chavicol
0.5% methyl thymol
0.4% terpinolene
0.4% γ-gurjunene
0.3% α-phellandrene
0.3% γ-muurolene
0.3% trans-sabinene hydrate
0.3% thymyl acetate
0.2% cis-α-bisabolene
0.2% camphene
0.2% piperitone

0.2% α-thujene
0.2% 1-octenol-3
0.1% calamenene
0.1% α-copaene
0.1% cis-p-menth-2-en-1-ol
0.1% β-pinene
0.1% cis-sabinene hydrate
0.1% trans-α-bergamotene
0.1% δ-cadinene
0.1% γ-cadinene
0.1% p-cymen-8-ol
0.1% sabinene
trace carveol
trace 2-ethylfuran
trace ethyl isobutyrate
trace ethyl 2-methylbutyrate
trace 2-methylbutanal
trace 2-methylpropanal
trace δ-terpineol
trace umbellulone
99.2% total
Source: Lawrence, 1996.

Myristica fragrans Houtt.
Nutmeg oil (from Indonesia)

34.6% sabinene
19.0% α-pinene
11.3% β-pinene
5.6% terpinen-4-ol
3.7% limonene
3.3% myristicin
2.7% γ-terpinene
2.4% 1,8-cineole
2.3% myrcene
2.2% α-terpinene
1.5% terpinolene
1.3% para-cymene
0.9% elemicin
0.9% α-phellandrene
0.8% β-caryophyllene
0.8% safrole
0.7% trans-sabinene hydrate
0.7% cis-sabinene hydrate
0.6% α-terpineol
0.3% β-phellandrene
95.1% total
Source: Lawrence, 1990.

Myristica fragrans Houtt.
Nutmeg oil (from Sri Lanka)

20.3% α-pinene
16.1% sabinene
12.0% β-pinene
6.7% γ-terpinene
6.7% terpinen-4-ol
4.0% myristicin
3.9% limonene
3.7% α-terpinene
3.0% 1,8-cineole
2.1% para-cymene
2.1% myrcene
2.0% elemicin
1.6% terpinolene
1.5% safrole
1.2% α-terpineol
0.8% α-phellandrene
0.8% β-caryophyllene
0.7% cis-sabinene hydrate
0.6% trans-sabinene hydrate
0.3% β-phellandrene
89.7% total
Source: Lawrence, 1990.

Myristica fragrans Houtt.
Nutmeg oil (from Sri Lanka)

34.1% sabinene
13.8% α-pinene
10.7% β-pinene
6.8% terpinen-4-ol
4.8% myristicin
4.0% γ-terpinene
3.7% limonene
2.5% α-terpinene
2.4% β-phellandrene
2.1% myrcene
2.1% elemicin
1.4% terpinolene
1.4% safrole
0.9% δ-3-carene
0.9% para-cymene
0.7% α-phellandrene
0.6% α-terpineol
0.6% β-caryophyllene
0.6% methyl eugenol
0.6% trans-sabinene hydrate
0.5% α-copaene
0.4% linalool
0.4% cis-sabinene hydrate
0.3% geranyl acetate
0.3% cis-p-menth-2-en-1-ol
0.2% camphene
0.2% α-terpinyl acetate
0.2% δ-cadinene
0.2% α-cubebene
0.2% trans-p-menth-2-en-1-ol

0.2% eugenol
0.1% bornyl acetate
0.1% α,p-dimethylstyrene
97.7% total
Source: Analytical Methods Committee, 1988.

Nigella sativa L.
Black cumin oil

31.7% para-cymene
24.5% thymoquinone
9.4% ethyl linoleate
9.3% α-pinene
2.8% ethyl hexadecanoate
2.7% ethyl oleate
2.2% β-pinene
1.6% limonene
1.1% carvacrol
0.8% sabinene
0.6% thymohydroquinone
0.6% terpinen-4-ol
0.5% γ-terpinene
0.5% myrcene
0.4% bornyl acetate
0.4% longifolene
0.3% butyl propyl disulfide
0.2% ethyl tetradecanoate
0.2% ethyl octadecanoate
0.2% methyl linoleate
0.2% carvone
0.2% α-longipinene
0.1% artemisia ketone
0.1% p-cymen-8-ol
0.1% 2-heptenal
0.1% 1,8-cineole
0.1% trans-sabinene hydrate
0.1% ethyl octanoate
0.1% camphene
0.1% α-terpinene
0.1% terpinolene
0.1% linalool
0.1% camphor
0.1% (E)-anethole
0.1% 2-undecanone
trace β-phellandrene
trace borneol
trace β-thujone
trace cis-sabinene hydrate
trace ethyl hexanoate
trace ethyl heptanoate
trace ethyl nonanoate
trace dipropyl disulfide
trace dibutyl disulfide
91.4% total
Source: Aboutabl et al., 1986.

Ocimum basilicum L.
French basil oil (from Philippines)

53.3% methyl chavicol
22.0% linalool
4.5% β-caryophyllene
3.7% 1,8-cineole
1.4% eugenol
1.4% α-cubebene
0.8% geranyl acetate
0.7% (E)-β-ocimene
0.7% geraniol
0.5% δ-guaiene
0.5% α-terpineol
0.5% myrcene
0.4% neral
0.3% camphor
0.3% β-pinene
0.3% δ-3-carene
0.3% limonene
0.3% α-pinene
0.1% terpinolene
0.1% chavicol
0.1% para-cymene
0.1% methyl eugenol
0.1% γ-terpinene
0.1% copaene (unknown isomer)
0.1% 3-octanol
0.1% camphene
trace (Z)-β-ocimene
trace (Z)-3-hexenol
trace octyl acetate
trace α-phellandrene
trace α-terpinene
trace α-thujene
trace benzaldehyde
trace borneol
trace (Z)-3-hexenyl acetate
92.6% total
Source: Hasegawa et al., 1997.

Ocimum basilicum L.
Réunion basil oil (from Taiwan)

84.7% methyl chavicol
5.5% 1,8-cineole
2.4% methyl eugenol
1.3% (Z)-β-ocimene
0.9% β-elemene
0.9% T-cadinol
0.9% α-terpineol

0.7% α-muurolene
0.5% (E)-β-farnesene
0.4% linalool
0.4% β-pinene
0.2% sabinene
0.2% 1-octenol-3
0.1% myrcene
0.1% α-pinene
0.1% cadina-1,4-diene
0.1% β-eudesmol
0.1% β-phellandrene
0.1% (E)-anethole
trace (Z)-3-hexenol
trace α-cadinol
trace chavicol
trace α-copaene
trace eugenol
trace limonene
trace 3-octanol
trace trans-α-bergamotene
trace γ-elemene
trace ethyl linolenate
trace germacrene B
trace 1-hexanol
trace sabinene hydrate
trace viridiflorol
99.7% total
Source: Sheen et al., 1991.

Origanum majorana L.
Marjoram oil (from Portugal)

36.3% terpinen-4-ol
15.9% cis-sabinene hydrate
9.5% para-cymene
8.2% α-terpineol
3.9% linalool
3.7% trans-sabinene hydrate
3.7% cis-p-menth-2-en-1-ol
3.5% linalyl acetate
2.5% sabinene
2.5% bicyclogermacrene
2.0% β-caryophyllene
1.2% p-cymen-8-ol
1.0% caryophyllene oxide
0.9% carvone
0.6% trans-p-mentha-2,8-dien-1-ol
0.5% limonene
0.5% geranyl acetate
0.4% terpinen-4-yl acetate
0.3% α-pinene
0.2% myrcene
0.2% neryl acetate
0.2% copaene (unknown isomer)
0.2% methyl carvacrol
0.2% α-terpinyl acetate
0.1% α-thujene
0.1% β-pinene
0.1% terpinolene
0.1% 1,8-cineole
0.1% α-humulene
0.1% 1-octenol-3
0.1% camphene
0.1% α-phellandrene
0.1% α-terpinene
0.1% β-phellandrene
0.1% (Z)-β-ocimene
0.1% (E)-β-ocimene
0.1% γ-terpinene
0.1% geraniol
0.1% β-bisabolene
0.1% carvacrol
0.1% cuminaldehyde
0.1% (Z)-3-hexenol
0.1% 3-octanol
0.1% (E)-2-hexenal
0.1% α,p-dimethylstyrene
0.1% cis-alloocimene
99.5% total
Source: Oberdieck, 1981.

Origanum majorana L.
Marjoram oil

25.0% cis-sabinene hydrate
22.1% terpinen-4-ol
10.9% γ-terpinene
6.8% α-terpinene
6.6% trans-sabinene hydrate
5.5% sabinene
3.3% α-terpineol
3.0% cis-sabinene hydrate acetate
2.7% limonene
2.3% terpinolene
1.7% myrcene
1.6% trans-p-mentha-2,8-dien-1-ol
1.0% linalool
0.6% cis-p-menth-2-en-1-ol
0.5% linalyl acetate
93.5% total
Source: Fischer et al., 1987.

Origanum vulgare L.
Greek oregano oil (from Turkey)

40.0% carvacrol
20.0% thymol
10.0% para-cymene

9.0% γ-terpinene
4.8% cis-sabinene hydrate
1.8% cis-dihydrocarvone
1.8% α-pinene
1.7% myrcene
1.4% α-terpinene
1.0% β-caryophyllene
0.8% trans-dihydrocarvone
0.8% α-terpineol
0.8% trans-sabinene hydrate
0.7% 1,8-cineole
0.6% β-bisabolene
0.6% caryophyllene oxide
0.6% 1-octenol-3
0.3% camphene
0.3% linalool
0.2% p-cymen-8-ol
0.2% γ-elemene
0.2% α-humulene
0.2% limonene
0.2% methyl carvacrol
0.2% (E)-β-ocimene
0.2% β-pinene
0.2% terpinen-4-ol
0.2% sabinene
0.2% terpinolene
0.1% γ-cadinene
0.1% β-farnesene
0.1% heptadecane
0.1% isoborneol
0.1% β-phellandrene
0.1% spathulenol
0.1% δ-3-carene
0.1% methyl 2-methylbutyrate
0.1% T-cadinol
0.1% carvacryl acetate
0.1% (E)-2-hexenal
0.1% (Z)-β-ocimene
trace linalyl acetate
trace 6-methyl-3-heptanol
trace α-bergamotene
trace calamenene
trace carveol
trace nonanal
trace α-phellandrene
99.8% total
Source: Baser et al., 1994.

Perilla frutescens (L.) Britton
Perilla oil

74.0% perillaldehyde
12.8% limonene
3.8% β-caryophyllene
3.5% β-bergamotene
2.6% linalool
1.6% benzaldehyde
0.9% pulegone
0.6% β-pinene
0.5% ocimene
0.4% sabinene
0.3% perillyl alcohol
0.3% isoeugenol
0.3% aromadendrene
0.2% pseudolimonene
0.2% 2-hexanol
0.1% terpinolene
0.1% limonene oxide
0.1% farnesene
0.1% α-terpinyl acetate
0.1% α-caryophyllene
trace myrcene
102.5% total
Source: Kang et al., 1992.

Persicaria odorata (Lour.) Soják
Rau ram leaf oil (from Australia)

44.1% dodecanal
27.7% decanal
10.9% 1-decanol
3.8% β-caryophyllene
2.6% 1-dodecanol
1.5% α-humulene
1.1% undecane
0.4% tetradecanal
0.3% 3-hexenol-1
0.3% 1-undecanol
0.2% caryophyllene oxide
0.2% 6-methyl-5-hepten-2-ol
0.1% 6-methyl-5-hepten-2-one
0.1% (E)-β-ocimene
0.1% undecanal
trace nonanal
trace (Z)-β-ocimene
93.4% total
Source: Hunter et al., 1997.

Petroselinum crispum (Miller) Nyman ex A.W. Hill
Flat-leaved parsley leaf oil (from Germany)

20.0% 1,3,8-p-menthatriene
18.0% limonene
9.1% myristicin
6.2% isomyristicin
3.2% psoralen
3.1% heraclenol

2.3% terpinolene
2.0% myrcene
1.5% germacrene D
1.3% α,p-dimethylstyrene
1.1% α-phellandrene
0.9% 9-octadecenal
0.8% α-pinene
0.7% xanthotoxin
0.7% para-cymene
0.6% β-elemene
0.6% α-terpinene
0.4% β-phellandrene
0.4% sedanenolide
0.4% α-thujene
0.4% falcarinol
0.3% diepoxide of 1,3,8-menthatriene
0.3% β-pinene
0.3% germacrene B
0.3% imperatorin
0.3% γ-terpinene
0.2% β-bisabolene
0.2% α-copaene
0.2% isopimpinellin
0.2% β-caryophyllene
0.2% decanal
0.2% p-menthatriene dimers
0.1% 1,4-dioxetan of 2,8-menthadiene
0.1% 4-methylacetophenone
0.1% apiole
0.1% bergaptene
0.1% (E)-β-ocimene
0.1% (Z)-β-ocimene
0.1% tetramethoxy-allylbenzene
0.1% bicyclogermacrene
0.1% β-cubebene
0.1% α-terpineol
0.1% zingiberene
0.1% 3-n-butylphthalide
0.1% cuminaldehyde
0.1% p-cymen-8-ol
0.1% α-humulene
0.1% tridecane
trace camphene
trace sabinene
trace linalool
trace carotol
trace citronellal
trace falcarindiol
trace (E)-β-farnesene
77.2% total
Source: Spraul, 1991.

Petroselinum crispum (Miller) Nyman ex A.W. Hill
Curly-leaved parsley leaf oil (from Germany)

32.0% myristicin
20.0% 1,3,8-p-menthatriene
14.0% limonene
3.5% myrcene
3.0% terpinolene
2.0% α,p-dimethylstyrene
1.6% β-elemene
1.5% apiole
1.5% bergaptene
1.2% α-phellandrene
1.0% elemicin
1.0% germacrene B
1.0% α-pinene
0.8% carotol
0.7% germacrene D
0.6% β-pinene
0.5% β-caryophyllene
0.5% isopimpinellin
0.5% β-phellandrene
0.4% xanthotoxin
0.3% β-bisabolene
0.3% diepoxide of 1,3,8-menthatriene
0.2% linalool
0.2% 9-octadecenal
0.2% β-bourbonene
0.2% para-cymene
0.2% (E)-β-farnesene
0.2% p-menthatriene dimers
0.2% γ-terpinene
0.2% tetramethoxy-allylbenzene
0.2% α-zingiberene
0.1% bicyclogermacrene
0.1% camphene
0.1% citronellal
0.1% α-copaene
0.1% p-cymen-8-ol
0.1% 1,4-dioxetan of 2,8-menthadiene
0.1% 4-methylacetophenone
0.1% (E)-β-ocimene
0.1% sabinene
0.1% β-sesquiphellandrene
0.1% tridecane
0.1% α-terpineol
0.1% isomyristicin
0.1% bornyl acetate
0.1% cinnamic aldehyde
0.1% citronellol
0.1% falcarinol
0.1% p-1,8-menthadienol-5
0.1% psoralen

0.1% thymol
trace decanal
trace 3-n-butylphthalide
trace α-humulene
trace sedanenolide
trace α-bergamotene
trace calarene
trace δ-3-carene
trace γ-elemene
trace falcarindiol
trace heraclenol
trace imperatorin
trace (Z)-β-ocimene
trace trans-sabinene hydrate
trace α-terpinene
trace tatradecane
trace α-thujene
91.0% total
Source: Spraul, 1991.

Petroselinum crispum (Miller) Nyman ex A.W. Hill
Flat-leaved parsley fruit oil (from France)

33.3% apiole
22.5% myristicin
16.7% allyl-2,3,4,5-tetramethoxybenzene
13.9% α-pinene
8.9% β-pinene
1.9% elemicin
1.9% limonene
0.3% terpinolene
0.2% sesquiterpene hydrocarbons (unknown)
0.1% myrcene
0.1% α-phellandrene
0.1% β-phellandrene
99.9% total
Source: Lamarti et al., 1991.

Petroselinum crispum (Miller) Nyman ex A.W. Hill
Curly-leaved parsley fruit oil (from France)

56.0% myristicin
19.0% α-pinene
11.8% β-pinene
4.7% elemicin
4.6% allyl-2,3,4,5-tetramethoxybenzene
2.0% limonene
0.8% apiole
0.5% sesquiterpene hydrocarbons (unknown)
0.2% β-phellandrene
0.2% myrcene
0.2% α-phellandrene
0.1% terpinolene
100.0% total
Source: Lamarti et al., 1991.

Pimenta dioica (L.) Merrill
Pimento berry oil

80.1% eugenol
5.0% methyl eugenol
4.5% β-caryophyllene
1.1% α-muurolene
1.1% α-selinene
0.8% ledene
0.7% allo-aromadendrene
0.3% calamenene
0.3% para-cymene
0.2% 10-α-cadinol
0.2% methyl chavicol
0.2% spathulenol
0.2% δ-cadinene
0.2% γ-cadinene
0.2% 1,8-cineole
0.2% myrcene
0.1% α-gurjunene
0.1% linalool
0.1% terpinolene
0.1% (E)-β-ocimene
0.1% globulol
0.1% γ-terpinene
0.1% δ-3-carene
0.1% p-cymen-8-ol
0.1% copaene (unknown isomer)
0.1% α,p-dimethylstyrene
0.1% limonene
0.1% α-pinene
0.1% α-thujene
trace α-phellandrene
trace 2-methylbutyl acetate
trace α-terpinene
96.2% total
Source: Lawrence, 1979.

Pimenta dioica (L.) Merrill
Pimento berry oil (from Cuba)

87.0% eugenol
3.3% 1,8-cineole
2.5% β-caryophyllene
1.6% α-humulene
0.7% para-cymene
0.5% terpinen-4-ol
0.5% terpinolene
0.4% δ-cadinene
0.4% guaiene (unknown isomer)

0.4% limonene
0.4% α-phellandrene
0.2% camphene
0.2% β-elemene
0.2% myrcene
0.2% α-pinene
0.2% β-selinene
0.2% γ-terpinene
0.2% α-terpineol
0.1% calamenene
0.1% caryophyllene oxide
0.1% α-copaene
0.1% γ-muurolene
0.1% β-phellandrene
0.1% β-pinene
0.1% α-terpinene
0.1% γ-cadinene
0.1% α,p-dimethylstyrene
0.1% humulene oxide
100.0% total
Source: Pino et al., 1989.

Pimenta dioica (L.) Merrill
Pimento leaf oil (from Cuba)

54.3% eugenol
8.7% β-caryophyllene
4.6% 1,8-cineole
3.9% α-humulene
3.2% α-cadinol
3.1% T-cadinol
2.1% δ-cadinene
1.7% menthol
1.3% caryophyllene oxide
1.3% carvacrol
1.2% α-muurolene
1.1% para-cymene
1.0% carvone
0.9% γ-gurjunene
0.9% α-phellandrene
0.9% terpinolene
0.8% thymol
0.8% terpinen-4-ol
0.6% α-pinene
0.5% germacrene D
0.5% γ-terpinene
0.4% α-copaene
0.3% α-calacorene
0.3% myrcene
0.3% β-guaiene
0.3% limonene
0.3% α-thujene
0.2% α-terpineol
0.2% calamenene
0.2% 1-epi-cubenol
0.1% ledene
0.1% cyperene
0.1% (Z)-β-ocimene
0.1% linalool
0.1% δ-3-carene
0.1% piperitone
0.1% α-terpinene
0.1% γ-cadinene
0.1% α,p-dimethylstyrene
trace carophylladienols
trace β-pinene
96.6% total
Source: Pino & Rosado, 1996.

Pimpinella anisum L.
Anise fruit oil

94.1% (E)-anethole
2.0% methyl chavicol
1.0% γ-himachalene
1.0% 2-(1-E-propenyl)-5-methoxyphenyl 2-methylbutyrate
0.5% anisaldehyde
0.2% (Z)-anethole
0.2% α-zingiberene
0.1% β-bisabolene
0.1% germacrene D
0.1% 2-(1,2-epoxypropane)-5-methoxyphenyl 2-methylbutyrate
0.1% ar-curcumene
trace geijerene
trace pregeijerene
99.4% total
Source: Kubeczka et al., 1986.

Piper cubeba L.f.
Cubeb oil

11.0% β-cubebene
10.4% copaene (unknown isomer)
10.0% cubebol
8.8% δ-cadinene
7.1% α-cubebene
4.9% α-humulene
4.6% sabinene
4.2% allo-aromadendrene
3.7% β-caryophyllene
3.7% calamenene
3.7% cesarone
3.5% nerolidol (unknown isomer)
3.5% epi-cubebol
2.2% α-terpineol
2.0% α-pinene

1.5% β-bisabolene
1.2% α-muurolene
1.2% β-elemene
1.0% 10-α-cadinol
0.7% 1,8-cineole
0.3% apiole
0.2% α-thujene
89.4% total
Source: Lawrence, 1980.

Piper longum L.
Indian long pepper oil

17.8% pentadecane
17.0% β-caryophyllene
11.2% β-bisabolene
6.8% tridecane
5.7% heptadecane
5.0% α-zingiberene
4.9% germacrene D
3.7% cis-β-farnesene
3.0% spathulenol
2.6% globulol
2.3% heptadecene
1.9% α-humulene
1.8% pentadecene
1.8% germacrene B
1.5% α-copaene
0.9% tridecene
0.8% γ-elemene
0.8% α-gurjunene
0.6% γ-terpinene
0.5% undecanone
0.5% isopulegyl acetate
0.5% acetophenone
0.5% β-elemene
0.4% limonene
0.4% 1,8-cineole
0.4% β-bourbonene
0.3% δ-cadinol
0.2% nonadecane
0.1% undecane
0.1% terpinen-4-ol
0.1% para-cymene
0.1% nonadecene
0.1% linalool
0.1% cuminaldehyde
0.1% cubenol
0.1% δ-elemene
0.1% α-ylangene
0.1% α-terpineol
0.1% α-phellandrene
0.1% α-cubebene
trace α-pinene
trace β-pinene
trace β-selinene
trace γ-muurolene
trace calamenene
trace camphor
trace myrcene
trace naphthalene
95.0% total
Source: Shankaracharya et al., 1997.

Piper nigrum L.
Pepper oil (from India)

24.0% limonene
17.9% sabinene
15.7% β-pinene
9.9% α-terpinene
7.8% α-pinene
5.3% β-caryophyllene
3.0% nerolidol (unknown isomer)
2.1% α-thujene
2.0% δ-3-carene
1.2% bisabolene (unknown isomer)
1.2% α-copaene
1.0% α-amorphene
0.6% α-humulene
0.6% trans-linalool oxide (5) (furanoid)
0.6% β-phellandrene
0.6% terpinen-4-ol
0.5% δ-cadinene
0.5% (E)-β-ocimene
0.5% sesquiterpene hydrocarbons (unknown)
0.5% γ-terpinene
0.3% elemol
0.3% linalool
0.2% β-bisabolol
0.2% cadinol (unknown structure)
0.2% camphene
0.2% α-terpineol
0.1% carvone oxide (unknown structure)
0.1% caryophyllenol
0.1% citronellal
0.1% α-cubebene
0.1% δ-elemene
0.1% farnesene (unknown isomer)
0.1% α-guaiene
0.1% trans-p-menth-2-en-1-ol
0.1% sesquiterpene alcohols (unknown)
0.1% terpinolene
0.1% caryophyllene oxide
0.1% β-cubebene
0.1% β-elemene
0.1% α-eudesmol
0.1% β-eudesmol

0.1% guaiol
0.1% β-selinene
0.1% valencene
98.3% total
Source: Chacko et al., 1996.

Piper nigrum L.
Pepper oil

19.0% limonene
19.0% sabinene
16.0% δ-3-carene
12.0% β-pinene
10.0% β-caryophyllene
8.2% α-pinene
2.5% nerolidol (unknown isomer)
1.3% α-phellandrene
1.2% myrcene
0.9% elemol
0.8% linalool
0.8% terpinen-4-ol
0.8% α-thujene
0.7% caryophyllene oxide
0.7% cis-sabinene hydrate
0.6% β-bisabolene
0.6% β-eudesmol
0.6% α-selinene
0.5% δ-cadinol
0.4% trans-sabinene hydrate
0.3% para-cymene
0.3% α-humulene
0.2% α-copaene
0.2% guaiol
0.2% γ-terpinene
0.2% α-terpineol
0.2% terpinolene
0.1% camphene
0.1% camphor
0.1% 1,8-cineole
0.1% humulene oxide
0.1% (E)-β-ocimene
0.1% (Z)-β-ocimene
0.1% α-terpinene
trace δ-cadinene
trace α-cubebene
trace ar-curcumene
trace β-elemene
trace δ-elemene
trace eugenol
trace (E,E)-α-farnesene
trace (Z,E)-farnesol
trace α-guaiene
trace δ-guaiene
trace nerol
trace β-selinene
99.0% total
Source: Pino et al., 1990.

Rosmarinus officinalis L.
Rosemary oil (from Spain)

35.3% camphor
24.0% 1,8-cineole
11.0% limonene
3.8% α-terpineol
2.3% para-cymene
2.0% caryophyllene oxide
1.3% α-bisabolol
1.3% borneol
1.2% verbenone
0.9% camphene
0.9% α-pinene
0.8% geranyl acetate
0.7% carvone
0.6% myrtenal
0.5% linalyl acetate
0.5% myrcene
0.5% terpinen-4-ol
0.3% α-humulene
0.2% bornyl acetate
0.2% thymol
0.1% carvacrol
0.1% β-caryophyllene
0.1% myrtenol
0.1% (E)-β-ocimene
0.1% pinocamphone
0.1% sabinene
0.1% trans-sabinene hydrate
0.1% α-thujene
0.1% tricyclene
trace linalool
trace γ-terpinene
89.2% total
Source: Arnold et al., 1997.

Rosmarinus officinalis L.
Rosemary oil (from Turkey)

36.9% 1,8-cineole
17.5% borneol
10.5% para-cymene
7.6% camphor
3.8% camphene
3.6% terpinen-4-ol
3.3% α-terpinene
1.9% cis-sabinene-hydrate
1.7% carvacrol
1.6% bornyl acetate

1.5% γ-terpinene
1.4% trans-sabinene hydrate
1.2% β-caryophyllene
0.9% thymol
0.8% α-terpineol
0.8% limonene
0.8% piperitone
0.5% cis-piperitol
0.4% α-pinene
0.4% β-pinene
0.4% sabinene
0.4% myrcene
0.4% α-phellandrene
0.4% trans-piperitol
0.4% α-thujene
0.3% bornyl formate
0.3% α-humulene
100.0% total
Source: Perez-Alonso et al., 1995.

Rosmarinus officinalis L.
Rosemary oil (from Spain)

25.0% 1,8-cineole
17.0% α-pinene
16.0% camphor
8.8% camphene
7.3% limonene
5.5% β-pinene
2.8% para-cymene
2.0% bornyl acetate
1.9% α-terpineol
1.8% borneol
1.6% myrcene
1.3% linalool
1.0% α-thujene
0.4% β-caryophyllene
0.3% fenchone
0.3% isofenchone
0.3% terpinen-4-ol
0.2% terpinolene
93.5% total
Source: Analytical Methods Committee, 1993.

Salvia officinalis L.
Sage oil (from Spain)

22.8% α-thujone
15.7% 1,8-cineole
10.9% viridiflorol
8.9% β-pinene
6.7% borneol
5.0% camphor
4.3% β-thujone
3.6% manool
3.1% α-terpineol
3.0% α-pinene
2.7% β-caryophyllene
2.3% δ-cadinol
2.1% camphene
1.4% caryophyllene oxide
0.8% limonene
0.8% (Z)-β-ocimene
0.7% terpinen-4-ol
0.5% myrcene
0.5% para-cymene
0.4% α-terpinene
0.4% bornyl acetate
0.3% γ-terpinene
0.3% linalool
0.3% α-humulene
0.3% spathulenol
0.2% δ-cadinene
0.2% δ-terpineol
0.2% α-cadinol
0.2% (E)-β-ocimene
0.2% terpinolene
0.2% geraniol
0.1% linalyl acetate
0.1% sabinene
0.1% α-thujene
99.0% total
Source: Sanchez-Gomez et al., 1995.

Salvia officinalis L.
Sage oil (from Italy)

26.9% β-thujone
23.0% α-thujone
11.8% 1,8-cineole
6.7% pinocarveol
5.8% camphene
4.6% β-caryophyllene
3.7% α-pinene
3.0% borneol
2.6% limonene
2.0% linalool
1.6% β-pinene
1.5% bornyl acetate
0.9% para-cymene
0.7% myrcene
0.5% α-terpinyl acetate
0.4% terpinen-4-ol
0.3% caryophyllene oxide
0.2% γ-terpinene
0.1% α-thujene
0.1% α-terpineol
96.2% total

Source: Carta et al., 1996.

Satureja hortensis L.
Summer savory oil (from Poland)

40.9% γ-terpinene
39.3% carvacrol
6.2% para-cymene
4.0% α-terpinene
2.5% myrcene
1.9% α-thujene
1.5% α-pinene
0.8% β-caryophyllene
0.8% β-pinene
0.6% β-bisabolene
0.3% limonene
0.3% β-phellandrene
0.3% α-phellandrene
0.1% terpinen-4-ol
0.1% camphene
0.1% sabinene
0.1% methyl carvacrol
0.1% α-terpineol
trace α-bisabolene
trace borneol
trace trans-carveol
trace trans-dihydrocarvone
trace germacrene B
trace α-humulene
trace linalool
trace cis-sabinene hydrate
trace β-sesquiphellandrene
trace spathulenol
trace thymol
100.1% total
Source: Gora et al., 1996.

Stevia rebaudiana (Bertoni) Bertoni
Stevia oil (from Italy)

12.2% β-cubebene
11.7% γ-elemene
10.0% β-caryophyllene
8.1% sesquiterpene alcohols (unknown)
5.6% α-humulene
5.6% β-elemene
4.3% (E)-β-farnesene
3.7% α-terpineol
3.3% α-cadinol
3.1% torreyol
2.1% spathulenol
1.8% linalool
1.3% 1-octenol-3
1.1% 3-hexenyl acetate
0.1% α-pinene
0.1% β-pinene
0.1% δ-cadinene
0.1% γ-cadinene
0.1% eugenol
0.1% carvacrol
0.1% caryophyllene oxide
0.1% nerolidol (unknown isomer)
0.1% (Z)-3-hexenol
0.1% β-bourbonene
0.1% α-bergamotene
74.5% total
Source: Martelli et al., 1985.

Syzygium aromaticum (L.) Merrill & Perry
Clove bud oil

75.6% β-caryophyllene
14.1% α-humulene
2.3% δ-cadinene
1.4% cubebene (unknown isomer)
0.8% calamenene
0.5% α-copaene
0.5% α-cubebene
0.5% myrcene
0.4% α-muurolene
0.4% γ-muurolene
0.3% β-pinene
0.3% α-thujene
trace geraniol
trace β-selinene
trace γ-cadinene
97.1% total
Source: Muchalai & Crouzet, 1985.

Syzygium aromaticum (L.) Merrill & Perry
Clove bud oil (from Madagascar)

70.0% eugenol
22.1% eugenyl acetate
4.5% β-caryophyllene
0.4% α-humulene
0.4% methyl benzoate
0.2% humulene oxide
0.2% caryophyllene oxide
0.1% 10-α-cadinol
0.1% methyl chavicol
0.1% ethyl benzoate
0.1% calacorene (unknown isomer)
0.1% carvone
0.1% α-terpinyl acetate
0.1% α-amorphene

trace methyl eugenol
trace 2-nonanone
trace 2-heptanone
trace α-muurolene
trace benzyl acetate
trace 2-heptanol
trace copaene (unknown isomer)
trace 2-nonanol
trace linalool
trace γ-cadinene
trace α-cubebene
trace (E)-anethole
trace cinnamic aldehyde
trace calamenene
trace benzyl alcohol
trace 2-undecanone
trace 2-phenylethyl acetate
trace ethyl cinnamate
trace ethyl hexanoate
trace ethyl octanoate
trace methyl octanoate
trace zonarene
trace benzyl tiglate
trace humulenol
98.7% total
Source: Lawrence, 1979.

Syzygium aromaticum (L.) Merrill & Perry
Clove leaf oil (from Indonesia)

95.0% eugenol
1.0% β-caryophyllene
0.1% α-humulene
0.1% α-pinene
0.1% para-cymene
0.1% limonene
0.1% linalool
0.1% terpinen-4-ol
0.1% geranial
0.1% 1,8-cineole
0.1% carvone
0.1% linalyl acetate
0.1% β-selinene
0.1% caryophyllene oxide
0.1% methyl eugenol
0.1% methyl chavicol
0.1% germacrene D
0.1% eremophilene
0.1% ethanol
0.1% ethyl acetate
0.1% 6-methyl-5-hepten-2-one
0.1% anethole
0.1% benzyl benzoate
0.1% 1-octanol
0.1% cubebol
0.1% δ-selinene
0.1% methyl thymol
0.1% cis-calamenene
0.1% γ-cadinol
0.1% methyl carvacrol
0.1% copaenol
0.1% propyl isobutyrate
0.1% trans-calamenene
0.1% humulol
trace α-ylangene
trace α-muurolene
trace δ-cadinene
trace γ-cadinene
trace α-copaene
trace α-cubebene
trace γ-muurolene
trace cubenol
trace δ-cadinol
trace α-cadinol
trace ledol
trace allo-aromadendrene
trace cadalene
trace β-bourbonene
trace zingiberene
trace calamenene
trace humulene oxide
trace α-calacorene
trace palustrol
trace calamenol
trace humuladienone
97.9% total
Source: Vernin et al., 1989.

Syzygium aromaticum (L.) Merrill & Perry
Clove leaf oil (from Indonesia)

71.0% eugenol
14.0% β-caryophyllene
1.8% α-humulene
0.9% caryophyllene oxide
0.6% α-copaene
0.3% calamenene
0.2% δ-cadinene
0.2% γ-cadinene
0.2% α-cubebene
0.1% humulene oxide
0.1% methyl eugenol
0.1% eugenyl acetate
89.4% total
Source: Vernin et al., 1994.

Thymus vulgaris L.
Thyme oil (from Denmark)

39.1% thymol
24.2% para-cymene
11.0% γ-terpinene
5.1% carvacrol
2.2% linalool
2.1% myrcene
1.7% trans-sabinene hydrate
1.6% α-pinene
1.6% α-thujene
1.5% α-terpinene
1.3% β-caryophyllene
1.2% borneol
1.0% camphene
0.8% 1-octenol-3
0.7% terpinen-4-ol
0.6% methyl thymol
0.6% 1,8-cineole
0.5% methyl carvacrol
0.5% β-pinene
0.4% limonene
0.4% cis-sabinene hydrate
0.2% camphor
0.2% caryophyllene oxide
0.2% 3-octanol
0.1% δ-3-carene
0.1% cis-dihydrocarvone
0.1% β-phellandrene
0.1% α-phellandrene
0.1% germacrene D
0.1% (Z)-nerolidol
0.1% α-bergamotene
0.1% α-thujone
0.1% neral
0.1% terpinolene
0.1% β-ionone
0.1% α-terpineol
trace tricyclene
trace citronellol
trace nerol
trace aromadendrene
trace β-bisabolene
trace bornyl acetate
trace δ-cadinene
trace γ-cadinene
trace T-cadinol
trace trans calamenene
trace p-cymen-8-ol
trace β-elemene
trace γ-eudesmol
trace eugenol
trace farnesol (unknown isomer)
trace geranial
trace geraniol
trace geranyl acetate
trace (Z)-3-hexenol
trace α-humulene
trace α-ionone
trace isoborneol
trace isomenthone
trace isopulegol
trace lynalyl acetate
trace menthone
trace methyl chavicol
trace α-muurolene
trace γ-muurolene
trace (E)-nerolidol
trace (E)-β-ocimene
trace (Z)-β-ocimene
trace sabinene
trace thymyl acetate
100.0% total
Source: Venskutonis et al., 1996.

Thymus vulgaris L.
Thyme oil (from New Zealand)

37.0% para-cymene
22.5% thymol
10.0% γ-terpinene
6.2% carvacrol
4.1% linalool
3.0% borneol
2.6% β-caryophyllene
2.2% methyl carvacrol
1.9% methyl thymol
1.5% myrcene
1.2% caryophyllene oxide
1.2% 1,8-cineole
1.0% limonene
0.9% camphene
0.9% β-pinene
0.8% camphor
0.8% germacrene D
0.6% α-pinene
0.6% α-thujene
0.5% terpinen-4-ol
0.5% α-terpineol
99.9% total
Source: McGimpsey et al., 1994.

Trigonella foenum-graecum L.
Fenugreek oil

7.5% dihydroactinidiolide
7.5% 2,3-dihydrobenzofuran

7.5% 1-hexanol
2.5% aniline
2.5% calamenene
2.5% calarene
2.5% camphor
2.5% diphenylamine
2.5% dodecanoic acid
2.5% β-elemene
2.5% δ-elemene
2.5% eugenol
2.5% heptanal
2.5% heptanoic acid
2.5% 2-heptanone
2.5% hexadecane
2.5% 1-hexadecene
2.5% 2-hexylfuran
2.5% methylcyclohexyl acetate
2.5% ε- and γ-muurolene each
2.5% γ-nonalactone
2.5% 3-octen-2-one
2.5% pentadecane
2.5% phenol
2.5% tetradecane
2.5% thymol
0.5% decanoic acid
0.5% 1-dodecene
0.5% β-ionone
0.1% 3-hydroxy-4,5-dimethyl-2(5H)-furanone
84.1% total
Source: Girardon et al., 1985/1986.

Vanilla planifolia H.C. Andrews

Vanilla extract

85.0% vanillin
8.5% 4-hydroxybenzaldehyde
1.0% 4-hydroxybenzyl methyl ether
0.5% acids and esters
0.5% acetic acid
0.5% phenols (alkyl) (unknown structures)
0.5% esters (unknown structure)
0.5% alkanes & alkenes
0.5% alkylbenzenes
0.1% sesquiterpene hydrocarbons
97.6% total
Source: Klimes & Lamparsky, 1976.

Zingiber montanum (Koenig) Dietrich

Cassumunar ginger oil (from Indonesia)

10.2% terpinen-4-ol
10.1% sabinene
9.8% trans-1-(3,4-dimethoxyphenyl) butadiene
7.4% trans-1-(3,4-dimethoxyphenyl) but-1-ene
7.0% sesquiphellandrene
5.2% para-cymene
3.7% cis-1-(3,4-dimethoxyphenyl) butadiene
3.6% γ-terpinene
3.4% terpinolene
2.9% δ-3-carene
2.8% trans-sabinene hydrate
2.6% myrcene
2.4% ar-curcumene
2.4% β-pinene
2.0% α-terpinene
1.9% p-2,4(8)-menthadiene
1.8% cis-p-menth-2-en-1-ol
1.7% cis-1-(3,4-dimethoxyphenyl) but-1-ene
1.7% trans-p-menth-2-en-1-ol
1.7% zingiberene
1.6% α-terpineol
1.3% β-phellandrene
1.3% α-pinene
1.1% β-bisabolene
1.0% allo-ocimene (unknown isomer)
1.0% camphene
1.0% cis-sabinene hydrate
0.8% α-thujene
0.7% α-phellandrene
0.7% trans-piperitol
0.7% 1-(2,4,5-trimethoxyphenyl) but-1-ene
0.6% cis-1-(2,4,5-trimethoxyphenyl) butadiene
0.5% limonene
trace bornylene
trace camphor
trace curzerenone
trace cis-1,2-epoxyterpin-4-ol
trace linalool
trace cis-piperitol
trace terpinyl acetate (unknown isomer)
trace thujyl alcohol
trace trans-1-(2,4,5-trimethoxyphenyl) butadiene
96.7% total
Source: Taroeno et al., 1991.

Zingiber montanum (Koenig) Dietrich

Cassumunar ginger oil (from Indonesia)

8.7% trans-1-(3,4-dimethoxyphenyl) butadiene
8.1% sabinene
7.8% terpinen-4-ol
7.5% trans-4-(3,4-dimethoxyphenyl) but-3-ene
6.0% sesquiphellandrene
5.5% trans-1-(3,4-dimethoxyphenyl) but-1-ene
2.9% cis-sabinene hydrate
2.7% cis-1-(3,4-dimethoxyphenyl) but-1-ene
2.7% terpinolene
2.5% para-cymene

2.5% cis-1-(3,4-dimethoxyphenyl) butadiene
2.5% trans-1-(2,4,5-trimethoxyphenyl) butadiene
2.4% trans-4-(3,4-dimethoxyphenyl) but-3-ene
2.2% cis-4-(3,4-dimethoxyphenyl) but-3-ene
2.2% trans-sabinene hydrate
2.0% myrcene
1.7% γ-terpinene
1.6% ar-curcumene
1.6% p-2,4(8)-menthadiene
1.4% α-phellandrene
1.3% β-pinene
1.1% β-bisabolene
1.0% 1-(3,4-dimethoxyphenyl) butane
1.0% 1-(2,4,5-trimethoxyphenyl) but-1-ene
1.0% zingiberene
0.9% trans-p-menth-2-en-1-ol
0.9% terpinyl acetate (unknown isomer)
0.8% cis-4-(3,4-dimethoxyphenyl) but-3-ene
0.8% cis-p-menth-2-en-1-ol
0.8% α-terpineol
0.7% bornylene
0.7% 3,4-dimethoxycinnamaldehyde
0.7% α-terpinene
0.5% cis-piperitol
0.5% cis-1-(2,4,5-trimethoxyphenyl) butadiene
0.4% allo-ocimene (unknowm isomer)
trace curcumalactone
trace curzerenone
trace β-phellandrene
trace thujyl alcohol
trace vanillin
87.7% total
Source: Taroeno et al., 1991.

Zingiber officinale Roscoe
Ginger oil (from India)

30.0% zingiberene
9.0% β-sesquiphellandrene
8.0% camphene
8.0% ar-curcumene
7.0% cis-γ-bisabolene
6.0% β-bisabolene
4.2% β-phellandrene
3.1% limonene
2.5% α-pinene
2.0% citronellol
1.4% α-terpinyl acetate
1.0% 1,8-cineole
0.9% myrcene
0.9% geranial
0.8% nerolidol (unknown isomer)
0.6% linalool
0.6% β-eudesmol
0.5% neral
0.5% germacrene D
0.5% germacrene B
0.4% β-pinene
0.4% citronellal
0.4% citronellyl acetate
0.4% zingiberenol
0.4% trans-β-sesquiphellandrol
0.3% α-phellandrene
0.3% cis-sesquisabinene hydrate
0.2% elemol
0.2% phellandral
0.2% 6-methyl-5-hepten-2-one
0.2% rosefuran
0.1% α-thujene
0.1% sabinene
0.1% para-cymene
0.1% γ-terpinene
0.1% borneol
0.1% α-terpineol
0.1% β-caryophyllene
0.1% fenchyl acetate
0.1% cis-sabinene hydrate
0.1% perillene
0.1% isoborneol
0.1% α-eudesmol
0.1% 2-hexanone
0.1% (–)-isopulegol
0.1% 2-nonanone
0.1% 2-heptanone
0.1% cubebol
0.1% carvotanacetone
0.1% δ-3-carene
0.1% α-terpinene
0.1% (Z)-β-ocimene
0.1% (E)-β-ocimene
0.1% terpinolene
93.0% total
Source: Lawrence, 1988.

Zingiber officinale Roscoe
Ginger oil (from China)

38.1% zingiberene
17.1% ar-curcumene
7.2% β-sesquiphellandrene
5.2% β-bisabolene
4.7% camphene
2.5% β-phellandrene
2.2% borneol
2.1% 1,8-cineole
1.3% α-pinene
1.2% β-elemene
1.0% limonene

0.8% α-terpineol
0.7% geraniol
0.6% myrcene
0.5% β-caryophyllene
0.4% nerolidol (unknown isomer)
0.4% 6-methyl-5-hepten-2-one
0.3% zingiberenol
0.2% cis-sesquisabinene hydrate
0.2% β-pinene
0.2% terpinolene
0.2% α-phellandrene
0.1% trans-β-sesquiphellandrol
0.1% 2-undecanone
0.1% sabinene
0.1% para-cymene
trace 2-heptanol
trace 2-nonanone
trace α-copaene
87.0% total
Source: Vernin & Parkanyi, 1994.

Zingiber officinale Roscoe
Ginger oil (from Malaysia)

65.0% sesquiterpene hydrocarbons
5.1% bornyl acetate
4.6% camphene
2.7% limonene
2.5% linalyl acetate
2.2% α-pinene
2.0% 1,8-cineole
1.2% β-bisabolene
1.1% linalool
1.0% ar-curcumene
0.4% β-copaene
0.4% β-pinene
0.4% camphor
0.4% α-humulene
0.3% terpinen-4-ol
0.3% β-farnesene
0.2% neral
0.2% β-caryophyllene
0.2% β-elemene
0.2% α-guaiene
0.2% para-cymene
90.8% total
Source: Ibrahim, H. & Zakaria, M.B., 1987.

Zingiber spectabile Griffith
Black gingerwort leaf oil (from Tahiti)

49.4% β-pinene
16.6% β-phellandrene
10.8% α-pinene
3.3% ar-curcumene
2.2% β-sesquiphellandrene
1.9% β-caryophyllene
1.6% linalool
1.4% α-terpineol
1.1% (E)-β-farnesene
0.6% cryptone
0.6% farnesol (unknown isomer)
0.6% humulene oxide (unknown isomer)
0.4% sabinene
0.4% myrcene
0.4% α-phellandrene
0.4% pinocarveol (unknown isomer)
0.4% β-elemene
0.4% α-humulene
0.3% terpinen-4-ol
0.3% bornyl acetate
0.3% farnesol (unknown isomer)
0.2% camphene
0.2% terpinolene
0.2% pinocarvone
0.2% borneol
0.2% palmitic acid
0.1% γ-terpinene
0.1% α-copaene
0.1% (E)-nerolidol
0.1% caryophyllene oxide
trace (Z)-β-ocimene
trace 1,8-cineole
trace limonene
95.0% total
Source: Vahirua-Lechat et al., 1996.

Zingiber spectabile Griffith
Black gingerwort stem oil (from Tahiti)

38.1% β-phellandrene
26.2% β-pinene
13.7% α-pinene
1.2% cryptone
1.2% β-sesquiphellandrene
1.0% myrcene
0.9% linalool
0.9% ar-curcumene
0.8% p-cymene
0.8% terpinen-4-ol
0.8% humulene oxide (unknown isomer)
0.7% farnesol (unknown isomer)
0.6% α-phellandrene
0.6% borneol
0.6% α-terpineol
0.6% β-caryophyllene
0.5% camphene
0.5% pinocarveol (unknown isomer)

0.5% (E)-β-farnesene
0.5% farnesol (unknown isomer)
0.5% palmitic acid
0.3% terpinolene
0.2% sabinene
0.2% γ-terpinene
0.2% pinocarvone
0.2% α-humulene
0.1% bornyl acetate
0.1% α-copaene
0.1% β-elemene
0.1% (E)-nerolidol
0.1% caryophyllene oxide
trace (Z)-β-ocimene
trace 1,8-cineole
trace limonene
92.4% total
Source: Vahirua-Lechat et al., 1996.

Zingiber zerumbet (L.) J. E. Smith
Zerumbet ginger rhizome oil (from Vietnam)

72.3% zerumbone
4.2% α-humulene
3.8% humulene oxide I
3.3% humulene oxide II
3.1% camphene
1.5% caryophyllene oxide
1.2% camphor
0.8% 1,8-cineole
0.8% sesquiterpenes, oxygen-containing-
0.7% α-pinene
0.4% limonene
0.4% linalool
0.4% 12-norcaryophyllen-2-one
0.3% β-caryophyllene
0.2% borneol
0.2% δ-3-carene
0.2% β-eudesmol
0.2% myrcene
0.2% α-terpineol
0.1% (E)-nerolidol
0.1% α-phellandrene
0.1% β-pinene
0.1% terpinen-4-ol
0.1% bornyl acetate
0.1% camphene hydrate
0.1% para-cymene
0.1% fenchone
0.1% isoborneol
0.1% sabinene
0.1% terpinolene
0.1% α-thujene
0.1% tricyclene
95.1% total
Source: Nguyen Xuan Dung et al., 1993.

Zingiber zerumbet (L.) J. E. Smith
Zerumbet ginger stem oil (from Vietnam)

21.3% zerumbone
16.8% (Z)-nerolidol
10.4% β-caryophyllene
7.0% phytol
5.4% β-pinene
3.6% β-chamigrene
2.5% α-humulene
2.1% (E,E)-α-farnesene
1.9% β-bisabolene
1.6% β-eudesmol
1.1% caryophyllene oxide
1.1% linalool
1.1% α-pinene
0.8% borneol
0.8% 2-heptadecanone
0.8% terpinen-4-ol
0.7% cis-α-bergamotene
0.7% trans-pinocarveol
0.6% (E)-β-ocimene
0.5% ledol
0.5% 2-methyl-6-methylene-1,7-octadiene
0.5% sabinene
0.3% 10-(acetylmethyl)-3-carene
0.3% camphor
0.3% 1,8-cineole
0.3% edulan II, dihydro-
0.3% 2-undecanone
0.2% camphene
0.2% edulan I, dihydro-
0.2% α-terpineol
0.1% para-cymene
0.1% limonene
0.1% myrcene
0.1% myrtenyl acetate
0.1% δ-3-carene
0.1% ar-curcumene
0.1% isoborneol
0.1% (Z)-β-ocimene
0.1% α-thujene
84.6% total
Source: Nguyen Xuan Dung et al., 1995.

Zingiber zerumbet (L.) J. E. Smith
Zerumbet ginger leaf oil (from Vietnam)

22.3% (Z)-nerolidol
12.6% phytol
11.2% β-caryophyllene

5.5% caryophyllene oxide
5.2% β-pinene
2.9% α-humulene
2.4% linalool
2.4% zerumbone
1.6% α-pinene
1.4% cis-α-bergamotene
1.2% camphor
1.0% 2-methyl-6-methylene-1,7-octadiene
0.9% δ-3-carene
0.9% (E,E)-α-farnesene
0.9% 2-heptadecanone
0.8% edulan II, dihydro-
0.7% borneol
0.7% ledol
0.6% 10-(acetylmethyl)-3-carene
0.6% 1,8-cineole
0.6% β-eudesmol
0.6% (E)-β-ocimene
0.6% terpinen-4-ol
0.6% 2-undecanone
0.5% β-bisabolene
0.5% para-cymene
0.5% edulan I, dihydro-
0.5% myrtenol
0.4% β-chamigrene
0.4% α-terpineol
0.3% limonene
0.3% myrtenal
0.3% trans-pinocarveol
0.1% camphene
0.1% ar-curcumene
0.1% isoborneol
0.1% myrcene
0.1% myrtenyl acetate
0.1% (Z)-β-ocimene
0.1% sabinene
0.1% α-thujene
82.3% total
Source: Nguyen Xuan Dung et al., 1995.

Zingiber zerumbet (L.) J. E. Smith
Zerumbet ginger flower oil (from Vietnam)

36.3% (Z)-nerolidol
13.2% β-caryophyllene
4.7% linalool
4.4% hexadecanoic acid
3.2% zerumbone
2.2% caryophyllene oxide
2.1% (E,E)-α-farnesene
1.9% β-chamigrene
1.9% α-humulene
1.8% 2-methyl-6-methylene-1,7-octadiene
1.8% phytol
1.4% cis-α-bergamotene
1.3% (Z)-β-farnesene
1.3% (E)-β-ocimene
0.9% linoleic acid
0.7% 1,8-cineole
0.7% docosane
0.6% δ-3-carene
0.6% β-eudesmol
0.5% tetracosane
0.4% limonene
0.4% β-pinene
0.3% oleic acid
0.3% α-pinene
0.2% β-bisabolene
0.2% β-sesquiphellandrene
0.2% tetradecanoic acid
0.2% 2-undecanol
0.1% camphene
0.1% camphor
0.1% ar-curcumene
0.1% edulan I, dihydro-
0.1% myrcene
0.1% terpinen-4-ol
0.1% borneol
0.1% α-copaene
0.1% para-cymene
0.1% edulan II, dihydro-
0.1% geraniol
0.1% (Z)-β-ocimene
0.1% α-phellandrene
0.1% sabinene
0.1% undecanone (unknown structure)
84.8% total
Source: Nguyen Xuan Dung et al., 1995.

Table on standard physical properties of some dried spices

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:

ISO 927–1982: Determination of extraneous matter content.
ISO 928–1980: Determination of total ash.
ISO 930–1980: Determinatioin of acid-insoluble ash.
ISO 939–1980: Determination of moisture content – Entrainment method.
ISO 6571–1984: Determination of volatile oil content.

In the last column the number of the standard referring to the spice in question is given. If available, the ISO standard with the year of its publication is indicated. ISO/DIS refers to a standard that is currently under review.

Species	Extraneous matter % (m/m), max.	Moisture content % (m/m), max.	Total ash % (m/m), on dry basis, max.	Acid-insoluble ash % (m/m), on dry basis, max.	Volatile oil % (ml/100g), on dry basis, min.	ISO
Artemisia dracunculus						
tarragon						7926 '91
– whole	1.0	10.0	12.0	1.5	0.6	
– ground	1.0	10.0	12.0	1.5	0.5	
Carum carvi						
caraway						5561 '90
– whole						
biennial	1.0	13.0	8.0	1.5	2.5	
annual	1.0	12.0	9.0	2.0	1.5	
Cinnamomum burmanni						
Indonesian cassia						6538 '97
– whole	1.0	15.0	5.0	1.0	1.0	
– ground	1.0	14.0	5.0	1.0	0.8	
Cinnamomum cassia						
Chinese cassia						6538 '97
– whole	1.0	15.0	4.0	0.8	1.5	
– ground	1.0	14.0	4.0	0.8	1.1	
Cinnamomum loureirii						
Vietnamese cassia						6538 '97
– whole	1.0	15.0	4.5	2.0	3.0	
– ground	1.0	14.0	4.5	2.0	3.0	
Cinnamomum verum						
cinnamon (Sri Lanka)						6539 '97
– whole	1.0	12.0	5.0	1.0	1.0	
– ground	1.0	12.0	5.0	1.0	0.7	
Cinnamomum verum						
cinnamon (Seychelles)						6539 '97
– whole	1.0	12.0	7.0	2.0	0.4	
– ground	1.0	12.0	7.0	2.0	0.3	

Coriandrum sativum						
coriander						2255 '96
– whole						
Grade 1	1.5	9.0	7.0	1.5	0.1	
Grade 2	2.0	9.0	7.0	1.5	0.1	
Grade 3	4.0	9.0	7.0	1.5	0.1	
– ground		9.0	7.0	1.5	0.1	
Cuminum cyminum						
cumin						6465 '84
– whole						
Grade 1	1.0	9.0	9.5	1.5	2.5	
Grade 2	3.0	10.0	12.0	3.0	1.5	
Grade 3	5.0	13.0	15.0	5.0	1.5	
Elettaria cardamomum						
cardamom						882 '93
– whole capsules	5.0	13.0	9.5		3.5	
– seeds	2.0	13.0	9.5		3.5	
Illicium verum						
star anise						11178 '95
– whole	2.0	10.0	4.0		8.0	
Laurus nobilis						
laurel						6576 '84
– whole and pounded leaves	2.0	8.0	7.0	2.0	1.0	
Myristica fragrans						
nutmeg						6577 '90
– whole or broken	0.5	10.0	3.0	0.5	6.5	
Myristica fragrans						
mace						6577 '90
– whole or broken	0.5	10.0	4.0	0.5	7.5	
– sifting or pickings	0.5	10.0	4.0	0.5	5.0	
Ocimum basilicum						
basil						11163 '95
– cut (rubbed) leaves	1.0	12.0	16.0	2.0	0.3	
Origanum majorana						
(sweet) marjoram						10620 '95
– bouquet	3.0	12.0	16.0	4.5	0.3	
– rubbed	1.0	12.0	16.0	4.5	0.7	

Species	Extraneous matter % (m/m), max.	Moisture content % (m/m), max.	Total ash % (m/m), on dry basis, max.	Acid-insoluble ash % (m/m), on dry basis, max.	Volatile oil % (ml/100g), on dry basis, min.	ISO
Origanum vulgare						ISO/DIS
oregano						7925 '85
– whole or cut leaves						
processed	1.0	12.0	10.0	2.0	1.8	
semi-processed	3.0	12.0	12.0	2.0	1.5	
– ground		12.0	12.0	2.0	1.5	
Pimenta dioica						ISO/DIS
pimento						973 '80
– whole	1.0	12.0	4.5	0.4	3.5	
– ground					2.8	
Pimpinella anisum						
anise						7386 '84
– whole						
Grade 1	1.0	12.0	10.0	2.5	2.0	
Grade 2	3.0	12.0	10.0	2.5	1.5	
Grade 3	4.0	12.0	10.0	2.5	1.0	
Piper nigrum						
dehydrated green pepper						10621 '97
– whole	1.0	8.0	5.0			
Piper nigrum						
black pepper						959–1 '98
– whole						
non or semi-processed	2.5	13.0	7.0		2.0	
processed	1.5	13.0	6.0		2.0	
– ground		13.0	6.0		1.0	
Piper nigrum						
white pepper						959–2 '98
– whole						
semi-processed	1.0	14.0	3.5		1.0	
processed	0.8	14.0	3.5		1.0	
– ground		14.0	3.5		1.0	

Rosmarinus officinalis						
rosemary						11164 '95
– dried leaves	1.0	11.0	8.0	1.0	0.8	
Salvia officinalis						
sage						11165 '95
– whole or cut leaves	1.0	12.0	11.0	2.0	1.5	
Syzygium aromaticum						
clove						2254 '80
– whole						
Grade 1	0.5	12.0			17.0	
Grade 2	1.0	12.0			17.0	
Grade 3	1.0	12.0			15.0	
– ground						
Grade 1		10.0	7.0	0.5	16.0	
Grade 2		10.0	7.0	0.5	16.0	
Grade 3		10.0	7.0	0.5	14.0	
Thymus vulgaris						
thyme						6754 '96
– bouquet or cleaned thyme	2.0	12.0	14.0	5.0	1.0	
– rubbed thyme	1.0	12.0	14.0	3.5	1.0	
Vanilla planifolia						ISO/DIS
vanilla						5565 '82
– cut		30.0				
– bulk		30.0				
– powder		20.0				
Zingiber officinale						
ginger						1003 '80
– whole or in pieces						
bleached	2.0	12.0	2.5		1.5	
unbleached	2.0	12.0	1.1		1.5	
– ground				2.3		

Source: ISO Standards.

Table on standard physical properties of some spice 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:

ISO 279–1981: Determination of relative density at 20°C.
ISO 280–1976: Determination of refractive index.
ISO 592–1981: Determinatioin of optical rotation.
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 indicated. ISO/DIS refers to a standard that is currently under review. If no ISO standard was available for an essential oil, the information was supplemented with data published in the Food Chemicals Codex (FCC) (Committee on Food Chemicals Codex, 1996).

Species **oil**	**Relative density**	**Refractive index**	**Optical rotation**	**Miscibility in ethanol**	**ISO/FCC**
Anethum graveolens dill seed oil (Europe)	0.890–0.915	1.483–1.490	+70° to +82°	1:2 (80%)	FCC
Anethum graveolens dill seed oil (India)	0.925–0.980	1.486–1.495	+40° to +58°	1:0.5 (90%)	FCC
Anethum graveolens dillweed oil (America)	0.884–0.900	1.480–1.485	+84° to +95°	1:1 (95%)	FCC
Artemisia dracunculus tarragon oil	0.914–0.956	1.504–1.520	+2° to +6°	1:4 (90%)	ISO/DIS 10115 '89
Carum carvi caraway oil	0.905–0.920	1.484–1.489	+67° to +80°	1:5 (80%)	ISO 8896 '87
Cinnamomum cassia cassia oil (leaves)	1.052–1.070	1.600–1.614		1:3 (70%)	ISO/DIS 3216 '94
Cinnamomum verum cinnamon bark oil (Sri Lanka)	1.010–1.030	1.573–1.591	–2° to 0°	1:3 (70%)	FCC
Cinnamomum verum cinnamon leaf oil (Sri Lanka)	1.037–1.053	1.530–1.540	–2.5° to +2°	1:2 (70%)	ISO 3524 '77
Coriandrum sativum coriander oil	0.862–0.878	1.462–1.470	+7° to +13°		ISO/DIS 3516 '94
Cuminum cyminum cumin oil	0.905–0.925	1.500–1.506	+3° to +8°	1:8 (80%)	FCC
Elettaria cardamomum cardamom oil	0.919–0.936	1.462–1.468	+22° to +41°	1:5 (70%)	ISO 4733 '81
Foeniculum vulgare (sweet) fennel oil	0.953–0.973	1.532–1.543	+12° to +24°	1:1 (90%)	FCC
Illicium verum star anise oil	0.979–0.985	1.553–1.556	–2° to +2°	1:3 (90%)	ISO/DIS 11016 '96
Laurus nobilis laurel leaf oil	0.905–0.929	1.465–1.470	–19° to –10°	1:1 (80%)	FCC
Myristica fragrans mace oil (Indonesia)	0.883–0.934	1.474–1.488	+2° to +30°	1:3 (90%)	ISO 4734 '81

Myristica fragrans mace oil (West Indies)	0.857–0.880	1.469–1.480	+20° to 45°	1:3 (90%)	ISO 4734 '81
Myristica fragrans nutmeg oil (Indonesia)	0.885–0.905	1.475–1.485	+8° to +18°	1:5 (90%)	ISO/DIS 3215 '94
Myristica fragrans nutmeg oil (West Indies)	0.862–0.882	1.472–1.476	+25° to +40°	1:5 (90%)	ISO/DIS 3215 '94
Ocimum basilicum basil oil (Réunion)	0.952–0.973	1.512–1.520	−2° to +2°	1:4 (80%)	FCC
Ocimum basilicum basil oil (Europe)	0.900–0.920	1.483–1.493	−5° to −15°	1:4 (80%)	FCC
Origanum majorana (sweet) marjoram oil	0.890–0.906	1.470–1.475	+14° to +24°	1:2 (80%)	FCC
Origanum vulgare oregano oil	0.935–0.960	1.502–1.508	−2° to +3°	1:2 (70%)	FCC
Petroselinum crispum parsley leaf oil	0.908–0.940	1.503–1.530	−9° to +1°	(95%)	FCC
Petroselinum crispum parsley seed oil	1.043–1.083	1.511–1.522	−11° to −4°	1:5 (80%)	ISO 3527 '75
Pimenta dioica pimento leaf oil	1.036–1.053	1.531–1.536	−2° to +0.5°	1:2 (70%)	ISO 4729 '84
Pimenta dioica pimento berry oil	1.027–1.048	1.525–1.540	−5° to 0°	1:2 (70%)	ISO 3043 '75
Pimpinella anisum anise oil	0.980–0.990	1.552–1.559	−2° to +2°	1:3 (90%)	ISO 3475 '75
Piper cubeba cubeb oil	0.906–0.930	1.492–1.502	−43° to −20°	1:10 (90%)	ISO 3756 '76
Piper nigrum (black) pepper oil	0.870–0.890		−16° to +4°	1:3 (95%)	ISO 3061 '79
Rosmarinus officinalis rosemary oil (Spain)	0.895–0.905	1.467–1.474	−3° to +10°		ISO 1342 '88
Rosmarinus officinalis rosemary oil (North Africa)	0.908–0.920	1.467–1.474	−1° to +6°		ISO 1342 '88

Species oil	**Relative density**	**Refractive index**	**Optical rotation**	**Miscibility in ethanol**	**ISO/FCC**
Salvia officinalis sage oil (Dalmatia)	0.910–0.930	1.458–1.474	+2° to +30°	1:8.5 (70%)	ISO/DIS 9909 '91
Satureja hortensis savory oil	0.875–0.954	1.486–1.505	–5° to +4°	1:2 (80%)	FCC
Syzygium aromaticum clove leaf oil	1.039–1.051	1.531–1.535		1:2 (70%)	ISO/DIS 3141 '94
Syzygium aromaticum clove bud oil	1.044–1.057	1.528–1.538	–1.5° to 0°	1:2 (70%)	ISO/DIS 3142 '94
Syzygium aromaticum clove stem oil	1.043–1.063	1.528–1.538	–1.5° to 0°	1:2 (70%)	ISO/DIS 3143 '94
Thymus vulgaris thyme oil	0.915–0.935	1.495–1.505	up to –3°	1:2 (80%)	FCC
Zingiber officinale ginger oil	0.870–0.882	1.488–1.494	–47° to –28°		FCC

Sources: Bauer et al., 1997; Committee on Food Chemicals Codex, 1996; ISO Standards.

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Acronyms of organizations

- ASTA: American Spice Trade Association (United States).
- CAB(I): Commonwealth Agricultural Bureaux International (Wallingford, United Kingdom).
- DGIS: Directorate-General for International Cooperation of the Netherlands Ministry of Foreign Affairs (Den Haag, the Netherlands).
- EOA: Essential Oil Association of the United States.
- ESCOM: European Scientific Cooperative on Phytotherapy.
- 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).
- IOFI: International Organization of Flavour Industries (Geneva, Switzerland).
- IPGRI: International Plant Genetic Resources Institute (Rome, Italy).
- ISO: International Standardization Organization (Geneva, Switzerland).
- 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 (United States).
- 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).
- WAU: Wageningen Agricultural University (Wageningen, the Netherlands).

Glossary

abaxial: on the side facing away from the axis or stem (dorsal)
abortifacient: causing abortion; an agent that causes abortion
absolute: A highly concentrated, alcohol-soluble liquid, normally obtained by alcoholic extraction of concretes or pomades and considered to reflect most accurately the taste and odour of the original material
accession: in germplasm collections: plant material of a particular collection, usually indicated with a number
accessory buds: those additional to the axillary and normal buds; more than one bud in an axil
accrescent: increasing in size with age
achene: a small dry indehiscent one-seeded fruit
acicular: needle-shaped; with a sharp point
acid value: a measure of the content of free acid present in an aromatic material, which tends to increase with increasing age of products such as essential oils and esters, particularly esters of lower and terpene alcohols
actinomorphic: radially symmetrical; applied to flowers which can be bisected in more than one vertical plane
aculeate: furnished with prickles; prickly
acumen: the point of an acuminate leaf; the drip-tip
acuminate: ending in a narrowed, tapering point with concave sides
acute: in botany: sharp; ending in a point with straight or slightly convex sides; in medicine: with a short and relatively severe course
adaxial: on the side facing the axis (ventral)
adherent: the union of parts usually separate
adnate: united with another part; with unlike parts fused, e.g. ovary and calyx tube
adpressed (appressed): lying flat for the whole length of the organ
adulterate: falsify by admixture of ingredients
adventitious: not in the usual place, e.g. roots on stems, or buds produced in other than terminal or axillary positions on stems
agarbatti, joss stick: incense stick consisting of a blend of aromatic plant matter wrapped around a thin length of bamboo, impregnated with a perfume compound. In high-quality agarbattis the base material is sufficiently fragrant not to require perfuming
agroforestry: land-use systems in which trees or shrubs are grown in association with crops (agricultural crops or pastures) in a spatial arrangement or a rotation and in which there are both ecological and economic interactions between the trees and the other components of the system
air layering: a form of layering in which soil (rooting medium) is brought to the branch to be layered; the ball of soil in a polyethene cover is wrapped around the girdled branch; after adventitious roots grow out above the girdle, the layer can be separated
albumen: the nutritive material stored within the seed, and in many cases surrounding the embryo (endosperm)
aliphatic compounds: acyclic organic compounds; the chain of C-atoms in these compounds may be straight or branched and some of the bonds between C-atoms may be unsaturated
alkaloid: large group of organic bases containing nitrogen and usually oxygen that occur for the most part in the form of salts with acids; usually optically and biologically active
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: destructive to worms: a drug or agent that destroys worms
anther: the part of the stamen containing the pollen
antheriferous: bearing anthers
anthesis: the time the flower is expanded, or, more strictly, the time when pollination may take place
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: pertaining to asepsis (prevention of contact with micro-organisms); preventing decay or putrefaction; a substance inhibiting the growth and development of micro-organisms without necessarily killing them
antispasmodic: relieving spasm; an agent that relieves spasm
apetalous: without petals
apex (plural: apices): the tip or summit of an organ
aphrodisiac: stimulating sexual desire; a drug arousing the sexual instinct
apical: at the apex of any structure
apiculate: ending abruptly in a short point
apocarpous: with the carpels free from each other
apomixis: reproduction by seed formed without sexual fusion (apomictic)
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 oil are usually used in diluted form as massage oils or preparations for the bath, or in products acting as odour carriers for the purported psychological benefits of essential oils when smelled
aromatic compounds: see benzene derivatives
arthritis: inflammation of a joint or joints
articulate: jointed, or with places where separation takes place naturally
ascendent, ascending: curving or sloping upwards
astringent: an agent or substane causing constriction of the skin, mucous membranes or raw or exposed tissues; as such, ethanol is used in skin-toning lotions and aluminium chlorohydrate in anti-perspirants
attar: liquid perfume traditional in India. It 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 author mentioned
auricle: a small lobe or ear
auriculate: eared, having auricles
awn: a bristle-like appendage, especially occurring on the glumes of grasses
axial: in the direction of the axis; in longitudinal direction
axil: the upper angle between the leaf and the stem
axillary: arising from the axil
axis: the main or central line of development of a plant or organ
bark: the tissue external to the vascular cambium collectively, being the secondary phloem, cortex and periderm
basifixed: attached or fixed by the base
basionym: the synonym of a scientific name that supplies the epithet for the correct name
batteuse: industrial equipment for washing concretes with alcohol to produce absolutes
beak: a long, prominent and substantial point, applied particularly to prolongations of fruits
bearded: awned; having tufts of hairs

benzene derivatives (benzenoids): chemical compounds containing a characteristic benzene ring often represented as a C_6 ring with 3 double bonds alternating with single bonds between the C-atoms
berry: a juicy indehiscent fruit with the seeds immersed in pulp; usually several-seeded without a stony layer surrounding the seeds
biennial: a plant which flowers, fruits and dies in its second year or season
bifid: forked, divided in two but not to the base
bilabiate: two-lipped
bipinnate: when the primary divisions (pinnae) of a pinnate leaf are themselves pinnate
biseriate: arranged in two rows
bisexual: having both sexes present and functional in the same flower
blade: the expanded part, e.g. of a leaf or petal
blennorrhoea: an excessive discharge of mucus; former name for gonorrhoea
body note: the note or combination of notes by which the odour of an essential oil is characterized; on a smelling strip body notes appear after evaporation of monoterpenes and other highly volatile compounds
bole: the main trunk of a tree, generally from the base up to the first main branch
brachyblast: a short reproductive branch
bract: a reduced leaf subtending a flower, flower stalk or the whole or part of an inflorescence
bracteole: a secondary bract on the pedicel or close under the flower
bristle: a stiff hair or a hair-like stiff slender body
bronchitis: inflammation of the bronchial tubes
bud: the nascent state of a flower or branch; often applied to those primordial vegetative or reproductive branches that are enclosed in a prophyllum and have a resting stage
bullate: surface much blistered or puckered
bunch: cluster, growing together
bush: a low thick shrub without a distinct trunk
buttress: the enlargement of the base of trunks of tropical trees that ranges from a small spur or swelling to massive structures, partly root, partly stem, reaching as high as 10 m up the stem, thin and flat to thick, twisted or anastomose
caducous: falling off
callus: in plants, small hard outgrowth at the base of spikelets in some grasses, or tissue that forms over cut or damaged plant surface
calorific value: the heat produced by the combustion of a unit weight of a fuel
calyx: the outer envelope of the flower, consisting of sepals, free or united
cambium (plural: cambia) : a layer of nascent tissue between the wood and bark, adding elements to both
campanulate: bell-shaped
canaliculate: channelled, with a longitudinal groove
canopy: the uppermost leafy layer of a tree, forest or crop
capitate: headed, like the head of a pin in some stigmas, or collected into compact headlike clusters as in some inflorescences
capsule: in botany: a dry dehiscent fruit composed of two or more carpels and either splitting when ripe into valves, or opening by slits or pores
carminative: relieving flatulence; an agent relieving flatulence and assuaging pain
carpel: one of the foliar units of a compound pistil or ovary; a simple pistil has only one carpel
carpophore: the part of the receptacle which is prolonged between the carpels as a central axis
cartilaginous: hard and tough
caryopsis: the fruit of a grass, in which the outer layer (testa) of the seed proper is fused to the ovary wall
cataphyll: reduced or scale-like leaf present in certain seedlings on the lower stem nodes and sometimes elsewhere on the seedling stem
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: in botany: the hairs at the end of some seeds; a tuft of leafy bracts or leaves at the top of an inflorescence (e.g. pineapple)

commissural: of the face by which two carpels adhere, as in *Umbelliferae*

compatibility: in floral biology: capable of cross- or self-fertilization; in plant propagation: stock–scion combinations resulting in a lasting union

compound: in botany, of two or more similar parts in one organ, as in a compound leaf or compound fruit; in chemistry, a substance consisting of 2 or more elements combined chemically in fixed proportions; in perfumery, a perfume concentrate in which the ingredients of a perfume formula are mixed together

concave: hollow

concolorous: similarly coloured on both sides or throughout; of the same colour as a specified structure

concrescent: growing together

concrete: a fatty or waxy aromatic product obtained from a natural source by extraction with a pure, volatile hydrocarbon solvent, a mixture of solvents or carbondioxide; they are mainly used as raw material for production of absolutes

condenser: in distillation that part of a still in which the hot vapours from a distillation vessel are condensed to liquid by cooling, usually by cold water circulating round a coiled part of the vapour pipe known as 'worm'

cone: the fruit of a pine or fir tree (gymnosperms), largely made up of imbricated scales

conical: having the shape of a cone (cone-shaped)

connate: united or joined

connective (botany): tissue between the pollen sacs of an anther

conspecific: belonging to the same species

contorted: twisted or bent

convex: having a more or less rounded surface

coppice: a small wood which is regularly cut at stated intervals; the new growth arising from the stools

cordate: heart-shaped, as seen at the base of a leaf, etc., which is deeply notched

cordiform: heart-shaped

core: central part; the seeds and integuments of a pome, such as an apple; pith in dicotyledonous plants

coriaceous: of leathery texture

corolla: the inner envelope of the flower consisting of free or united petals

corona: any appendage or extrusion that stands between the corolla and stamens; crown; the remains of the calyx limb on e.g. apples or pears

cortex: the bark or rind

corymb: a flat-topped indeterminate inflorescence in which the branches or pedicels sprout from different points, but attain approximately the same level, with the outer flowers opening first

corymbose: flowers arranged to resemble a corymb

cotyledon: seed-leaf, the primary leaf; dicotylous embryos have two cotyledons and monocotylous embryos have one

cover crop: a close-growing crop primarily grown for the purpose of protecting and improving soil between periods of regular crop production or between trees or vines in orchards and plantations

crenate: the margin notched with blunt or rounded teeth

crenulate: slightly crenate, with small teeth

crest: an elevation or ridge upon the summit of an organ

cross-pollination: the transfer of pollen from one flower to the stigma of a flower of another plant which is not of the same clone

crown: the aerial expanse of a tree, not including the trunk; corona; a short rootstock with leaves; the base of a tufted, herbaceous, perennial grass

culm: the stem of grasses and sedges

cultigen: a plant species or race that has arisen or is known only in cultivation

cultivar (cv., plural: cvs): an agricultural or horticultural variety that has originated and persisted under cultivation, as distinct from a botanical variety; a cultivar name should be written with an initial capital letter and given single quotation marks (e.g. banana 'Gros Michel') unless preceded bij 'cv.' (e.g. cv. Gros Michel)

cuneate: wedge-shaped; triangular, with the narrow end at the point of attachment, as the bases of leaves or petals

cupular: furnished with or subtended by a cupule

cupule: a small cup-like structure; the cup of such fruits as the acorn, consisting of an involucre composed of adherent bracts

cusp: a sharp, rigid but small point

cuspidate: abruptly tipped with a sharp rigid point

cuticle: the outermost skin of plants, consisting of a thin continuous fatty film

cutting: a portion of a plant, used for vegetative propagation

cyme: a determinate inflorescence, often flat-topped, in which each growing point ends in a flower and the central flowers open first

cymose: bearing cymes or inflorescences related to cymes *damping-off*: a disease of seeds or seedlings caused by fungi which cause various effects, from failure to germinate to the dying off of the seedling

deciduous: shedding, applied to leaves, petals, etc.

declinate: bent or curved downward or forward

decoction: a medicinal preparation or other substance made by boiling, especially in water

decompound: several times divided or compounded

decumbent: reclining or lying on the ground, but with the summit ascending

decurrent: extending down and adnate to the petiole or stem, as occurs in some leaves

decussate: of leaves, arranged in opposite pairs on the stem, with each pair perpendicular to the preceding pair

deflexed (reflexed): abruptly recurved; bent downwards or backwards

dehiscent: opening spontaneously when ripe, e.g. of capsules, anthers

deltoid: shaped like an equilateral triangle

density: the ratio of mass to volume of a substance at a given moisture content (see also: specific gravity)

dentate: margin prominently toothed with the pointed teeth directed outwards

denticulate: minutely toothed

depressed: sunk down, as if flattened from above

determinate: of inflorescences, when the terminal or central flower of an inflorescence opens first and the prolongation of the axis is arrested; of shoot growth, when extension growth takes the form of a flush, i.e. only the previously formed leaf primordia unfold; for pulses also used to indicate bush-shaped plants with short duration flowering in one plane

dextrorse: twining to the right (clockwise)

diaphoretic: pertaining to, characterized by, or promoting (profuse) perspiration; an agent inducing sweating, having the power to increase perspiration

dichasium (plural: dichasia): a cymose inflorescence with 2 equal or nearly equal lateral branches arising below the terminal flower, this pattern being repeated or not (compound and simple dichasium respectively)

dichotomous: forked, parted by pairs

dicotyledon: angiosperm with two cotyledons or seed-leaves

didynamous: with the stamens in two pairs, two long and two short ones

dieback: the dying off of parts of the aboveground structure of the plant, generally from the top downward

digestibility: the percentage of a foodstuff taken into the digestive tract that is absorbed into the body

digitate: a compound leaf whose leaflets diverge from the same point like the fingers of a hand

dilated: expanded into a flat structure

dimorphic: of two forms, as may occur with branches, etc.

dioecious: with unisexual flowers and with the staminate and pistillate flowers on different plants (dioecy)

diploid: with two sets (genomes) of chromosomes, as occurs in somatic or body cells; usually written $2n$, having twice the basic chromosome number of the haploid germ cells

discolorous: dissimilarly coloured on both sides or throughout; of a different colour as a specified structure

disjunct: separated

disk: a fleshy or elevated development of the receptacle within the calyx, corolla or stamens, often lobed and nectariferous

dispersal: the various ways by which seeds are scattered, e.g. by wind, water or animals

distal: situated farthest from the place of attachment

distichous: regularly arranged in two opposite rows on either side of an axis

distillation: the process of transforming (fractions of) a liquid or solid into the vapour state, and condensing the vapour back to liquid or solid, named the distillate

diuretic: tending to increase the flow of urine; an agent that promotes the excretion of urine

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

dryout: the final notes perceptible from an aromatic material or perfume after the body notes have evaporated

dysmenorrhoea: painful menstruation
dyspepsia: a condition of disturbed digestion
ecotype: a biotype resulting from selection in a particular habitat
eglandular: without glands
ellipsoidal: a solid which is elliptical in outline
elliptical: oval in outline but widest about the middle
emarginate: notched at the extremity
emetic: tending to induce or cause vomiting; an agent that induces or causes vomiting
emmenagogue: a substance or measure that induces menstruation
endemic: exclusively native to a specified or comparatively small region; also used as a noun for a taxon thus distributed
endo-: prefix, referring to the inside or the inner surface or part
endocarp: the innermost layer of the pericarp or fruit wall
endosperm: the starchy or oily nutritive material stored within some seeds, sometimes referred to as albumen; it is triploid, having arisen from the triple fusion of a sperm nucleus and the two polar nuclei of the embryo sac
energy value: the heat produced by the combustion of a unit weight of a fuel or food (= calorific value)
enfleurage: the process of transferring the volatile compounds responsible for the scent of picked flowers to a fixed oil or fat spread out on a glass plate; enfleurage is successful only with flowers that continue to produce aroma compounds for several hours after picking, such as jasmine and tuberose
entire (botany): with an even margin without teeth, lobes, etc.
epicalyx: an involucre of bracts below the flower, resembling an extra calyx
epidermis: in plants, the true cellular skin or covering of a plant below the cuticle; in humans, the outermost and nonvascular layer of the skin
epigeal: above the ground; in epigeal germination the cotyledons are raised above the ground
epigynous: on the pistil, apparently above the ovary
epipetalous: borne upon or placed before the petals
epiphyte: a plant that grows on another plant but without deriving nourishment from it
epithet: the second part of the scientific name of a species, the first part denoting the genus to which the species belongs
erect: directed towards summit, not decumbent
erecto-patent: between spreading and erect
essential oil: a volatile product, obtained from a natural source, which agrees with that source in odour and name; in a narrow sense, only volatile products obtained by steam or water distillation are called essential oils
evapotranspiration: loss of water from the soil by evaporation from the surface and by transpiration from the plants growing thereon
evergreen: bearing foliage all year long; a plant that changes its leaves gradually
ex situ: in an artificial environment or unnatural habitat
exocarp: the outer layer of the pericarp or fruit wall
expectorant: promoting the ejection of mucus or other fluids from the respiratory tract; an agent tending to promote discharge of mucus or other fluids from the respiratory tract
expression: any process for the removal of essential oil from the outer rind of a citrus fruit, involving scarification and compression of the peel
exsert, exserted: protrude beyond, as stamens beyond the tube of the corolla
exstipulate: without stipules
extra-axillary: beyond or outside the axil
extraction: any process for separating aroma compounds from animal or plant matter using a volatile solvent; the product is called a concrete; the composition, and hence odour quality, of an aromatic extract depends strongly on the nature of the solvent used
extrorse: directed outward, as the dehiscence of an anther
F1, F2, etc.: symbols used to designate the first generation, second generation, etc., after a cross
falcate: sickle-shaped
fallow: land resting from cropping, often covered by natural vegetation or planted with fast growing herbs, shrubs or trees (fallow crop)
fascicle: a cluster of flowers, leaves, etc., arising from the same point
fasciculate: connected or drawn into a fascicle
febrifuge: an agent serving to reduce fever
fermentation: a chemical change accompanied by effervescence and suggestive of changes produced in organic materials by yeasts
ferrugineous (ferruginous): rust-coloured
fertile (botany): capable of completing fertilization and producing seed; producing seed capable of germination; having functional sexual organs
fertilization (biology): union of the gametes (egg and sperm) to form a zygote
fibre (botany): any long, narrow cell of wood or bark other than vessel or parenchyma elements
fibrous: composed of or containing fibres

filament: thread; the stalk supporting the anther
filiform: slender; threadlike
fimbriate: fringed
fissured: provided with fissures (cracks of considerable length and depth), e.g. in the bark of some trees
fixed oil: a non-volatile oil, chemically a triglyceride of fatty acids; many fixed oils from plants have faint odours, even when purified, showing that they contain traces of volatile compounds
flavonoid: water-soluble phenolic compound, consisting of 2 aromatic rings joint together with a 3-carbon unit
fleshy: succulent
floret: a small flower, one of a cluster as in grasses or *Compositae*; a grass floret typically consists of a lemma, palea, 2 lodicules, 3 stamens and a pistil with 2 plumose stigmas
flowering branch: a leafy or leafless segmented axis that bears one or more inflorescences
flush: a brief period of rapid shoot growth, with unfolding of the leaf primordia which had accumulated during the previous quiescent period
fluted: of a bole, with rounded grooves and folds
fodder: something fed to domesticated animals, especially coarse, dried food from plants (hay, straw, leaves)
foliaceous: leaf-like
foliolate (2-, 3-, 4- etc.): with 2-, 3-, 4- leaflets
follicetum: a whorl of follicles
follicle: in plants: a dry, unicarpellate fruit, dehiscing by the ventral suture to which the seeds are attached
forage: grassland and fodder plants suitable as feed for herbivores, usually with lower nutrient concentration and digestibility than concentrates such as grain
fougère: a French word meaning fern; fougère-type perfumes are based on coumarin in combination with oak-moss, and with lavender accentuated in the topnote; their odour has no relation with that of ferns
fractionation, fractional distillation: a distillation process in which a fractionating column is interposed between the distillation vessel and the condenser. During fractionation of a homogeneous mixture of volatile components of different boiling point, components with a lower boiling point move up the column faster than components with a higher boiling point and the components distil over in sequence
free: neither adhering nor united
fringed: fimbriate; with hair-like appendages along the margin
fruit: the ripened ovary with adnate parts
fugaceous: withering or falling off rapidly or early
fungicide: an agent that destroys fungi or inhibits their growth
funicle: the cord or thread which sometimes connects the ovule or seed to the placenta
funicle (funiculus): the little cord which attaches the ovule or seed to the placenta
fusiform: spindle-shaped; tapering towards each end from a swollen centre
galenical: herbal medicine, after the famous physician Galenius
gamete: either of two mature reproductive cells, an ovum or sperm, which in uniting produce a zygote
gamopetalous: with united petals either throughout their length or at the base
gamosepalous: with united sepals either throughout their length or at the base
gas-liquid chromatography (GLC): a technique for the separation of the constituents of liquid or gaseous mixtures; in combination with mass spectroscopy it is a powerful tool for the qualitative and quantitative analysis of complex mixtures of chemical compounds such as essential oils or perfumery products
gastralgia: gastric colic
gastrodynia: stomach pain
geitonogamy: the fertilization of a pistil by pollen from another flower of the same plant
gene: the unit of inheritance located on the chromosome
geniculate: abruptly bent so as to resemble the knee-joint
genome: a set of chromosomes as contained within the gamete and corresponding to the haploid chromosome number of the species
genotype: the genetic makeup of an organism comprising the sum total of its genes, both dominant and recessive; a group of organisms with the same genetic makeup
genus (plural: genera): the smallest natural group containing distinct species
geometrical isomerism (cis-trans isomerism): a from of stereoisomerism in which the orientation of structural elements on each side of a double bond in the molecule of one isomer is at a 180° angle to that of the other isomer
germplasm: the genetic material that provides the physical basis of heredity
girth: a measure around a body
glabrate: devoid of pubescence and of any roughness
glabrescent: becoming glabrous or nearly so

glabrous: devoid of hairs
glandular: having or bearing secreting organs or glands
glaucous: pale bluish-green, or with a whitish bloom which rubs off
globose: spherical or nearly so
glomerule: a condensed head of almost sessile flowers; a cluster of heads in a common involucre
glucoside: compound that is an acetal derivative of sugars and that on hydrolysis yields glucose
glume (plural: glumes): the chaffy or membranous two-ranked members of the inflorescence of grasses and similar plants; lower glume and upper glume, two sterile bracts at the base of a grass spikelet
glycoside: compound that is an acetal derivative of sugars and that on hydrolysis yields one or more molecules of a sugar and often a noncarbohydrate
gonorrhoea: a venereal disease characterized by inflammation of the mucous membrane of the genitourinary tract and a discharge of mucus and pus
graft: a union of different individuals by apposition, the rooted plant being termed the stock, the portion inserted the scion
grafting: the process of inserting a scion, which consists of a piece of stem and two or more buds of the plant to be propagated, into another plant (rootstock) with the intention that it will unite and grow
grain (botany): a general term for cereals, those grasses cultivated for food; the caryopsis or the fruit of cereals
granular: divided into or bearing little knots or tubercles (also granulate)
granulose (granular): composed of or covered with grain-like minute particles
green manure: green leafy material applied to and mostly worked into the soil to enrich the soil with nutrients and organic matter
gregarious: growing in associated groups or clusters but not matted; at the same time
gynoecium: the female part or pistil of a flower, consisting, when complete, of one or more ovaries with their styles and stigmas
gynophore: a stalk supporting the gynoecium formed by elongation of the receptacle
habit (botany): external appearance or way of growth of a plant
habitat: the kind of locality in which a plant grows
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
hyperaemia: an excess of blood in a part of the body
hypocotyl: the young stem below the cotyledons
hypogeal: below ground; in hypogeal germination the cotyledons remain below ground within the testa

hypoglycemia: abnormal decrease of sugar in the blood

idioblast: a cell differing markedly in form and contents from other constituents of the same tissue, like crystalliferous cells, oil and mucilage cells

imbricate: overlapping like tiles; in a flower bud when one sepal or petal is wholly external and one wholly internal and the others overlapping at the edges only

imparipinnate: of leaves, pinnate with an unpaired terminal leaflet

impressed: marked with slight depressions

in situ: in the natural environment; in medicine: in the natural or normal place

in vitro: outside the living body and in an artificial environment

incised: cut deeply

incompatibility: in floral biology: not capable of cross- or self-fertilization; in plant propagation: not capable of making stock–scion combinations resulting in a lasting union

indehiscent: not opening when ripe

indented: forced inward to form a depression

indeterminate: of inflorescences: a sequence in which the terminal flowers are the last to open, so that the floral axis may be prolonged indefinitely by the terminal meristem; of shoot growth: when the shoot apex forms and unfolds leaves during extension growth, so that shoot growth can continue indefinitely

indigenous: native to a particular area or region

indumentum: a covering, as of hairs, scales, etc.

inferior: beneath, lower, below; an inferior ovary is one which is situated below the sepals, petals and stamens

inflexed: bent or curved inward toward the centre

inflorescence: the arrangement and mode of development of the flowers on the floral axis; the branch that bears the flowers, including all its bracts and branches

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, like a node in plants and a place of union of two bones in the human body; articulated

joss stick: see agarbatti

jugate: connected or yoked together; e.g. in leaves 1–n-jugate: with 1–n pairs of leaflets

juvenile phase (stage): the period between germination and the first signs of flowering, during which vegetative processes preclude flower initiation even under the most favourable conditions

keel (carina): a ridge like the keel of a boat; the two anterior and united petals of a papilionaceous corolla; the principal vein of a sepal or glume

kernel: the nucellus of an ovule or of a seed, that is, the whole body within the coats

labellum: lip; the lowest petal of an orchid; petaloid anterior staminode in *Zingiberaceae*

lacerate: torn; irregularly cleft or cut

laciniate: slashed, cut into narrow lobes

lamellate: made up of thin plates

lamina: see blade

lanate: with woolly hairs

lanceolate: lance-shaped; much longer than broad, being widest at the base and tapering to the apex

landrace: a locally developed kind of cultivar, without formal recognition, and usually much more variable than an official registered cultivar and from which usually several cultivars can be selected

lanose: woolly

lateral: on or at the side

latex: a juice, usually white and sometimes sticky, exuding from broken surfaces of some plants

lax: loose, distant

leaflet: one part of a compound leaf

lemma: the lower of the two glumes which surround each floret in the spikelet of grasses

lenticel: lenticular masses of loose cells protruding through fissures in the periderm on stems, fruits and roots, usually arising beneath individual stomata; their main function is gaseous exchange
lenticular: shaped like a double-convex lens
leucorrhoea: a whitish, viscid discharge from the female genitals
liana: a woody climbing vine
ligulate: possessing an elongated flattened strap-shaped structure or ligule
ligule: an elongated flattened strap-shaped structure; a membranous outgrowth on the upper surface of a grass leaf at the junction of the sheath and the blade which may be presented by a ridge or by a line of hairs; in palms it is a distal projection of the leaf sheath, often coriaceous
limb (botany): the expanded part of a tubular corolla, as distinct from the tube or throat; the lamina of a leaf or of a petal; the branch of a tree
linear: long and narrow with parallel sides
lingulate: tongue-shaped
lobe: any division of an organ or specially rounded division
lobed: divided, but not to the base
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 and bamboo 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 polythene cover is wrapped around the girdled branch; after adventitious roots grow out above the girdle, the layer can be separated
mass spectroscopy: a technique of analysis in which the molecules of a pure compound are subjected to bombardment with high energy electrons; the molecules of the sample are fragmented and separated according to their masses, producing a graphical 'fragmentation pattern'; the molecular structure of the compound can be derived from this pattern
membranaceous (membranous): thin and semi-transparant, like a fine membrane
membranous: thin and semi-transparent, like a fine membrane
mericarp: one of the separate halves or parts of a fruit, as in *Umbelliferae*
meristem: undifferentiated tissue of the growing point whose cells are capable of dividing and developing into various organs and tissues
merous (4-, 5- etc.): with 4, 5 etc. parts or numbers of sepals, petals etc.
mesocarp: the middle layer of the pericarp or fruit wall which is often fleshy or succulent
mesophyll: the interior parenchyma of a leaf
midrib: the main vein of a leaf which is a continuation of the petiole
miscibility: the capability of liquids of being mixed to form a homogeneous substance (see also: solubility)
monadelphous: of stamens, united into one group by their filaments
monocarp: a plant that flowers and fruits only once during its lifetime; the single carpel of an apocarpous fruit
monochasium: a cymose inflorescence where a pattern of a single lateral branch arising below the terminal flower is repeated
monocotyledon: angiosperm having a single cotyledon or seed-leaf
monoculture: the cultivation during an extended period of time of a single product to the exclusion of other possible uses of the land
monoecious: with unisexual flowers, but male and female flowers borne on the same plant
monoterpene: a terpene of molecular formula $C_{10}H_{16}$, e.g. limonene, myrcene and phellandrene; most monoterpenes are readily oxidized to coarse-smelling products, so essential oils containing them must be carefully preserved to minimize this tendency
monotypic: consisting of a single element, e.g. of a genus consisting of only one species
mucilage: a gelatinous substance that is similar to gum but that swells in water without dissolving and forms a slimy mass

mucilaginous: slimy
mucro: a sharp terminal point
mucronate: ending abruptly in a short stiff point
mulch: plant or non-living materials used to cover the soil surface with the object of protecting it from the impact of rainfall, controlling weeds, temperature and evaporation
muricate: rough, with short and hard tubercular excrescences
mycorrhiza: a symbiotic association of roots with a fungal mycelium which may form a layer outside the root (ectotrophic) or within the outer root tissue (endotrophic)
narcotic: pertaining to or producing narcosis or stupor; an agent that in moderate doses dulls the senses, relieves pain and induces sleep, but in excessive doses may cause stupor, coma, convulsions and death
naturalized: introduced into a new area and established there, giving the impression of wild growth
nectar: a sweet fluid exuded from various parts of the plant (e.g. by the flower to attract pollinators)
nectary: a group of modified subepidermal cells in flowers or leaves (extrafloral) secreting nectar
nematode: small elongated cylindrical worm-like micro-organism, free-living in soil or water, or parasitic in animals or plants
nerve: in botany: a strand of strengthening and/or conducting tissue running through a leaf, which starts from the midrib and diverges or branches throughout the blade
neuralgia: pain radiating along the course of one or more nerves
neuter: sexless, neither male or female; having neither functional stamens nor pistils
node: the point on the stem or branch at which a leaf or lateral shoot is borne
nucellar: belonging to the body of the ovule or macrosporangium containing the embryo sac or macrospore
nucellus: the nutritive tissue in an ovule
nut: a one- to many-seeded indehiscent fruit with a hard dry pericarp or shell
nutlet: a little nut
ob-: prefix, indication inverse or opposite condition (obtriangular, obcordate, etc.)
oblanceolate: reverse of lanceolate
oblique: slanting; of unequal sides
oblong: longer than broad, with the sides parallel or almost so
oblongoid: a solid object which is oblong in section
obovate: reverse of ovate
obovoid: a solid object which is obovate in section
obtuse: blunt or rounded at the end
offset (offshoot, rhizome cutting): a lateral shoot used for propagation
oil cell (anatomy): a parenchymatous idioblast filled with oil
oil gland: a glandular cell which secretes oil
oleoresin: a natural plant product consisting of a viscous mixture of mainly essential oil and non-volatile odourless solids
olfaction: the process of smelling
operculum: a lid or cover which separates by a transverse line of division
opposite: of leaves and branches when two are borne at the same node on opposite sides of the stem
optical activity: in organic chemistry, the property of a compound, containing an asymmetrical carbon atom, of rotating the plane of polarized light, clockwise in the case of dextrorotatory (abbreviated d-) compounds, and counterclockwise in the case of laevorotatory (abbreviated l-) compounds; in perfumery d- and l-compounds may have different odours, e.g. d- and l-limonene
optical isomerism: isomerism in which the molecular structures of the molecules are mirror-images of one another; optical isomers have the same structural formula, but their molecules cannot be superimposed
optical rotation: see optical activity
orbicular: flat with a more or less circular outline
oriental: in perfumery, a heavy and long-lasting perfume; ambergris-like and/or spicy notes combined with woody and balsamic tonalities are typical of this perfume family; middle notes are generally floral, topnotes tend to be contrastingly fresh and light
orifice: an opening by which spores, etc., escape; ostiole
orthotropic: having a more or less vertical direction of growth
outer bark: the periderm or rhytidome; the non-living layer of fibrous or corky tissue outside the cambium in woody plants which may be shed or retained
ovary: in plants, that part of the pistil, usually the enlarged base, which contains the ovules and eventually becomes the fruit
ovate: egg-shaped in outline or in section; a flat surface which is scarcely twice as long as broad with the widest portion below the middle
ovoid: a solid object which is egg-shaped (ovate in section)

ovule (botany): the immature seed (egg) in the ovary before fertilization
palea: the upper of two membranous bracts enclosing the flower in grasses
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
panduriform: fiddle-shaped, drawn in at the middle
panicle: an indeterminate branched racemose inflorescence
paniculate: resembling a panicle
pantropical: distributed throughout the tropics
papillate: having minute nipple-like protuberances
papillose: covered with minute nipple-like protuberances
pappus: the various tufts of hairs on achenes or fruits; the limb of the calyx of *Compositae* florets
papyraceous: papery, like paper
parasitic: deriving nourishment from some other organism
paratracheal: applied to wood-elements arranged about the vessels
parenchyma: in plants: ground tissue composed of thin-walled, relatively undifferentiated cells, e.g. the pith and mesophyll
paripinnate: a pinnate leaf with all leaflets in pairs
partite (parted): cleft, but not quite to the base
patent (botany): spreading out widely
pedicel: the stalk of an individual flower
pedicellate: furnished with a pedicel
peduncle: the stalk of an inflorescence or partial inflorescence
pedunculate: furnished with a peduncle
pellucid: translucent
peltate: of a leaf, with the stalk attached to the lower surface, not at the edge
pendent, pendulous: drooping; hanging down from its support
penninerved: pinnately veined, parallel veins arise at an angle from a midvein (as in Musa)
pentamerous: having five parts in a flower-whorl
perennial: a plant living for many years and usually flowering each year
perfect flower: a flower possessing both male and female organs
perfume: a harmonious composition prepared from natural and/or synthetic aromatic materials having aesthetic appeal alone, or after incorporation in an end-product
perianth: the floral leaves as a whole, including both sepals and petals if both are present
pericarp: the wall of the ripened ovary or fruit whose layers may be fused into one, or may be more or less divisible into exocarp, mesocarp and endocarp
persistent: remaining attached; not falling off, not deciduous; applies to organs that remain in place after they have fulfilled their natural functions
petal: a member of the inner series of perianth segments (corolla) which are often brightly coloured
petaloid: petal-like
petiolate: having a petiole
petiole: the stalk of a leaf
petiolule: the stalk of a leaflet
phenology: the complex annual course of flushing, quiescence, flowering, fruiting and leaf fall in a given environment
phenotype: the physical or external appearance of an organism as distinguished from its genetic constitution (genotype); a group of organisms with similar physical or external make-up
phloem: the principal food-conducting tissue of vascular plants; the bast element of a vascular bundle and basically composed of sieve elements, parenchyma cells, fibres and sclereids
photoperiod: the relative duration of illumination in a cycle of light and darkness, whether occurring naturally (day and night) or imposed in an artificial way
photosensitive: sensitive to the action of radiant energy such as light
phylogenetic: based on natural evolutionary and genealogical relationships
phytosanitary: of or relating to health or health measures of plants
pilose: hairy with rather long soft hairs
pilosellous: hairy with short soft hairs
pinna (plural: pinnae): a primary division or leaflet of a pinnate leaf
pinnate: arranged in pairs along each side of a common axis
pinnatifid: pinnately divided about halfway to the midrib
pinnatisect: pinnately divided down to the midrib
pistil: the female part of a flower (gynoecium) of one or more carpels, consisting, when complete, of one or more ovaries, styles and stigmas
pistillate: a unisexual flower with pistil, but no stamens
pistillode: a sterile, often reduced pistil
placenta: in plants, the part of the ovary to which

the ovules are attached

placentation: the way in which the placentae are arranged in the ovary

plagiotropic: having an oblique or horizontal direction of growth

ploidy: degree or repetition of the basic number of chromosomes

plumose: featherlike with fine hairs

plumule: the primary bud of an embryo or germinating seed

pod: a dry fruit composed of a single carpel and dehiscing by sutures, as in legumes; a general term for a dry dehiscent fruit

pollarding: cutting a tree back to the trunk to promote the growth of a dense head of foliage

pollen: spores or grains borne by the anthers containing the male element (gametophyte)

pollination: the transfer of pollen from the dehiscing anther to the receptive stigma

polyembryonic: with more than a single embryo in an ovule

polygamous: with unisexual and bisexual flowers in the same plant

polymorphic, polymorphous: with several or various forms; variable as to habit

polyploid: with more than two sets (genomes) of chromosomes in the somatic cells

pomade (pommade): the highly fragrant, essential-oil-soaked fat resulting from enfleurage, usually used for absolute production

posterior: next to or towards the main axis

poultice: a soft, moist, usually heated and sometimes medicated mass spread on cloth and applied to sores or other lesions to create moist local heat or counterirritation

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: in botany: the part nearest the axis (as opposed to distal)

pruinose: having a waxy powdery secretion on the surface, a bloom

pruning: cutting off the superfluous branches or shoots of a plant for better shape or more fruitful growth

puberulent: covered with down or fine hairs

puberulous: minutely pubescent

pubescent: covered with soft short hairs

pulp: the soft fleshy part of the fruit; mechanically ground or chemically digested wood used in manufacturing paper and allied products

pulvinus: 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: plant requiring short days to flower, (often with quantitative response); if the daylength surpasses a certain value (the critical daylength) the plant does not flower

quantitative short-day plant: plant flowering sooner under short-day conditions, but short days are not absolutely necessary to flower

raceme: an unbranched elongated indeterminate inflorescence with stalked flowers opening from the base upwards

racemose: raceme-like

rachilla: a diminutive or secondary axis, e.g. the branch that bears a flower or the stalk of the spikelet in grasses

rachis (plural: rachides): the principal axis of an inflorescence or a compound leaf beyond the peduncle or petiole

radical: arising from the root, or its crown

radicle: the first root of an embryo or germinating seed

rain forest: a tropical forest receiving an annual rainfall of at least 1800 mm, characterized by lofty evergreen trees forming a continuous canopy below which terrestrial herbs and shrubs are poorly developed

ray: the radiating branch of an umbel; the outer floret of an inflorescence of the *Compositae* with straplike perianth which differs from those in the centre or disk

receptacle (botany): the flat, concave or convex part of the axis from which the parts of the flower arise

reconstitution: the reproduction of an aromatic material of natural origin; it involves identification of the components of the natural product, followed by close matching of the results of the analysis using mainly cheaper synthetic aroma chemicals to produce an essentially convincing representation of costly natural products; some products, e.g. bergamot oil, have been reconstituted with astonishing success, while other odours, e.g. those of cassie oil and ylang-ylang oil are more difficult to reproduce

rectification: a second distillation of an essential oil with the purpose of removing non-volatile matter

recurved: bent or curved downward or backward

reflexed: abruptly bent or turned downward or backward

reforestation: the planting of a formerly forested area with forest trees

refractive index: the ratio of the sine of the angle of incidence to the sine of the angle of refraction when a beam of light passes from a vacuum (or the atmosphere) into the medium studied; this ratio is equivalent to the ratio of the velocity of light in free space to that in the medium

refrigerant: in medicine: an agent that relieves fever and thirst

regular: of a radially symmetrical flower; actinomorphic

reniform: kidney-shaped

resin: solid to soft semisolid amorphous fusible flammable substance obtained as exudate or as an extract of plants

resinoid: prepared by solvent extracting exudates, highly lignified plant material, or animal substances; incorrectly but commonly used when describing the physical condition of absolutes

reticulate: netted, as when the smallest veins of a leaf are connected together like the meshes of a net

retrorse: turned or directed backward or downward (opposed to antrorse)

revolute: of leaves with the margins, rolled downwards towards the midrib

rhizome: an underground stem which is distinguished from a root by the presence of nodes, buds, and leaves or scales

rhombic: shaped like a rhomb, an equilateral oblique-angled figure

rind: the tough outer layer of the fruit

root sucker: a shoot originating from adventitious buds on the roots

rootstock: see rhizome; a stock for grafting consisting of a root and part of the main axis

rosette: a cluster of leaves or other organs in a circular form

rostrum: a beak-like extension

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: scratching or making incisions, e.g. to harvest latex from Papaver somniferum; of seed, the cutting or softening of the wall of a hard seed to hasten germination

schizocarp: a dry fruit formed from a syncarpous ovary which splits into one-seeded portions, mericarps or 'split fruits'

sciophyte: shade-loving plant

scrub: vegetation whose growth is stunted because of lack of water coupled with strong transpiration

secondary vegetation: a plant cover that has been disturbed by natural causes or by man

secondary venation: the collection of veins of a leaf blade branching off from midrib in pinnately veined leaves, or from the main veins in palmately veined ones

section (botany): a taxonomic rank between the genus and the species accommodating a single or several related species

seed: the reproductive unit formed from a fertilized ovule, consisting of embryo and seed-coat, and, in some cases, also endosperm

seedling: a plant produced from seed; a juvenile plant, grown from a seed

segment: one of the divisions into which a plant organ, as a leaf or a calyx, may be cleft; the division of a palmate or costapalmate leaf

self-compatible: capable of fertilization and setting seed after self-pollination

self-fertile: capable of fertilization and setting seed after self-pollination

self-pollination: pollination with pollen from the same plant or from other flowers of plants of the same clone
self-sterile: failure to complete fertilization and obtain seed after self-pollination
semi-: prefix, meaning half or incompletely, e.g. semi-inferior
sepal: a member of the outer series of perianth segments
sepaloid: sepal-like
septate: divided by one or more partitions
septum (plural: septa): a partition or cross-wall
sericeous: silky
serrate: toothed like a saw, with regular pointed teeth pointing forwards
serrulate: serrate with minute teeth
sesquiterpene: a terpene of molecular formula $C_{15}H_{24}$, e.g. caryophyllene and farnesene
sessile: without a stalk
seta (plural: setae): a bristle-like body
setose: set with bristles or bristle-like elements
shaggy: villous
sheath: a tubular structure surrounding an organ or part, as the lower part of the leaf clasping the stem in grasses
shoot: the ascending axis, when segmented into dissimilar members it becomes a stem; a young growing branch or twig
shrub: a woody plant which branches from the base, all branches being equivalent (see also tree)
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 of 4°C
spherical: globular
spicate: spike-like
spiciform: with the form of a spike
spicule: a fine, fleshy or brittle, needlelike spine
spike: a simple indeterminate inflorescence with sessile flowers along a single axis
spikelet: a secondary spike, one of the units of which the inflorescence is made in grasses, consisting of one or more florets on a thin axis, subtended by a common pair of glumes
spine (botany): a short, stiff, straight, sharp-pointed, hard structure usually arising from the wood of a stem
spinescent: ending in a spine or sharp point
spinose, spinous: having spines
spiral: as though wound round an axis
spur: in botany: a hollow and slender extension of some part of the flower, usually nectariferous; a small reproductive shoot; in forestry: a buttress-like projection of a tree trunk
squamose: scaly
stamen: one of the male reproductive organs of a flower; a unit of the androecium
staminate: a flower bearing stamens but no pistil
staminode: an abortive or rudimentary stamen without or with an imperfect anther
steam distillation: distillation using steam injected under pressure into a distillation vessel
stellate: star-shaped, as of hairs with radiating branches, or of petals arranged in the form of a star
stem: the main ascending axis of a plant; in bamboos usually named culm, in other plant groups occasionally
stereoisomerism: isomerism in which 2 or more compounds have the same molecular and structural formula, but differ in the spatial arrangement of the atoms in their molecules (see also: geometrical or cis-trans isomerism and optical isomerism)
sterile: unable to produce offspring; in plants: failing to complete fertilization and produce seed as a result of defective pollen or ovules; not producing seed capable of germination; lacking functional sexual organs (sterility)
stigma: the portion of the pistil which receives the pollen
still: an apparatus for distillation
stipe: the stalk supporting a carpel or gynoecium
stipitate: borne on a stipe or short stalk
stipule: a scale-like or leaf-like appendage at the base of a petiole
stolon: a trailing stem usually above the ground which is capable of producing roots and shoots at its nodes
stoloniferous: bearing a stolon or stolons
stoma (plural: stomata): a breathing pore or aperture in the epidermis

stomachic: pertaining to the stomach; a medicine stimulating the action of the stomach
stone: the hard endocarp of a drupe containing the seed or seeds
strain: a group of individuals of a common origin, usually a more narrowly defined group than a cultivar
striate: marked with fine longitudinal parallel lines, as grooves or ridges
strigose: with short stiff hairs lying close along the surface
stump: seedling with trimmed roots and shoot and used as planting stock; the part of anything that remains after the main part has been removed, e.g. the part of a tree remaining attached to the root after the trunk is cut
style: the part of the pistil connecting the ovary with the stigma
sub-: prefix, meaning somewhat or slightly (e.g. subacute), or below (e.g. subterranean) or less than, imperfectly
subfamily: a taxonomic rank between the family and the tribe denoting a part of a family
subglobose: nearly globular
subspecies: a subdivision of a species, in rank between a variety and a species
subulate: awl-shaped, sharply pointed
succulent: juicy, fleshy
sucker: a shoot, usually originating from adventitious buds on the roots or basal stem parts, which does not fit in the architectural model, but is capable of repeating the model
sudorific: causing or promoting the flow of sweat; an agent causing sweating
sulcate: grooved or furrowed
superior: of an ovary, with the perianth inserted below or around its base, the ovary being attached at its base only
supra-axillary: growing above an axil
sympetalous: with united petals
sympodial: of a stem in which the growing point either terminates in an inflorescence or dies, growth being continued by a new lateral growing point
syncarp: a multiple or fleshy aggregate fruit, including fruit produced from a more or less entire inflorescence (as in *Artocarpus*, *Ananas*, *Morus*)
syncarpous: of an ovary composed of two or more united carpels
tail (botany): any long and slender prolongation
tangential: lengthwise, in a plane at right angles to the radius but not passing through the pith (cf. radial)
taproot: the primary descending root, forming a direct continuation of the radicle
taxon (plural: taxa): a term applied to any taxonomic unit irrespective of its classification level, e.g. variety, species, genus, etc.
taxonomy: the study of principles and practice of classifying living organisms (systematics)
tendril: a thread-like climbing organ formed from the whole or part of a stem, leaf or petiole
tepal: a segment of a perianth, applied when no distinction between sepals and petals can be made
terete: cylindrical; circular in transverse section
terminal: placed at the end or apex; a termination, end or extremity
terpene: an unsaturated hydrocarbon of molecular formula $(C_5H_8)_n$. In monoterpenes n=2, in sesquiterpenes n=3. The term terpene is often used to refer to a terpenoid
terpenoid: a chemical compound derived from a terpene
terrestrial: on or in the ground
tertiary venation: generally the collection of the smallest veins of a leaf blade
testa: the outer coat of the seed
tetradynamous: of a flower, having four long stamens and two short ones, as in *Cruciferae*
tetraploid: having four times ($4n$) the basic number of chromosomes or twice the diploid number ($2n$)
thorn: a woody sharp-pointed structure formed from a modified branch
throat (botany): of a corolla, the orifice of a gamopetalous corolla
thyrse (thyrsus): a compound inflorescence composed of a panicle (indeterminate axis) with the secondary and ultimate axes cymose (determinate)
tiller: a shoot from the axils of the lower leaves, e.g. in some grasses and palms (making such shoots: tillering)
timber: any wood other than fuelwood
tissue culture: a body of tissue growing in a culture medium outside the organism
tomentellous: minutely tomentose
tomentose: densely covered with short soft hairs
tomentum: pubescence
tonic: restoring or producing the normal tone (degree of vigour and tension) of tissue or organs; characterized by continuous tension (e.g. tonic spasm); medicinal preparation believed to have the power of restoring normal tone to tissue or organs
top note: the first odour impression given by an aromatic material when smelled

tree: a perennial woody plant with a single evident trunk (see also shrub)
triad: a group composed of 3 elements; a special group of 2 lateral staminate and a central pistillate flower, structurally a short cincinnus
tribe: a taxonomic rank between the family and the genus
trichome: any hair, bristle or scale-like outgrowth of the epidermis
trifid: cleft in three parts
trifoliate: three-leaved
trifoliolate: with three leaflets
trigonous: three-angled, with plane faces
truncate: cut off more or less squarely at the end
trunk: the main stem of a tree apart from its limbs and roots
tuber: the swollen portion of an underground stem or root which acts as a storage organ and propagule; it is usually of one year's duration, those of successive years not arising directly from the old ones nor bearing any constant relation to them
tuberculate: covered with warty protuberances
tuberous: producing tubers or resembling a tuber
tufted: growing in tufts (caespitose)
turgid: swollen, but not with air
umbel: an indeterminate, often flat-topped inflorescence whose divergent peduncles (rays) and pedicels arise from a common point; in a compound umbel each ray itself bears an umbellule (small umbel)
umbellet (umbellule): diminutive of umbel
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 (botany): a strand of vascular tissue in a flat organ, such as a leaf
velutinous: see velvety
velvety: with a coating of fine soft hairs; the same as tomentose but denser so that the surface resembles (and feels like) velvet
venation (botany): the arrangement of the veins in a leaf
ventral: in botany: facing the central axis (adaxial), opposed to dorsal (abaxial)
vermifuge: an agent expelling worms or intestinal animal parasites; an anthelminthic
verrucose: warty
versatile (botany): turning freely on its support, as anthers on their filaments
verticil: whorl
verticillaster: a false whorl, composed of a pair of opposed cymes, as in *Labiatae*
verticillate: in a whorl with several elements arising at the same node
vesicular: bladder-like
vestigial: small and imperfectly developed
viability: ability to live, grow and develop
villose (villous): with long weak hairs
villous: bearing long weak hairs
vine: a plant having a stem that is too slender to hold itself erect and therefore supports itself by climbing over an object
viscid: sticky
viscous: glutinous, or very sticky
vitta (plural: vittae): an aromatic oil duct of the pericarp of most *Umbelliferae*
volatile: a volatile substance is one that evaporates at room temperature. It is an essential property of odorous materials
warty: covered with firm roundish excrescences
water distillation: a form of distillation in which an aromatic plant material is treated with boiling water to release, vaporize and subsequently condense the essential oil it contains; neroli oil is water distilled from citrus flowers to prevent clumping of the petals, which would occur under steam distillation
waterlogged: flooded with water, generally for a period of at least a few weeks
wax: waxes are mixtures of esters of higher alcohols and higher fatty acids. Waxes are used as stiffening agents in the manufacture of cosmetics. Natural plant waxes are removed from con-

cretes to produce absolutes

whorl: arrangement with more than two organs of the same kind arising at the same level

wind-break: one to several rows of closely spaced, preferably low branching trees planted to protect adjacent areas from strong winds

wing: any membraneous expansion attached to an organ; a lateral petal of a papilionaceous corolla

wood: the hard, compact, fibrous substance between pith and bark

woolly: clothed with long and tortuous or matted hairs

xylem: the main water-conducting tissue in vascular plants which extends throughout the body of the plant and is also involved in transport of minerals, food storage and support; primary xylem is derived from the procambium, secondary xylem (e.g. the wood of trees and shrubs) from the vascular cambium; xylem is composed of tracheary elements: tracheids and (in angiosperms) vessel elements; both are elongated hollow cells, with thickened, usually heavily lignified walls, and lacking protoplasts when mature; they are joined end to end to form a continuous conducting tube

zygomorphic: irregular and divisible into equal halves in one plane only

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Index of scientific plant names

Page numbers printed in bold refer to main treatment.

Index of vernacular plant names

Page numbers printed in bold refer to main treatment. For transcriptions of Vietnamese names, see at the end of the index.

Transcriptions of Vietnamese characters

[aa] = â	[ar] = ả	[ax] = ã	[ej] = ẹ	[oo] = ô	[ow] = ơ	[uj] = ụ	[uwx] = ữ
[aaf] = ầ	[as] = á	[ee] = ê	[er] = ẻ	[oof] = ồ	[owf] = ờ	[ur] = ủ	[ux] = ũ
[aaj] = ậ	[aw] = ă	[eef] = ề	[es] = é	[ooj] = ộ	[owj] = ợ	[us] = ú	
[aar] = ẩ	[awf] = ằ	[eej] = ệ	[ex] = ẽ	[oor] = ổ	[owr] = ở	[uw] = ư	
[aas] = ấ	[awj] = ặ	[eer] = ể	[if] = ì	[oos] = ố	[ows] = ớ	[uwf] = ừ	
[aax] = ẫ	[awr] = ẳ	[ees] = ế	[is] = í	[oox] = ỗ	[owx] = ỡ	[uwj] = ự	
[af] = à	[aws] = ắ	[eex] = ễ	[of] = ò	[or] = ỏ	[ox] = õ	[uwr] = ử	
[aj] = ạ	[awx] = ẵ	[ef] = è	[oj] = ọ	[os] = ó	[uf] = ù	[uws] = ứ	

The Prosea Foundation
(Plant Resources of South-East Asia)

Name, location, legal status and structure

- Prosea is a Foundation under Indonesian law, with an international charter, domiciled in Bogor. It is an autonomous, non-profit, international agency, governed by a Board of Trustees. It seeks linkage with existing regional and international organizations;
- Prosea is an international programme focusing on the documentation of information on plant resources of South- East Asia;
- Prosea consists of a Network Office in Bogor (Indonesia) coordinating 6 Country Offices in South-East Asia, and a Publication Office in Wageningen (the Netherlands).

Participating institutions

- Forest Research Institute of Malaysia (FRIM), Karung Berkunci 201, Jalan FRIM Kepong, 52109 Kuala Lumpur, Malaysia;
- Indonesian Institute of Sciences (LIPI), Sasana Widya Sarwono, Jalan Gatot Subroto 10, Jakarta 12710, Indonesia;
- Institute of Ecology and Biological Resources (IEBR), Hoang Quoc Viet Road, 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;
- PHOTFILE: photographs of useful plants of South-East Asia.

Publication

The handbook in blue cover (hardbound) is distributed by Backhuys Publishers, Leiden, the Netherlands (formerly by Pudoc, Wageningen, the Netherlands). The handbook in green cover (paperback) is distributed in two price-classes: a low-price paperback, distributed by Prosea South-East Asia for all developing countries; a medium-price paperback, distributed by Backhuys

Publishers, Leiden, the Netherlands, and by Prosea South-East Asia for developed countries (becoming available two years after publication of the hardbound edition). The bibliographies are distributed by Prosea South-East Asia.

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- 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.
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In brief, Prosea is

- an international programme, focused on plant resources of South-East Asia;
- interdisciplinary, covering the fields of agriculture, forestry, horticulture and botany;
- a research programme, making knowledge available for education and extension;
- ecologically focused on promoting plant resources for sustainable tropical land-use systems;
- committed to conservation of biodiversity;
- committed to rural development through diversification of resources and application of farmers' knowledge.

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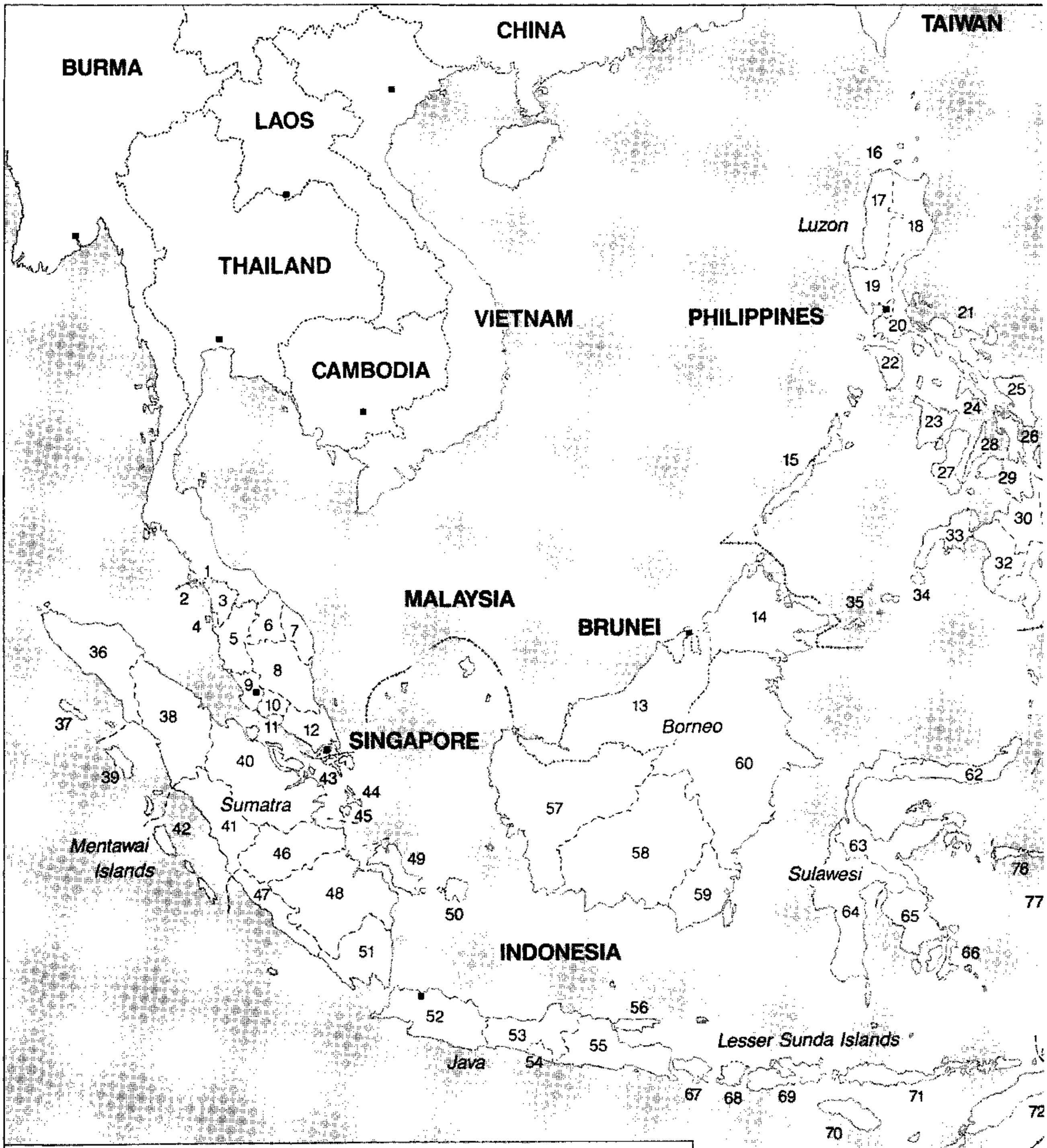
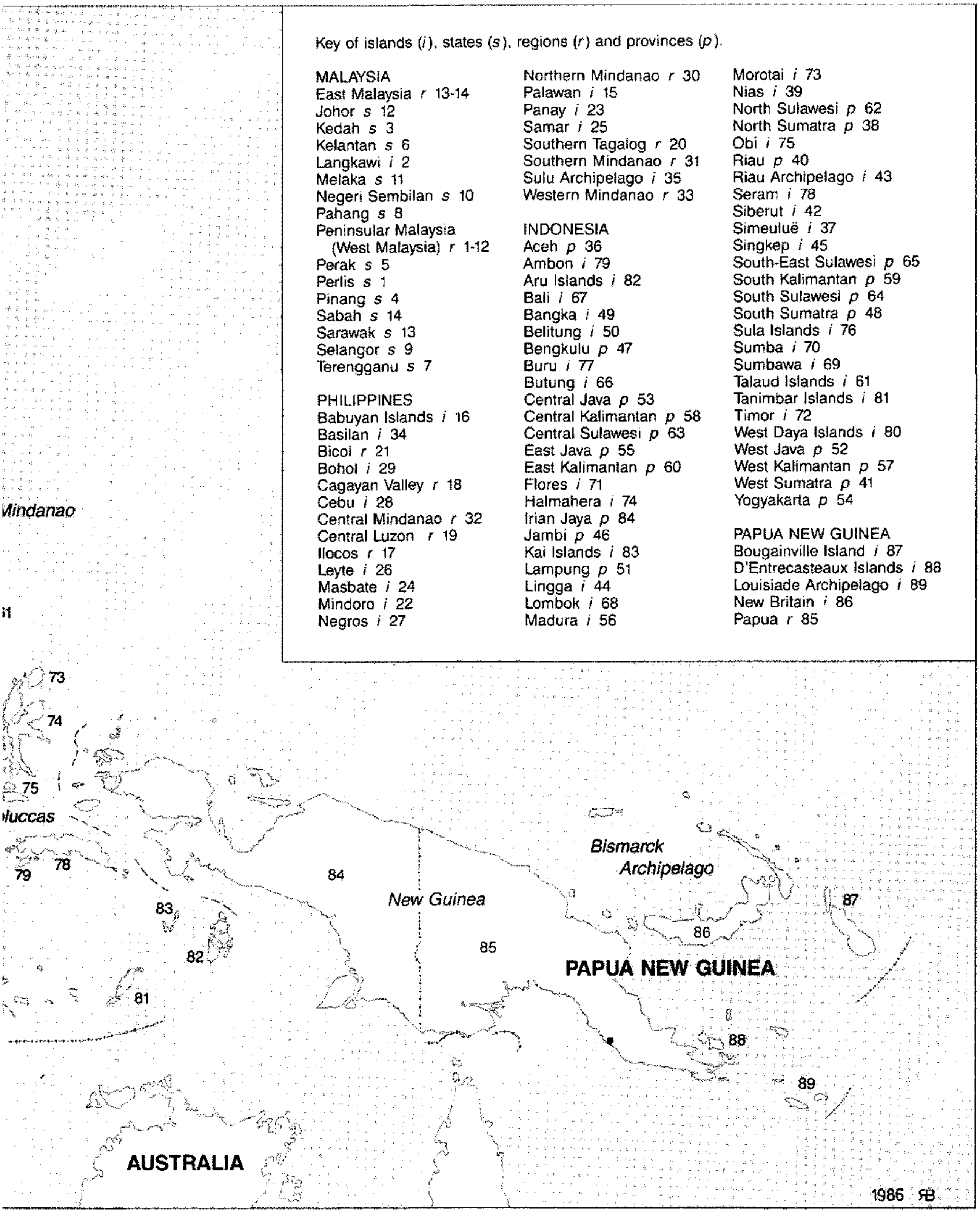


MAP OF SOUTH-EAST ASIA FOR PROSEA

Names of countries in capital letters and islands in lower case; numbers refer to the key.


Key of islands (i), states (s), regions (r) and provinces (p).
MALAYSIA
East Malaysia r 13-14
Johor s 12
Kedah s 3
Kelantan s 6
Langkawi i 2
Melaka s 11
Negeri Sembilan s 10
Pahang s 8
Peninsular Malaysia (West Malaysia) r 1-12
Perak s 5
Perlis s 1
Pinang s 4
Sabah s 14
Sarawak s 13
Selangor s 9
Terengganu s 7
PHILIPPINES
Babuyan Islands i 16
Basilan i 34
Bicol r 21
Bohol i 29
Cagayan Valley r 18
Cebu i 28
Central Mindanao r 32
Central Luzon r 19
Ilocos r 17
Leyte i 26
Masbate i 24
Mindoro i 22
Negros i 27
Northern Mindanao r 30
Palawan i 15
Panay i 23
Samar i 25
Southern Tagalog r 20
Southern Mindanao r 31
Sulu Archipelago i 35
Western Mindanao r 33
INDONESIA
Aceh p 36
Ambon i 79
Aru Islands i 82
Bali i 67
Bangka i 49
Belitung i 50
Bengkulu p 47
Buru i 77
Butung i 66
Central Java p 53
Central Kalimantan p 58
Central Sulawesi p 63
East Java p 55
East Kalimantan p 60
Flores i 71
Halmahera i 74
Irian Jaya p 84
Jambi p 46
Kai Islands i 83
Lampung p 51
Lingga i 44
Lombok i 68
Madura i 56
Morotai i 73
Nias i 39
North Sulawesi p 62
North Sumatra p 38
Obi i 75
Riau p 40
Riau Archipelago i 43
Seram i 78
Siberut i 42
Simeuluë i 37
Singkep i 45
South-East Sulawesi p 65
South Kalimantan p 59
South Sulawesi p 64
South Sumatra p 48
Sula Islands i 76
Sumba i 70
Sumbawa i 69
Talaud Islands i 61
Tanimbar Islands i 81
Timor i 72
West Daya Islands i 80
West Java p 52
West Kalimantan p 57
West Sumatra p 41
Yogyakarta p 54
PAPUA NEW GUINEA
Bougainville Island i 87
D'Entrecasteaux Islands i 88
Louisiade Archipelago i 89
New Britain i 86
Papua r 85
Mindanao
73
74
75
Moluccas
79
78
84
New Guinea
85
83
82
81
Bismarck Archipelago
86
87
PAPUA NEW GUINEA
88
89
AUSTRALIA
1986 RB