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Herbs, spices and essential oils

Post-harvest operations in developing countries

UNITED NATIONS
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FOOD AND AGRICULTURE
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UNITED NATIONS

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
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This publication has not been formally edited.

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PREFACE

There is a continuing and expanding international demand for herbs, spices and essential oils. Social changes, including food diversification, the desire for new flavours, increasing importance of "ethnic" food and the increased importance of processed food, which requires condiments and aromatic herbs for its preparation, are driving an increase in this demand. Developing countries have a significant opportunity to benefit from this increasing demand. Many of the products can be sold in a dried form or as extracts (e.g. essential oils), which gives them a high value per unit weight. These products could be a profitable source of diversification for small farmers in developing countries.

It is in this connection that FAO and UNIDO decided to support this publication to give extension services and small-scale producers basic information on processing herbs and spices in view of increasing the awareness on this area of industry and improving the quality and marketability of these products.

Spices and condiments are defined as "Vegetable products or mixtures, free from extraneous matter, used for flavouring, seasoning or imparting aroma in foods." Herbs are a subset of spices, generally derived from fresh or dried leaves, but in this guide no distinction is made between spices and herbs, in keeping with the International Standards Organization (ISO) definition. Essential oils or extracts are also derived from these plant sources either as a primary processing or a secondary opportunity.

This guide is a broad introduction to generic post-harvest operations, which are often the limiting factors in the establishment of a profitable production enterprise based around herbs, spices and essential oils in developing countries. It is not intended to replace specialist and specific crop advice in production and post harvest processing which is available in publications and from experts.

This guide was prepared by M. Douglas, J. Heyes and B. Smallfield of the New Zealand Institute for Crop and Food Research Inc. assisted with revisions by F. Mazaud (FAO) and C. Jenane (UNIDO). Special thanks to Ms. E. Jaklitsch, Ms. G. Garcia Nieto and Ms. V. Durand-Vuaille for the final editing and lay out of the guide.

1 Introduction

Spices are used for flavour, colour, aroma and preservation of food or beverages. Spices may be derived from many parts of the plant: bark, buds, flowers, fruits, leaves, rhizomes, roots, seeds, stigmas and styles or the entire plant tops. The term 'herb' is used as a subset of spice and refers to plants with aromatic leaves. Spices are often dried and used in a processed but complete state. Another option is to prepare extracts such as essential oils by distilling the raw spice material (wet or dry), or to use solvents to extract oleoresins and other standardized products. There are many texts which provide an overview of the industry in general [1], [2], [3], [4] or for specific crops, [5-7].

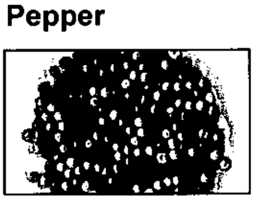
Essential oils are liquid products of steam or water distillation of plant parts (leaves, stems, bark, seeds, fruits, roots and plant exudates). Expression is used exclusively for the extraction of citrus oil from the fruit peel, because the chemical components of the oil are easily damaged by heat. Citrus oil production is now a major by-product process of the juice industry. An essential oil may contain up to several hundred chemical compounds and this complex mixture of compounds gives the oil its characteristic fragrance and flavour. An essential oil may also be fractioned and sold as individual natural components. Other processing options can also produce further products that can be sold alongside essential oils. The plant parts can be extracted with organic solvents to produce oleoresins, concretes and absolutes or extracted with a near or supercritical solvent such as carbon dioxide to produce very high quality extracts. These oleoresins and extracts contain not only the volatile essential oil but also the concentrated non-volatile flavour components and these have wide application in the food and pharmaceutical industries. The solvent extraction processes are more difficult and complex than steam distillation and will normally be beyond the financial resources of most small scale processors, but supplying the raw materials to these extraction plants can be a market option.

The most important spices traditionally traded throughout the world are products of tropical environments. The major exceptions to this group are the capsicums (chilli peppers, paprika), and coriander which are grown over a much wider range of tropical and non-tropical environments. Production of spices and essential oils in these wet and humid environments brings special difficulties for crop and product management. Drying the crop to ensure a stable stored product is of particular importance, and in wet humid environments this creates the need for efficient and effective drying systems.

2 Major spice crops in world trade

In terms of world trade value, the most important spice crops from the tropical regions are pepper, capsicums, nutmeg/mace, cardamom, allspice/pimento, vanilla, cloves, ginger, cinnamon and cassia, and turmeric. Coriander, cumin, mustard, and sesame seeds and the herbs sage, oregano, thyme, bay and the mints are the most important spice crops from non-tropical environments. The characteristics and environmental needs of the crops dominating the global spice trade are described below.

Pepper



Pepper (*Piper nigrum*) is a perennial vine, which produces a small berry fruit, which is dried to become pepper. Pepper is a plant of the humid tropics requiring adequate rainfall and warmth for its growth. It is grown successfully between latitudes of 20° North and 20° South and from sea level up to an altitude of 2400m. The crop can tolerate a temperature range between 10° and 40°C but the optimum is between 25°C-40°C. A well-distributed rainfall in the range of 1250mm-2000mm is considered necessary for pepper production.

Capsicums, Chilli peppers and Paprika

Capsicums (*Capsicum annuum* var. *annuum; C. chinense; C. frutescens*) are the dried and processed fruit of these annual peppers. A rainfall of 600-1250mm is desirable. Rainfall is needed over the growing season but is not needed as the fruits ripen. Heavy rain during flowering adversely affects pollination and wetness at ripening encourages fungal spoilage. Capsicums flourish in warm sunny conditions, require 3-5 months with a temperature range of 18°C-30°C; below 5°C growth is retarded, and frost kills plants at any growth stage. A seedbed temperature of 20-28°C is the optimum for germination.

Nutmeg, Mace and By-products

The perennial **nutmeg tree** (*Myristica fragrans*) grows to a height of 20m. Nutmeg is the kernel of the seed, while mace is the net like crimson coloured leathery outer growth (aril) covering the shell of the seed. The tree requires an optimal growing temperature between 20-30°C and the annual rainfall should be between 1500-2500mm.

Cardamom

Cardamom (*Elettaria cardamomum*; *E. major*; *E. speciosa*) is a tall growing (<5m) perennial herb and the fruit, borne on panicles at the base of the plants, is a trilocular capsule that contains 15-20 seeds. The natural altitudinal growing range is between 750-1500m while the most productive cultivated zone is between 1000 and 1200m. The annual rainfall is usually 2500-4000mm in the monsoon belt. A temperature range of 10-35°C occurs over the production areas with a lower limit of about 17°C and an optimum temperature between 22-24°C favoured. Cardamom grows naturally in shade but will produce good yields in only partial shade if well watered.

Allspice – Pimento

Allspice (*Pimenta dioica*) is a forest tree cultivated to produce the dried fruit berries which are the product allspice. It grows in semi-tropical lowland forests with a mean temperature of 18-24°C and an annual rainfall of 1500-1750mm. Evenly spread rainfall is desirable but trees will grow well with rainfall between 1200-2500mm.

Vanilla

Vanilla (*Vanilla planifolia,* Mexican vanilla); *V. pompona* (West Indian vanilla); *V. tahitensis* (Tahitian vanilla) are perennial vines which produce vanilla beans. Vanilla grows well in humid tropical climates with a well-distributed annual rainfall of 1900 – 2300mm but with no prolonged dry period. A warm humid climate with temperatures ranging between 24°C-30°C is preferred with a mean close to 27°C.

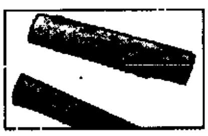
Cloves

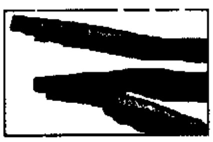
The **clove tree** (*Syzygium aromaticum*) is an evergreen which grows up to 15m in height. The clove tree produces buds which are used whole or ground as a spice. Bud and stem oils and oleoresins, and leaf oil, are used principally as a source of eugenol. An optimal rainfall is 1750-2500mm, with a dry season and a temperature range of 15-30°C in a maritime environment.

Ginger

Ginger (*Zingiber officinale*) rhizome is the source of the most important ginger products which are dried rhizome, whole or ground as spice with ginger oil and oleoresins used as flavourings. A well-distributed yearly rainfall of 2500-3000mm is the optimum with a minimum rainfall of 1500mm. The crop flourishes under warm sunny conditions but day temperatures above 30°C can cause leaf scorching while temperatures above 37°C without humidity and water can cause plant death. Ground temperatures of 25-30°C are optimum for initial rhizome growth. Frost will kill the foliage and rhizomes near the surface but altitude as such is not a constraint to ginger production.

Cinnamon and Cassia





Cinnamon and **cassia** spices (*Cinnamomum verum; Cinnamomum cassia* (China); *C. burmannii* (Indonesia), and *C. loureirii* (Vietnam), are the prepared dried bark of the trees belonging to the genus *Cinnamomum.* Cinnamon is the hardiest among the tree spices, tolerating a wide range of soil and climatic conditions. The optimum climate has an average temperature between 27-30°C and 2000-2500mm of rainfall. Cinnamon is an evergreen tree that is kept to a height of 2-3m. The soil conditions are very important, as waterlogged soil will produce a bitter cinnamon bark.

Turmeric

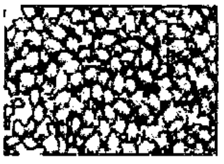
Turmeric (*Curcuma longa*) is a plant of open forests with partial or intermittent shade desirable, although recent research has shown crop yields can be higher in open cultivation. An annual rainfall between 1000-2000mm is necessary with 1500mm being optimum. Adequate soil moisture is the most significant factor affecting rhizome yield, the target product. Temperature is important, as the optimum varies with crop growth. High heat (30-35°C) is needed to encourage sprouting, 25-30°C during tillering, 20-25°C as rhizomes appear and 18-20°C during enlargement.

The major spice crops outside the tropical environments are the flower stigma of saffron, the fruits ("seeds") of coriander and cumin, seed of mustard and sesame, and the leaves of bay, sage, origanum and thyme.

Saffron

Saffron (*Crocus sativus*) is a sterile hybrid and re-propagates annually by producing replacement daughter corms. The dried tri-lobed stigma of the saffron crocus flower is the commercial product. The autumn flowering saffron grows best in Mediterranean environments with cool moist winters and hot dry summers, and under this type of environment strategic irrigation will aid flower production.

Coriander



Coriander (*Coriandrum sativum*) is a strong smelling annual herb extensively grown in many climates throughout the world. In commerce, coriander is broadly divided into two types according to the size of the fruit, which in turn determines the volatile oil content and end use. The small fruited type var. *microcarpum* (diameter 1.5-3mm) is grown widely in cooler temperate regions while the larger fruited type var. *vulgare* (diameter 3-5mm) is grown in tropical and subtropical environments. The small-fruited types contain higher oil (0.5-2%), which is extracted for its essential oil while the larger fruit with a lower oil (<1%), is used for grinding and blending. The fresh leaf (cilantro) is used in Asian cuisine.

Cumin

Cumin (*Cuminum cyminum*), a small annual herb native to the Mediterranean region, which is grown for its aromatic dried fruit that is widely used in cooking. Cumin prefers areas with low atmospheric humidity during the period of flowering, seed formation and ripening.

Mustard seed

White **Mustard** (*Sinapis alba*) and Indian mustard (pictured; *Brassica juncea*) are annual or biennial herbs. They are cultivated world-wide for dried ripe seeds, and used extensively in prepared mustards or in food products. The extracted mustard oil is also widely used as a food flavour ingredient.

Sesame seed

Sesame (*Sesamum indicum*), an annual herb, is now widely grown between 25°N and 25°S and can be grown to 40°N and 35°S. Sesame is grown for its seed in a wide range of environments from tropical to temperate and needs mean temperatures above 10°C and to 40°C maximum. The plant is killed by frost and, depending on cultivar, matures within 40 to 180 days.

In addition to the major spice crops listed above is detailed in Appendix I, Tables 1-5, the climatic range for 275 herb, spice and essential oil crops as per FAO website (http://ecocrop.fao.org). The Köppen biome classification for these growing regions is shown at: http://www.fao.org/waicent/faoinfo/sustdev/eldirect/climate/Elsp0054.htm.

3 Economic Impact and Trade

There are around 40 to 50 spices of global economic and culinary importance. There are also many other species that are used in traditional cooking in the region of their natural occurrence but have yet to reach any significant trade [8]. The major spices of international trade have well known stable long-term markets but most species tend to be commodities and as such there is competition and price fluctuations. The value of global spice imports is estimated at US$2 to 2.4 billion and in 2002 pepper topped the list with 20% of the total value followed by capsicum (18%), vanilla (13%), nutmeg/mace/cardamom (9%), spice seeds (8%) and ginger (6%). The major spice production is in the tropics from developing and least developed countries. There is also a very significant domestic consumption of spices in many spice-producing countries. The supply side of the industry has always been dynamic and has been punctuated by periodic relocations of the major production areas. To remain competitive, countries such as India are moving into the value-added sector, producing spice, essential oils, oleoresins, powders, speciality extracts and blends. *In addition, India has established spice Agri-Export Zones and they are* actively developing capabilities in quality management, improved packaging and technology innovation in production and processing. The largest spice importer is the European Union (with Germany being the leading country in the EU). The USA and Japan are the two largest single country importers of spices. In the EU countries, 55-60% of the total spice and herb use is for industrial consumption, 35-40% by the retail sector and 10-15% by the catering sector. The high industrial sector use reflects the growing popularity of ready-to-use spice mixtures. Another reason is the increasing consumption of processed foods and ready to eat dishes, which often rely on spices and herbs to retain and enhance food flavour.

The ever more stringent regulations governing the international trade in spices and their derivatives for culinary use in food processing will mean that spice producers who ignore such specifications will eventually lose their markets to quality producers. For example, the EU (European Union) has aflatoxin regulations to detect contaminated consignments and restrict their import while adulteration of spices with colourants has led to product bans.

Some two hundred essential oils are produced and traded internationally in volumes that range from 20-30,000 tonnes for orange oil to less than 100 kg for some specialty flower extracts. Prices vary widely, but for the majority of oils traded in volume, they fall within the range of US$4-$60/kg and for specialist minor oils, the price can be many hundreds of US$/kg. The citrus oils (orange, lemon, tangerine, lime, manadarin, grapefruit etc.) plus the mint oils have by far the largest number of important applications in tonnages as well as variety of flavours. The seasoning oils of spices and herbs (clove bud, coriander, cinnamon, garlic, nutmeg, onion etc) are traded in lesser quantities and have more selected applications. The majority of other oils are used in even lower quantities and have more targeted applications.

Estimating world production and trade of essential oils is fraught with difficulties [9]. In many countries domestic production statistics are not recorded and export statistics are recorded for some of the high volume oils and the rest are often included in codes that encompass a range of products. Therefore publications of global production must be treated with a high degree of suspicion as they are based on limited statistical data from a few countries and generally ignore factors such as domestic consumption.

Mature markets, where demand for essential oils is highly developed, have low potential growth because of low population growth. The European Union is the world's biggest importer of essential oils (with France, Germany and UK being the major importing countries). The USA is the world's largest importing country of essential oils followed by Japan. Most of the oils go into mainstream industries and the number of mainstream users continues to decline through mergers and acquisitions. Aromatherapy is seen as a potential high value growth area; however, it represents less than 1-2% of the total essential oil trade. It is predicted that the growth in essential oils will be led by the flavour oils [10]. Use of essential oil for perfume and fragrance applications is predicted to reduce. Derivatives of dual–purpose and industrial oils will be imported from processing factories located in oil producing countries rather than from imported oils.

The growth markets for uses of essential oils are predicted to be in the rapidly developing countries (dominated by China and India), Eastern Europe and Russia and less developed countries. Long-term, the amounts consumed in these growing markets is predicted to exceed the current consumption of the industrialised countries. Demand is predicted to be greatest for low-value fragrance oils used in soaps, detergents and related products with smaller growth in the flavour oils, mainly for non alcoholic beverages (citrus and spice oils) and oral care products (mint oils). A growth in use of flavour oils in the processed food industries will be confined mainly to developing countries with growing middle class populations.

The trade distribution structure in the spice and herb trade can be divided into lines of supply to the three broad market sectors – industrial, catering and retail (Figure 1). The structure of the supply tree shows there are a number different routes to market, and the most direct is the producer supplying directly to the industrial sector. It is estimated that about 85% of the international trade of herbs and spices is dried and cleaned for use in a crude form without further processing.

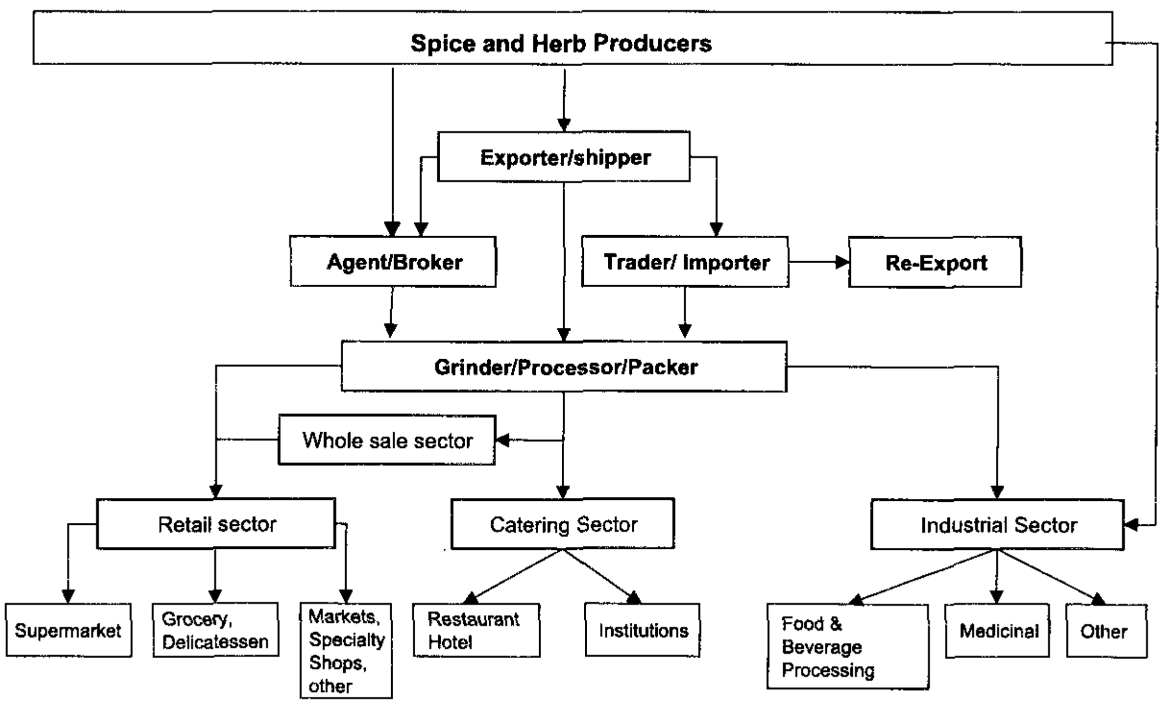


Figure 1: Trade distribution structure for spices and spice products.

The world trade for the major spice products shows that pepper is the most valuable spice in the global trade, with capsicum trade rising to higher annual tonnage but lesser value (Appendix II, Table 6).

The top three exporting countries for specific spices or groups of spices show the leading producing countries are in tropical environments, while countries in summer dry Mediterranean or continental environments are the major producers of spice fruits and seeds, saffron, thyme and bay leaves (Appendix II, Table 7). The major spice trading countries are China, Madagascar, Indonesia and India while Guatemala, Brazil, Vietnam and Sri Lanka are significant traders. The value of that trade varies annually, and fluctuates about $US2.5 billion (Appendix II, Table 8).

Closely linked to the spice and herb trade is the extraction of flavour and aroma compounds in essential oils. The trade distribution for essential oils and oleoresins can also have a number of routes to market. The most simple is the small oil producer selling to the local market or to tourists while the large-scale producers would normally deal through fragrance and flavour house formulators. There are many manufacturing industries where the extracts of spices, herbs, and aromatic resins are used for flavour, aroma or product formulation (Figure 2).

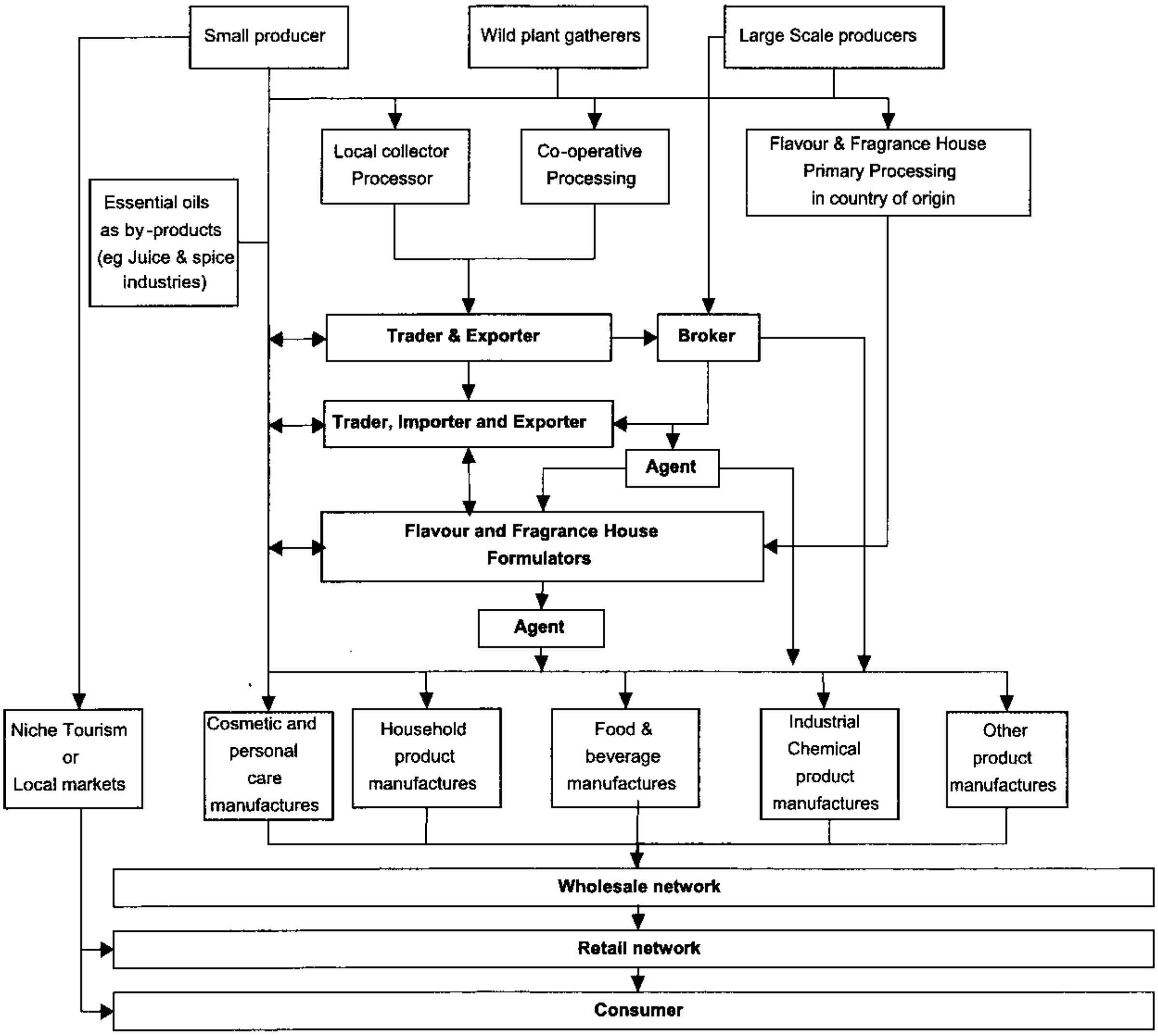


Figure 2: Trade distribution structure for essential oils and oleoresins.

The steam distilled essential oils or solvent-soluble oleoresins are primarily extracted from the herbs and spices in their raw form, but other plant parts such as leaves or rhizomes can also be extracted. The production tree for essential oils shows there are four broad sectors – flavour industries, personal care, pharmaceutical and industrial (Figure 3).

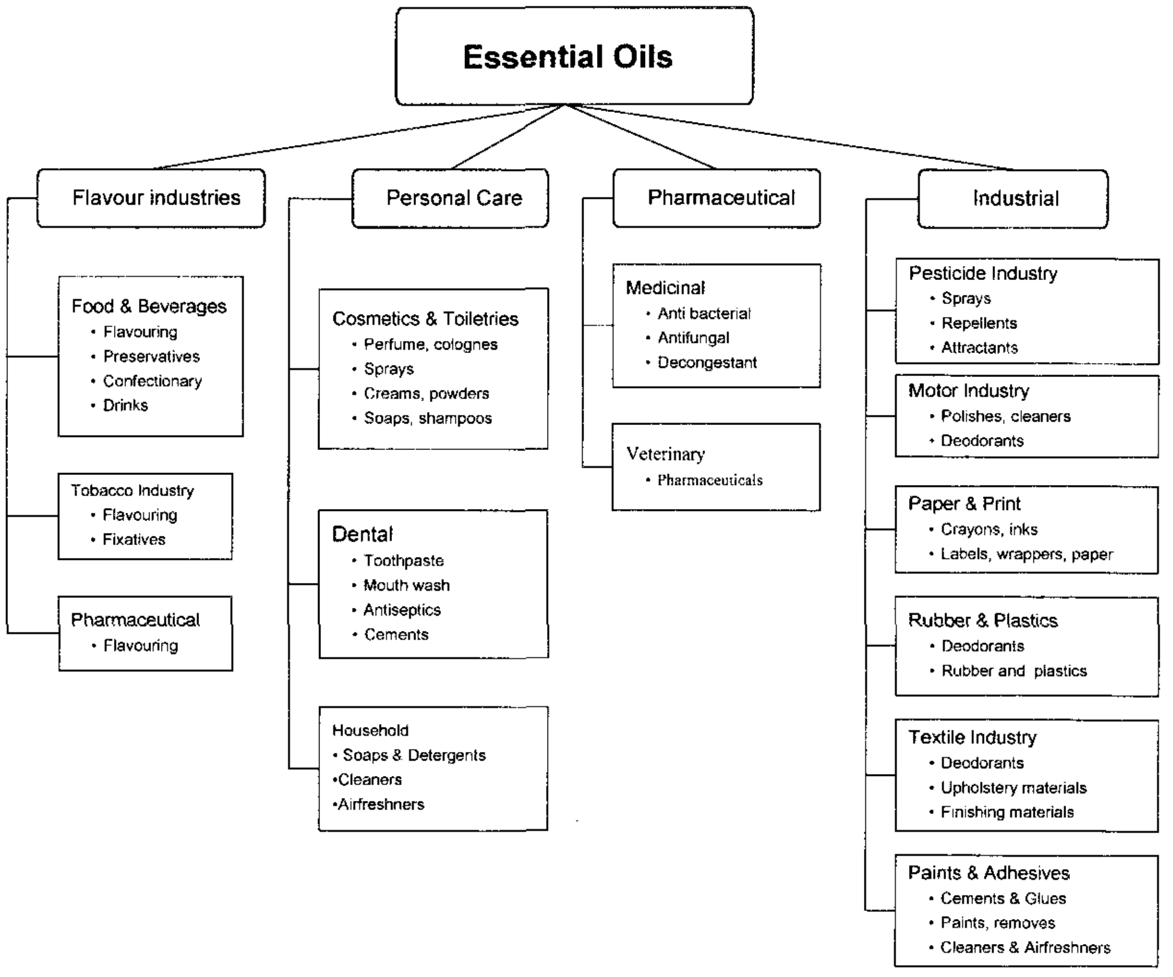


Figure 3: Industries and product categories that use essential oils.

The traded quantities and values of essential oils (see Appendix II, Table 9) provide a perspective of the international trade, although, as noted, up to date collated data is not readily available. It is also to be noted that extracts and oleoresins of spices which are becoming much more common and extracted in the countries of crop production, are not detailed within this data.

4 Products

4.1 Primary products

The primary products harvested for spice or essential oil production can be broadly divided into six categories: seeds and fruits, leaves and stems, flowers and buds, roots and rhizomes, and bark, wood and resins. Appendix I, Tables 1-5, separated by plant parts, details the most important spice and essential oil crops by species name, common name, family name and a broad description of the plant habit. In some cases, for example *Pinus*, the genus has been referred to but locally specific species have not been separated and detailed. Appendix I also details the plant part used as a source of product and the products obtained from the plant.

4.2 Secondary and Derived Products

The secondary and derived products are many and varied but the most common are spice mixtures (e.g. curry powders) and compounds extracted from the plant material such as essential oils or oleoresins. In cases where the primary spice does not meet the quality specification as a primary product it will often be purchased as a low value product extracted to produce the essential oil, oleoresin or aroma compounds. There is also considerable advantage to the industrial food processor purchasing standardised extracts of known quality, which have no microbial or other contaminants. The spice flavours for food, beverage, or industrial use may come from different extraction processes and these pathways are outlined in Figure 4.

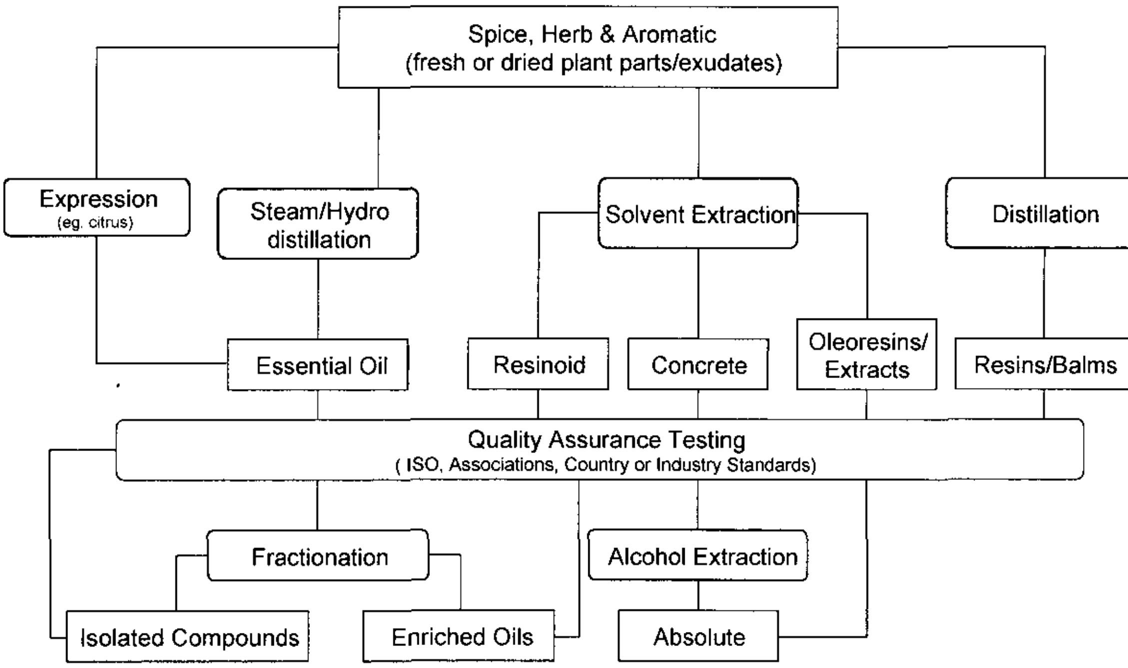


Figure 4: Extraction processes used and products from spice, herb and aromatic plants.

4.3 Requirements for Export and Quality Assurance

Spices, herbs and vegetable seasonings can be heavily contaminated with micro-organisms because of the environmental and processing conditions under which they are produced. The microbial load has to be reduced before they can be safely incorporated into food products. High temperature treatment can cause significant loss of flavour and aroma from a spice because the volatile oils are lost. Steam also results in a loss of volatile flavour and aroma components and colour changes. Steam can also result in an increase in moisture levels. Until recently, most spices and herbs were fumigated with sterilizing gases such as ethylene oxide to destroy contaminating micro-organisms. However, the use of ethylene oxide was prohibited by an EU directive in 1991 and has been banned in a number of other countries because it is a carcinogen. Irradiation has since emerged as a viable alternative and its use results in cleaner, better quality herbs and spices compared to those fumigated with ethylene oxide. Irradiation, a cold dry process, is ideal to kill the micro-organisms. Irradiation of herbs and spices is now widely practised on a commercial scale. The use of irradiation alone as a preservation technique will not solve all the problems of post-harvest food losses, but it can play an important role in reducing the dependence on chemical pesticides (International Atomic Energy Agency, IAEA, http://www.iaea.org/tcweb/publications/factsheets). A code of good irradiation practice for the control of pathogens and other micro-flora in spices, herbs and other vegetable seasonings has been developed by the International Consultative Group on Food Irradiation (ICGFI) under the aegis of FAO, IAEA and WHO. The purpose of the irradiation is to decontaminate the spices, herbs and vegetable seasonings of micro-organisms and/or insect pests. It is important to note irradiation is not used for the preservation of these ingredients and the process of preservation is obtained through proper drying, packaging and storage. Irradiation will not correct quality deficiencies. The code details pre-irradiation treatment, packaging requirements, the irradiation treatments and the dose requirement for radiation disinfection together with threshold doses that cause organoleptic changes (http://www.iaea.org/icgfi/documents/5spices.htm). Further details on irradiation including international facilities and the levels of allowable irradiation for foodstuffs entering many countries are available at:

http://www.iaea.org/icgfi.

There is reluctance by some countries and market segments to adopt irradiation, and there have been recent developments to sterilize botanical powders such as spices by contact with an oxidant such as nascent atomic oxygen (United States Patent 6,682,697; He *et al.* 2004).

The International Organisation for Standardization (ISO), a worldwide network of national standards institutes working in partnership, develops voluntary technical standards for a wide range of products that are traded internationally. ISO standards for specific spices and essential oils (Appendix III, Table 10) have been formulated and adopted by the technical committees representing the producer nations and are being continually updated. *The ISO standards help raise the levels of quality and provide assurance of minimum* standards as well as detailing standardized analytical methods. For example, the traditional method for evaluating pungency (heat level) of capsicum products, the organoleptic Scoville test, has now been replaced by HPLC (High performance liquid chromatography) where specific compounds are identified and levels quantified. The specific standards can be purchased on-line (http://www.iso.org).

The Codex Alimentarius Commission adopted a Code of Hygienic Practice for Spice and Dried Aromatic Plants in 1995 (CAC/RCP 42-1995). This code details hygienic requirements in the production/harvesting area, in the establishment design and facilities, for personnel hygiene, for hygienic processing requirements and the end-product specifications. This Code of Practice CAC/RCP 42 is available at:

www.codexalimentarius.net/standard_list.asp.

A summary of the main quality assurance hazard factors facing the spice processing industry is given in Table 1 together with the level of risk attached to the hazard if it exceeds the quality standards and the action that should be taken by the spice processor. A comprehensive guide of practical information about the quality parameters and specifications of the common spices imported into United States spice processing industry is available [11]. The Centre for Food Safety & Applied Nutrition within the USA Food and Drug Agency (http://www.cfsan.fda.gov) provides a useful site on issues of food safety and standards for food to be imported and sold in the USA. The FDA advice sheet for manufacturers of spices, spice seeds and herbs (www.cfsan.fda.gov/~dms/qa-ind5m.html) provides an overview for the industry. The FDACFSAN technical bulletin number 5 details micro-analytical methods and procedures to determine contamination in spices, herbs and botanicals caused by insects, animal excreta and extraneous matter.

Table 1: Main quality assurance factors for herb and spice processing.

Hazard	Risk	Action
Banned pesticides/ herbicides	Very High	Sale may be impossible. Liaison with growers
High levels of permitted pesticides/herbicides	Very High	Liaison with growers
Infestation by pests	High	Fumigation may be required
Foreign matter – stones, hair, excreta	Medium	Can be removed. sorting
Poor microbiological quality	Medium	Improve harvesting, handling and washing
Mould growth after packaging	High	Dry to correct moisture content. Improve packaging materials

Source: [11]

There is also a bacteriological analytical manual on-line which presents the FDA's preferred laboratory procedures for microbiological analysis of foods. For example, Chapter 5 presents the preferred spice analysis for salmonella and Chapter 18 for yeasts, moulds and mycotoxins http://www.cfsan.fda.gov/~ebam/bam-toc.html. The FAO site (http://faostat.fao.org) has under food quality control and Codex Alimentarius, the maximum permitted levels for specified pesticide compounds in specific food items. A code of hygienic practice for pepper and other spices has been written by the International Pepper Community and details the hygiene requirements in the production/harvest area, the design and facilities of spice processing establishments and their hygiene requirements, the hygienic processing requirements and quality standards for pepper (http://www.ipcnet.org). Finally, a number of regional organisations offer on-line guides to existing legislation (Appendix III, Table 11).

4.4 Consumer Preferences

Greater interest in a wide range of international and ethnic dishes has been stimulated in recent years by extensive foreign travel, the establishment of a diverse range of ethnic restaurants, and the affects of immigration on food markets and supply chains. A useful summary of the changing consumer trends for spices and seasoning in the United States is available that lists a range of herbs and spices characterising each ethnic cuisine [12]. The food industry has been very active in promoting an interest in exotic foods as a promising growth sector. Advertising and media promotion by means of television cooking programmes, radio and magazines has stimulated demand. Ethnic groups have shops dedicated to their national foods, as well as supermarkets selling authentic ethnic products which are quick and easy to prepare. These developments have stimulated a wider range of food choice in home cooking and created an increased demand for herbs and spices. It is important to note that it is generally true that the more affluent the market, the more demanding is its 'entry standards'. Affluent consumers are increasingly risk-averse and it will be necessary to invest in quality assurance systems, which include traceability through the marketing chain to meet these demands.

5 Post-Production Operations

Spice and herb production can be sub-divided into a number of activities, and although there is a route to market through by-product extraction, most spices and herbs have a series of post-harvest operations, which follows a logical sequence. The post-harvest processing tree shows each stage in the process (Figure 5).

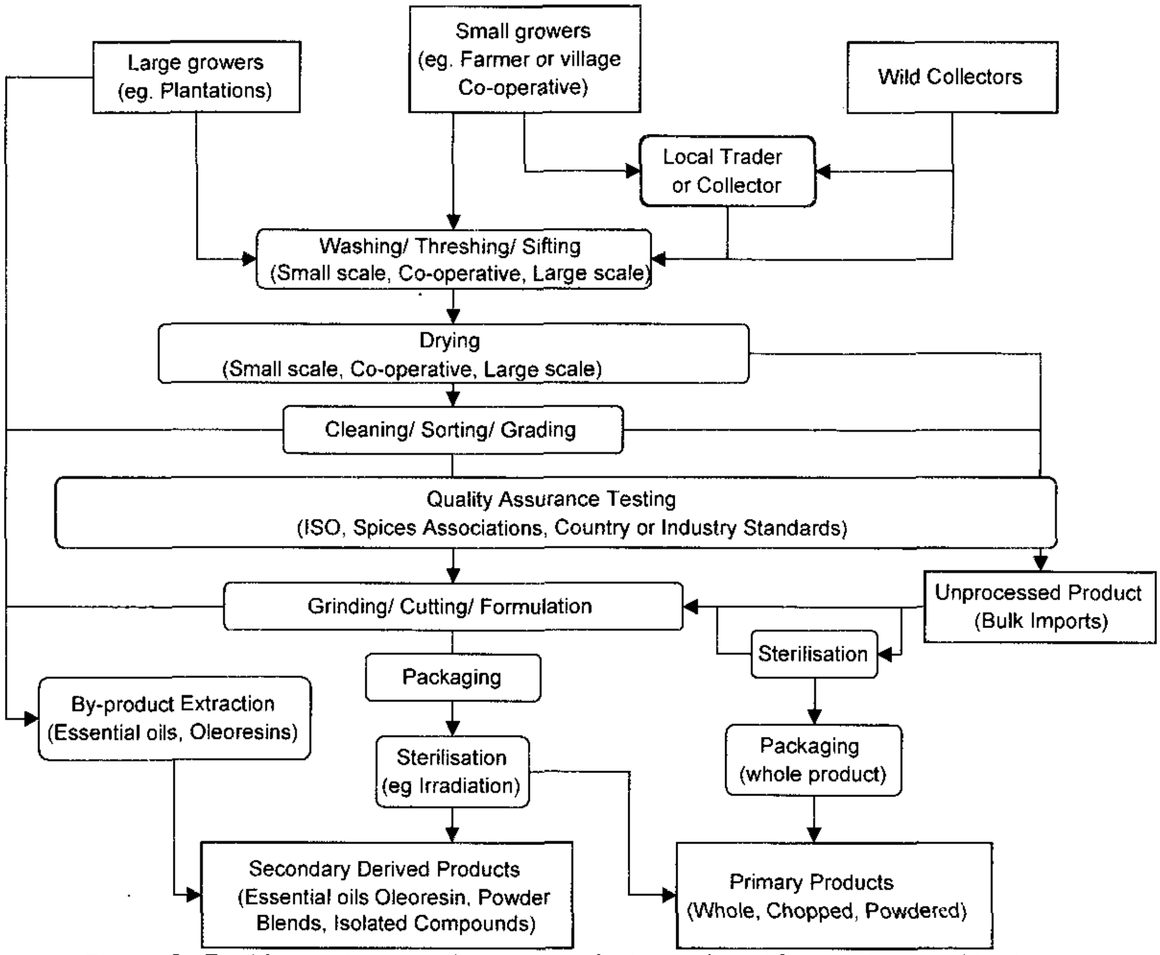


Figure 5: Post harvest processing and products produced from spices and herbs

5.1 Pre-harvest Operations

It is in the interests of the grower, and the industry, to produce a high quality product that will attract a premium market price. Pre-harvest operations involve the preparation of the facilities for the harvest material, which will ensure the crop is stored and dried quickly under hygienic conditions. The main reasons for low quality product are harvesting the crop when it is not mature; poor drying systems where there is a high risk of moisture retention and microbial contamination (dirt floors); and frequent rain during the drying process, which upsets the drying process. There is need to have buildings or structures at the harvesting area or to have a common facility for drying and curing products. Many growers of spices use traditional methods and high moisture retention, microbial contamination, and contamination with extraneous matter are common processing problems. International sanitary and phytosanitary agreements define measures to be taken to protect against risks arising from additives, contaminants, toxins or disease causing organisms in food or foodstuffs. In particular, there are problems with mould, high moisture contents and aflatoxin contents. Difficulties in reducing these problems to a low level are due to poor weather conditions at harvest associated with low cost processing technology; poor storage facilities and small-scale production units. Poor storage facilities and unhygienic and improper storage methods also contribute to contamination with mammalian and other excreta, as well as moulds or other microbes. In order to overcome these problems completely, capital investment is necessary, particularly for mechanised handling after harvest.

All personnel (including field workers) involved in the propagation, cultivation, harvest and post-harvest processing stages of plant production should maintain appropriate personal hygiene and should have received training regarding their hygiene responsibilities (see Code of Hygienic Practice for Spices and Dried Aromatic Plants CAC/RCP 42 1995 at http://www.codexalimentarius.net/standard_list.asp).

5.2 Harvesting

Harvesting is the primary process of collecting the target crop product from the field, where it is open to the vagaries of the climate and the growing environment, and placing that product in controlled processing and stable storage conditions. The harvesting requirements will differ for the final product sought, and there are specific needs such as maturity and evenness, that will dictate the harvesting management and timing [13], [14], [15], [16].

Plants should be harvested during the optimal season or time period to ensure the production of plant materials and finished spice products of the best possible quality. The time of harvest depends on the plant part to be used. Detailed information concerning the appropriate timing of harvest is often available in published standards, official monographs and major reference books. However, it is well known that the concentration of target constituents varies with the stage of plant growth and development. The best time for harvest should be determined according to the quality and quantity of target constituents.

During harvest, care should be taken to ensure that no foreign matter is mixed with the harvested plant materials. When possible, plant parts should be harvested under the best conditions, avoiding dew, rain or exceptionally high humidity. If harvesting occurs in wet conditions, the harvested material should be transported immediately to a drying shed and drying started in order to prevent microbial fermentation and mould. Cutting devices, harvesters, and other machines should be kept clean to reduce contamination from soil and other materials. They should be stored in an uncontaminated dry place, free from insects, rodents, birds and other pests, and inaccessible to livestock and domestic animals.

Soil can have a high microbial content, and contact between the harvested crop and the soil should be avoided so as to minimize the microbial load on the harvested plant materials. Where necessary, large drop cloths, preferably made of clean muslin, should be placed on the soil surface before the plants are harvested. If underground parts such as rhizomes are harvested, any adhering soil should be removed as soon as possible. Mechanical damage or compacting of raw plant materials as a consequence of overfilling or stacking of bags may result in fermentation or rot and should be avoided. Rotting plant materials should be discarded during harvest, post-harvest inspections and processing, in order to avoid contamination and loss of product quality.

5.2.1 Harvesting Seeds and Fruits

i) **Maturity** - The selection of seed or fruit to harvest which is at the correct maturity or ripeness, based on colour, is critical to obtaining a product of even high quality. Three examples are given here but maturity standards should be adopted locally for each spice.

Allspice (Pimento) fruit is harvested 3-4 months after flowering when mature but not ripe (green) fruit is most strongly flavoured. Small or over-ripe berries should be removed as they detract from the appearance of the finished product. Harvesting is undertaken manually by breaking off the twigs bearing the berry clusters. The berry clusters should be placed in a container and not placed on the ground, as soil contamination aids microorganism growth. Leaf oil is also produced from the material collected during the berry harvest or from specialized plantations.

Vanilla beans are ready to harvest 6-9 months after flowering. Colour is an important indicator for vanilla pod maturity and daily picking is advised to ensure pods are at the right stage, as immature pods produce an inferior product and over-mature pods split during curing. The right picking stage is when the distal end of the pod turns yellow and fine yellow streaks appear on the pods. Vanilla pods, when green, are almost odourless but they develop a faint phenolic odour as the beans reach a stage of harvest maturity.

Coriander harvest time is of paramount importance in determining the aroma quality of the spice. Immature fruit contain higher volatile oil than ripe fruit but have a disagreeable aroma to people of industrialised countries not familiar with the use of the green herb. The distinctive sweet spicy aroma of coriander spice doesn't develop until the fruit reaches maturity and begins to dry. Fruit ripening is progressive from the primary umbels down, therefore judgement is required in deciding the optimum harvest time. The normal harvest time is when the fruits on the primary umbel reach a chestnut colour. If fruits are allowed to over ripen there is a high risk of shattering during harvesting, cleaning and drying.

ii) **Maturity for end use and pre-drying treatment** – The time of harvest maturity is often dependent on the end usage for the spice.

Pepper provides an example. The volatile oil percentage (%) decreases with berry maturity but piperine % and starch % increase. The four marketed types of pepper, black, white red and green can be harvested from the some plant by changing the time of harvest and the processing method. To produce black pepper the berries are picked when they just start to turn yellow. The berries are then blanched with hot water for 1 minute. Blanching not only cleans the fruit, removes contaminants but also activates the phenolase enzyme responsible for producing the black colour. In addition blanching allows the fruit to dry faster. Mechanisation of these processes has been undertaken by spraying boiling water onto the fruits as they move on a conveyor belt fitted with mechanical brushes. The blanching time can be adjusted by the speed of the conveyor. The washed and blanched berries pass through sieves where the fruit are graded into selected sizes. The graded peppers are air-dried to remove the surface moisture and then placed in a drying yard or in a drier. Traditionally to produce white pepper berries are harvested fully ripe then retted in running water for 7 – 10 days and the disintegrated pericarp is removed manually or mechanically before drying. In the improved CFTRI method (India) fully mature, but unripe fruit is boiled in water for 10-15 minutes to soften the pericarp. After cooling the skin is rubbed off, the berries are then washed and dried.

Green pepper (canned, bottled, freeze dried, cured) is produced by harvesting berries at an under mature stage and subjected to a heat treatment to inactivate the enzymes responsible for the browning reaction. Pepper for powder is harvested when the berries are fully mature with maximum starch.

iii) **Cultivar difference** - The correct harvest maturity is often dependent on the choice of cultivar.

Cardamom fruits ripen over an extended period and are harvested every 3-5 weeks. There are maturity differences between cultivars. Fruits are individually picked with their pedicels when they are fully developed but unripe. Some cultivars change colour as they mature while others do not and local experience is necessary to judge the correct harvest time. After harvest, capsules are washed thoroughly in water to remove adhering soil. A pre-soaking of the capsules in hot water at 40°C and dipping the capsules for 10 minutes in a 2% sodium carbonate solution helps increase the green colour of the capsules.

iv) **Continuous harvesting** - In the tropics, a crop can produce and ripen continuously.

Nutmeg & Mace trees bear fruit all year. The fleshy drupe turns yellow when ripe. The pulpy outer husk (pericarp) splits into two halves exposing a purplish-brown seed surrounded by a red aril. The fruits are often allowed to split and fall to the ground before harvesting when they should be collected as soon as possible to prevent discolouration and the risk of mould or insect damage. A long pole may be used to take partially opened pods directly from the tree and this ensures a better quality aril but can result in damage to flowers and younger fruit. The frequency with which nutmegs are harvested is dependent on the availability of labour, level of production and the market price, but a daily harvest to every 2-3 days in off-peak times is typical.

v) **Chemical manipulation of ripeness** - Colour stage, that is the ripeness, dictates the harvesting maturity of chilli peppers for spice production. Chilli fruit on the bush have a wide range of ripeness due to the growth habit of the chilli plant and choice of cultivar. Fruit ripen from green, to green with some light red, to all light red, to deep red. Fruit of deep red colour are used for spice production. Partial drying of fruit on the plant does not reduce quality, as fruit will be dried in processing. Immature light red chilli has low colour content and spice quality, while the colour stability of red chilli spice is best when harvest is delayed. As the plant grows there is an increasing number of fruit set as branchlets develop and thus there is also a sequential maturity of fruit. To obtain high yields there is a need to allow the last fruit set to ripen. This can be done by either harvesting mature fruit repeatedly or by leaving fruit on the plant for a once-over harvest. The latter is needed for machine harvesting. Heat levels of fruit of the first fruit set is also likely to be higher than the last fruit set because of increased competition for the pungency precursors. Ethylene, a natural ripening hormone, in the form of ethephon sprays, is used to synchronize chilli ripening to make mechanical harvesting possible.

5.2.2 Harvesting Leaves and Stems

The aromatic herbs such as basil, bay leaves, mints, oregano, parsley, rosemary, sage, tarragon and thyme are often used fresh to garnish food, as dry seasonings or for extracted essential oils. The aroma, a function of their essential oil composition, is dependent on chemotype and specific chemotypes can be chosen for an end-use. The essential oil composition and yield will also change during the seasons, and crop harvest should be directed to maximise both the essential oil content and quality [17]. As a general rule, the leaf and stem should be cut when the growth has matured to an elongated flower stem but without full flower or significant senescence of the lower leaves. The essential oil can be distilled from fresh or dry plant material. Harvesting the plant material should be avoided when it is wet and if it is to be dried the plant material should be evenly spread onto the drying racks or drier to ensure there is no sweating, fermentation and microbial invasion.

5.2.3 Harvesting Flowers and Buds

When flowers and buds are the source of a spice or essential oil, the harvest time can be throughout the year in the tropics or during a limited flowering season in temperate regions. **Clove** clusters as an example in the tropics, do not ripen evenly and each tree is harvested five to eight times in the fruiting season. Clove clusters are picked when the unopened flower buds are full-sized, the calyx base has developed the characteristic pink flush, but no buds have opened or petals fallen to expose the stamens. The harvested clove clusters are taken to the storage centre and the stems, which are about 25% of the total dry weight, are removed and separated. Cloves are harvested by hand but modern orchards will have tractor-mounted platform pickers.

Ylang ylang tree flowers throughout the year. The flowers, a source of essential oil, are gathered principally after the rainy season and during the dry season. At this time the flowers are drier, contain more oil and the oil is of higher quality. Flowers are harvested early in the day. Only fully developed yellow flowers are picked as green flowers produce poor quality oil. In order to avoid fermentation, the flowers should not be held in a mass and distillation should be undertaken as soon as possible.

Saffron, a crop of temperate environments, flowers only in autumn. There can be up to 12 flowers per corm which should be hand-picked daily, after the flower has opened but not withered. The stigma is hand-separated or airflow-separated from the flower parts at the drying and processing facility.

5.2.4 Harvesting Roots and Rhizomes

The common spices which are derived from roots, bulbs and rhizomes are turmeric, ginger, onion, garlic and horseradish.

Turmeric, a perennial herb grown as an annual crop, is ready for digging when the lower leaves turn yellow. The length of time to harvest maturity is dependent on cultivar. Hand digging is the most common form of harvesting the rhizomes although diggers and lifters can be used. The leaves must be cut prior to mechanical lifting or after hand digging. Care is necessary to avoid damage to the rhizome (splitting or bruising) as injuries can result in fungal infection and rejection. Rhizomes are lifted whole, washed, sun dried and the rhizome fingers (which are kept as seed material) are separated from the mother rhizome.

Ginger is a perennial herb but is often grown as an annual. Its harvesting depends on the cultivar and varies from 7-9 months for annual crops while perennial crops are harvested at the growers' discretion. The time to harvest is also dependent on the projected end-use with fresh ginger with low fibre content harvested at about 190 days after planting. The harvesting method must ensure there is no rhizome damage and both manual and mechanical methods of rhizome digging are used. Some production areas use both methods by mechanically loosening the rhizomes to assist the hand lifting. Following lifting the rhizomes are washed, the roots removed and then killed by immersion in boiling water for about 10 minutes, dried and then stored.

Onion harvest time and maturity is based on top senescence when the bulb is converted from active growth to dormancy by under cutting that begins the drying process.

Garlic can be harvested at different stages of maturity for specialty markets but most commonly when the bulbs are well mature and the tops have dried completely.

Horseradish, a perennial that is grown for its enlarged root, is ready for harvest after the leaves have been killed by frost. Horseradish that is harvested while it is still actively growing does not store as well.

5.2.5 Harvesting Bark, Wood and Resins

Many plants which are harvested for wood or bark products, are managed under coppice plantation systems.

Cinnamon and **Cassia** production is an example of such a practice. Harvesting of the shoots is undertaken during the rainy season two years after coppicing. The selected shoots must have a uniform brown colour of bark and have at least two years growth. The rough outer bark of the selected shoots is first scraped off and the young tender inner bark is peeled off carefully from the stem. The inner bark curls naturally into the well-known quills. The best pieces of the peeled bark are packed with small pieces and tightly rolled to preserve the flavour and then dried. The coppiced shoots are left for fermentation for 24 hours, dried in the shade for one day and in the sun for four days. The smaller quills are inserted into larger ones to form compound quills. The products are graded as quills, quillings, featherings, scraped chips and powders. The finest quality bark is obtained from shoots (<1.25 m by 1.25 cm diameter) with uniform brown thin bark harvested at six-month intervals.

5.3 Transport

The harvested raw plant material of the spice crop should be transported promptly in clean, dry conditions. The crop may be placed in clean baskets, dry sacks, trailers, hoppers or other well-aerated containers and carried to a central point for transport to the processing facility. All containers used at harvest should be kept clean and free from contamination by previously-harvested plant products and other foreign matter. If plastic containers are used, particular attention should be paid to any possible retention of moisture that could lead to the growth of mould. When containers are not in use, they should be kept in dry conditions, in an area that is protected from insects, rodents, birds and other pests, and inaccessible to livestock and domestic animals. Conveyances used for transporting bulk plant materials from the place of production to storage for processing should be cleaned between loads. Bulk transport, such as ship or rail cars, where appropriate, should be well ventilated to remove moisture from plant materials and to prevent condensation.

5.4 Threshing

Threshing is the process of removing and separating the fruit or seed from the unwanted flower stems or plant stalks as well as removing damaged or immature material. This process can be undertaken by hand, assisted by sieves and screens, by use of winnowing or by mechanical shakers and sorters.

Pepper is an example where spikes need to be washed prior to threshing to remove dust and dirt. Harvested spikes are spread onto a clean floor and threshed (decorned) manually by trampling or by using a mechanical thresher. The berries are also graded at this stage by removing undersized berries and put into a size category.

5.5 Drying

This the most critical process in the production of dried herbs and spices. The aim of drying is to reduce the moisture content of the product from actively growing in the field to a level that prevents deterioration of the product and allows storage in a stable condition. Drying is a two stage process: firstly the transfer of heat to the moist product to vaporize the water in the product and secondly mass transfer of moisture from the interior to the product surface where it evaporates. The most important and immediate management concern is to ensure the harvested crop will not rot or become grossly invaded with yeasts, bacteria and mould (producing aflatoxins) or become contaminated by pests. This is the start of the preservation process, which for most spice crops requires drying that will enable the long-term crop storage and the opportunity for further processing. The drying phase of post-harvest management can include four preliminary stages - the selection of high quality produce from the field; cleaning the crop by washing and disinfection; preparing the crop for drying by peeling or slicing; pre-treating with anti-oxidants, blanching or sulfurizing. In some cases, washing prior to processing is desirable to remove field contaminants (dust, soil) using anti-microbial solutions to reduce the microbial populations to a low level prior to the drying process.

There are four main types of drying. The most basic method of drying is to spread the crop on a surface exposed to the sun. In this case, the process is aided by a cover system that prevents wetting with rainfall. An improved method, speeding up the drying, is to use a fuel source (wood, oil/diesel, gas or electricity) to heat the drying room. Solar drying systems together with solar powered fans are also available [18]. The drying process should dry the crop as quickly as possible, at temperature levels which do not drive off the volatile flavour compounds. The drying temperature regime will be specific to each crop as will be the final moisture percentage for storage [19].

The traditional open sun drying that is widely used in developing countries has major inherent limitations when trying to preserve product quality. High crop loss and low product quality result from inadequate drying, long drying times, fungal spoilage, insect infestations, bird and rodent damage and contamination plus the effects of sunlight and the weather. Even in the most favourable climate it is often not possible to get the moisture content of the product low enough for safe storage. In the tropics the high relative humidity of the air prevents drying of harvested crop products during the wet season.

The objective of a dryer is to supply the product with more heat than is available under ambient conditions. A relatively small amount of heating can greatly enhance the moisture carrying capability of the air. For example, heating air from a temperature of 20°C at 59% relative humidity (RH) to a temperature of 35°C at 25% RH increases the moisture holding capability three times. In a dryer the major requirement is the transfer of heat to the moist product by convection and conduction. The absorption of the heat by the product supplies the energy necessary for the vaporization of water from the product. The process that occurs at the surface of the product is simply the evaporation of the moisture. The moisture replenishment to the surface is by diffusion from the interior and this process depends on the nature of the product. Spices and essential oil crops derived from leaves or flowers are relatively thin and therefore relatively easy to dry due to their small diffusion thickness. Conversely in thick and fleshy materials such as roots, the drying process requires much more careful control of temperature, temperature ramp rate and airflow rate. If the temperature is too high, elevated too quickly or the airflow rate is too high when drying thick fleshy products, 'case hardening' may result, and only the outer surface will dry. This dry layer becomes impervious to subsequent moisture transfer.

In many rural locations, grid electricity and supply of other non-renewable sources of energy are too expensive, unavailable or unreliable and drying systems that use mechanical fans and electric heating are inappropriate. The high capital- and running-costs of fossil fuel-powered dryers presents an economic barrier to use by small-scale farmers.

Solar-energy drying systems are put forward as technology for small rural farmers and enterprises in developing countries. Solar dryers can be classified into two generic groups, passive or natural air circulation solar dyers and active or forced convection solar-energy dryers (Fig. 6). Forced convective dryers employ motorised fans for circulation of the drying air. The electricity for the fan can come from a solar photoelectric panel and battery. Each group can also be sub-divided into three subgroups:

i) **Integral types** (direct solar dryers where the crop is placed in a drying chamber with transparent walls, and the solar radiation falls directly on the crop, coupled with convection air flow from the heated surrounding air),
ii) **Distributed type** (indirect heating, where solar radiation heats a solar collector external to the drying chamber),
iii) **A mixed type** where there is both direct and indirect heating.

The integral type dryers are simple in both construction and operation and require little maintenance. However, they are likely to operate at lower efficiency due to their simplicity and there is less control of the drying operation. The distributed type are much more elaborate structures so require greater investment in materials and running costs, but have higher efficiency and as a result product quality is generally higher. The solar dryer has two significant disadvantages: a limited ability to process crops when the weather is poor; and drying can only occur during the daytime. This not only limits production and extends the drying time but also may have an adverse effect on production and product quality particularly fleshy crop products such as roots and stems that typically have drying times of several days.

This has led to the development of hybrid systems with auxiliary heating systems such as burners using biomass, biogas or fossil fuels. Alternatively, to achieve more efficient energy use, some active solar dryers are designed with thermal storage devices (mainly rocks or gravel) to extend the drying time during the night time and in periods of low sunshine. Desiccants (such as clay and rice husk) can be incorporated in the design to reduce the relative humidity of the drying air so as to improve the moisture carrying capacity. The use of desiccants is only possible in forced convection systems as they increase the resistance to airflow.

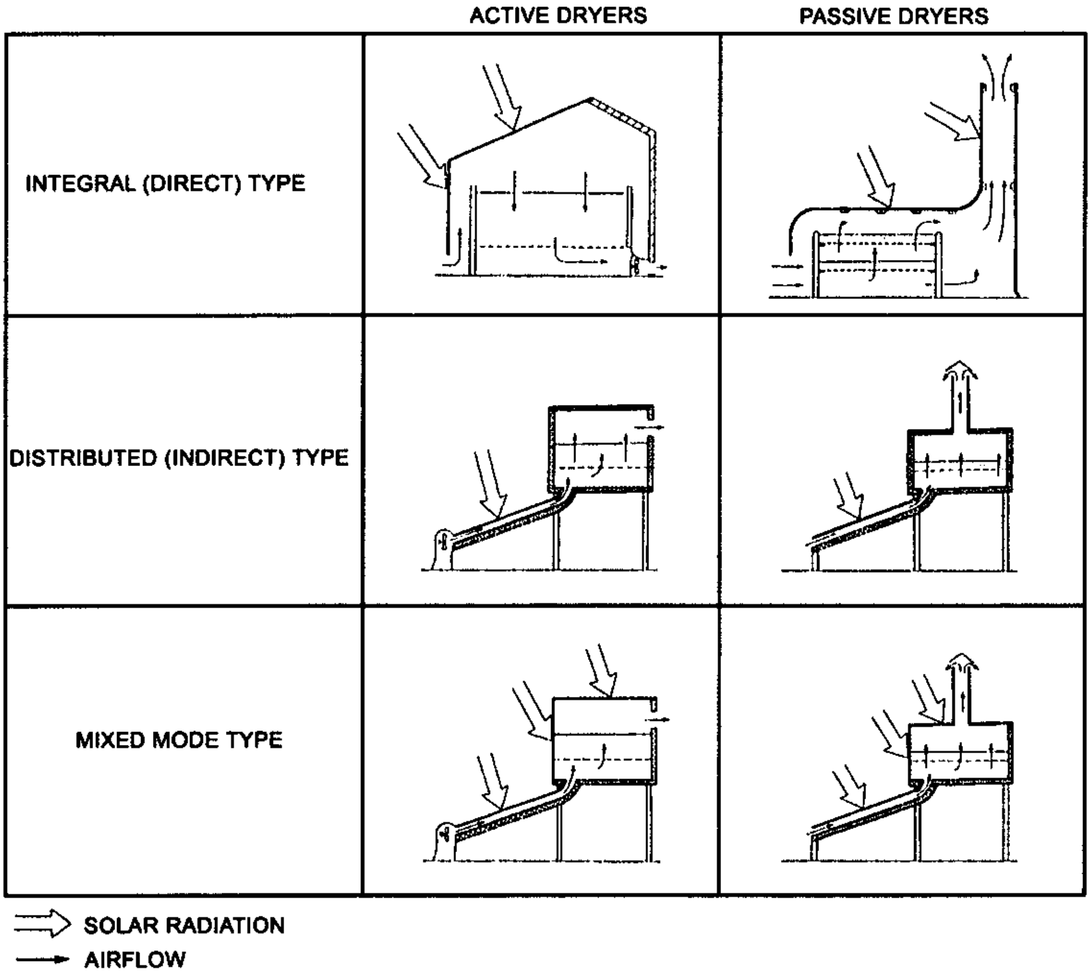


Figure 6: Typical Solar Dryer Designs.
Reprinted from Ekechukwu & Norton [20] with permission from Elsevier.

Some information on inexpensive commercial driers suitable for spices is available on the INPhO website; see for example:
A simple flat-plate drier from Pakistan:
http://www.fao.org/inpho/isma?m=equipment&txt=drier+dryer&i=INPhO&p=SimpleSearchDetail&lang=en&op=or&n=6

A solar drier from Mali:
http://www.fao.org/inpho/isma?m=equipment&txt=spice&i=INPhO&p=SimpleSearchDetail&lang=en&op=or&n=1

and a drier for red peppers from Korea:
http://www.fao.org/inpho/isma?m=equipment&txt=drier+dryer&i=INPhO&p=SimpleSearchDetail&lang=en&op=or&n=10

5.5.1 Drying Seeds and Fruits

(i) **Immediate drying** - Pepper, after threshing and blanching, the fruits are dried in the sun for 7-10 days till the moisture is about 10% and the seeds have the characteristic wrinkled appearance of black pepper. Pepper drying in the sun has to be turned over periodically to aid uniform drying and discourage mould infestation. The main disadvantage of sun drying is the lack of uniformity and potential contamination by microorganisms. Improvements in black pepper need to focus on the drying process. In areas where there is rainfall all year round and a high humidity, the quality of black pepper produced is dependent on drying. Mechanical driers have only had limited success at farm level and the cost of drying using fossil fuels is relatively high but other forms of drying such as solar driers or solid fuel driers have not been found as effective.

Nutmeg & Mace fruit are dried in their shells in the sun and turned each day to prevent fermentation. The nuts are sufficiently dry when they rattle and drying takes about one week. Artificial dryers are sometimes used. Once dried the nuts can be stored for a considerable time. The separated mace is flattened by hand and dried on mats in the sun. This takes between 2-4 hours. In Grenada mace is cured in dark storage for 4 months. This produces a brittle pale yellow mace that has a premium price.

Chillis (Capsicums, Chilli peppers and Paprika) have a thick waxy skin, which prevents rapid drying. Sun drying of fruit is the most common method and is undertaken by spreading the crop in a dry area exposed to the sun or under cover. Weather exposure can bring high losses and contamination is also a problem. Fruit are spread in thin layers on a hard dry surface. The use of black plastic under the fruit speeds the drying time. The fruit is regularly stirred to ensure uniform drying and to reduce discolouration and fungal growth. At night or in wet conditions the fruits are heaped and covered. Drying will take up to 15 days dependent on the sunshine hours and weather conditions. A 100kg of fruit produces about 25 to 35kg of dried spice. Large traders use racks that can be moved in or out of the sun until the fruits are dried below 10% whilst retaining colour and pungency. This system reduces the drying time by half and produces a more uniform product. A chemical emulsion 'Dipsol' can be sprayed on fresh fruit to accelerate sun drying. Artificial driers such as energy-efficient heat pump dryers are well suited for drying chillies as they operate at low temperatures. This can be essential for chilli drying under changeable weather conditions as the spice quality becomes less desirable when it becomes brown instead of bright red. The drying temperatures should be below 60°C.

(ii) <u>**Programmed drying - the enzymatic development of flavour compounds**</u>: **Vanilla** pods, during the curing process, develop flavour as a result of naturally-induced enzymatic action. The final vanilla quality depends mostly on the glucovanillin content in the green bean. This means that the quality of cured beans will be higher if the curing starts with mature beans that have the highest glucovanillin concentration. A number of procedures have been developed for curing vanilla, and they can be characterised into four stages. The first operation is to halt the plant's physiological functions by stopping vegetative development so that various enzymes can come into contact with cell substrates. The most practical methods are sun- or oven-wilting or hot water scalding. The second operation that is the most crucial step is sweating. Bean moisture is initially allowed to escape rapidly to get to a level that will reduce the risk of microbial spoilage during the subsequent processing. The curing enzymes are most active during this stage and vanillin and related compounds are released during this step that takes 7-10 days. At the end of the sweating process, the cured beans are still 60-70% moisture: too high for safe storage. The third operation is drying to protect the beans from microbial spoilage and also to inhibit further enzyme activity and biochemical changes. At the end of drying the beans should be at 25-30% moisture. The fourth step is storage in closed boxes for several months while chemical reactions take place. There are two main methods of curing, the Mexican process (sun method) or the Madagascar process (Bourbon method). The Mexican method begins with shed storage for some days until the beans start to shrink. The beans are then placed in sweating boxes, for at least 24 hours, where the temperature is maintained to encourage the slight fermentation and flavour-developing enzymatic reactions. This process of wilting and sweating may be repeated a number of times during the early part of curing and extend over a 2-3 week period. The moisture is reduced to the desired level of 25% by frequent exposure to sunlight and sweating. The final curing occurs when the beans are matured in boxes for 2-3 months. The Mexican process of curing takes 5-6 months. The Madagascar process is faster and begins when the pods are dipped in hot water at 80°C for 7-15 min. The beans are then spread out on blankets in the sun, and when well heated are rolled in blankets to stand and ferment overnight. This procedure is repeated over 10 days. At the end of this period the beans are placed on trays and allowed to further cure and dehydrate. The Madagascar process takes 35-40 days.

Allspice – Pimento berry clusters are taken to a drying shed and left in heaps or sacks for up to 5 days to ferment. Berries are then spread on outdoor drying floors, and turned daily to ensure even drying. The length of drying is dependent on the weather conditions (5-10 days) and the berries are covered at night and during rain. Moisture content close to 12% is the target and the yield from 100kg of green berries is about 55-65kg. Microbial contamination often occurs during the fermenting and drying phase, especially during wet and humid weather. This contamination is almost impossible to counteract and a high microbial count results in berries unsuitable for human consumption. These berries can be distilled. Correctly dried spice should have a pleasant characteristic odour and low microbial counts. These objectives are most easily met by artificial drying, under controlled conditions. Artificial driers (wood fired) are more common in areas where berries ripen in the wet season. Solar driers are more efficient but require a higher standard of post-harvest berry management. Permanently-placed large forced air driers, owned and operated by grower cooperatives or local government, are becoming more common. A maximum drying temperature up to 75°C can be used without loss of essential oil. The problems of microbial contamination can be kept to low levels with good drying and storage management. The dry berries are cleaned and bagged, and kept in a clean dry store.

(iii) **Drying to retain colour** - **Cardamom** capsule colour and the retention of greenness are important for highest quality. Capsules cured immediately after picking retained greener colour and the loss of greenness was more significant if the capsules were stored for more than 12 hours. Bagging of the capsules in jute bags, and cool storage, aids the retention of greenness. Cardamom capsules at picking contain 70-80% moisture and to enable storage the moisture has to be taken down to 8-10% by curing. Sun-drying is generally undesirable for cardamom because of bleaching and capsule splitting. The most widely-adopted drying system is a slow dry over 18-30 hours using a number of methods of artificial drying (electric, kiln, bin) with various methods of hot air flow. A temperature between 40-50°C helps retain the green colour and an increase in temperature significantly increases the percentage of yellow capsules, split capsules, and heat injury.

5.5.2 Drying Leaves and Stems

Drying is the transformation of the harvested leaf and stem, containing 80-90% water, to a stable state containing 5-10% water. It is important to minimise the holding time between harvest and drying, and these activities should be co-ordinated to prevent delays in drying and the chance of spoilage. The temperature during drying is critical and if the drying temperatures are too hot the volatile components in the essential oils will be depleted and lost. In general drying temperatures should be below 40°C with forced air movement.

5.5.3 Drying Flowers and Buds

Clove buds are spread onto matting and dried in the sun. Occasional gentle raking will aid even drying and it is important to overcome heating and mould formation. Damaged and spoiled buds are removed during this phase. Drying is completed in 4-6 days with buds losing about two-thirds of their weight.

Saffron stigma should be dried the same day as picked from the field, following separation from the floral parts. The stigma is about 85% moisture at field picking and to enable long-term storage of the filaments, a moisture level close to 10% is required after drying. To obtain high quality saffron, drying temperatures should initially be high (<90 °C) for a brief period (< 20 minutes) and then continued drying at a lower temperature (≤40 °C). Irrespective of the drying method, it is important not to over-dry to a brittle stigma. The duration of drying is dependent on the drying temperature used and the higher the temperature used, the shorter is the drying time.

5.5.4 Drying Roots and Rhizomes

Turmeric rhizomes have to be cured after harvest for both colour and aroma. The traditional method of curing rhizomes is to steam or boil fresh rhizomes in lime or a 0.1% sodium bicarbonate solution. The 'curing' is to remove the raw odour, reduce the drying time, gelatinise the starch and produce a more uniformly-coloured final product. Traditionally the cooked rhizomes were spread in the sun to dry and this process takes 10-15 days. The final moisture level should be close to 6% moisture content. Today the majority of internationally-traded turmeric rhizomes are artificially dried with hot-air drums, tray and continuous tunnel driers and in India a maximum temperature of 60°C is advised. An important factor in drying time is the preparation of the rhizome. Rhizomes to be dried can be sliced or whole, with slicing generally producing a more uniform and brightly coloured powder. The yield of the dried product varies from 10-30% depending on the variety and the crop-growing environment.

Ginger: curing of the rhizome prior to drying directly affects the fibre and volatile oil content. Removal of the skin reduces the fibre content and also increases the oil loss. Peeling also affects the pungency as these compounds (gingerols) are in the skin. When sun drying is not an option wood-fired or solar driers can be used while in Australia gas-heated dehydrators are used. The final dry matter should be in the 7-12% range with a weight loss during drying of 60-70%. Artificial drying minimises the loss of quality and can also eliminate microbial contamination. Drying temperature, airflow and the length of drying all affect the flavour compounds in ginger.

Garlic: subsequent to the field harvest, the bulb is broken into individual cloves and the loose paper shell removed by screening and airflow. The cloves are then washed and sliced. The sliced garlic cloves are dried down to about 10% moisture, with a drying temperature below 60°C. In the final drying procedures care is needed to ensure there is no heat damage to the slices and the garlic is dried to 6.5% moisture.

Onions can be dehydrated in the form of flakes, rings, kibbles and powder. Small-scale onion drying has been achieved by solar drying, but cabinet drying at 55-60°C for 10-15 hours gives a better product than sun drying or drying in solar huts. Commercial dehydration is achieved by forced hot air with an initial temperature of 75°C reducing to 55-60°C as the moisture content falls. Final storage moisture content close to 4% is sought.

Horseradish are very sensitive to wilting and immediately after harvest the roots should be pre-cooled to <5°C using forced air cooling or placed at 0°C with 90-98% RH. Roots can be stored for 12 months under those conditions but pungency is rapidly lost at higher temperatures and roots dry out at lower RH. Perforated polyethylene bags and lined crates can maintain high RH during storage.

5.6 Cleaning

Cleaning the spice prior to packaging and sale, is to ensure that the spice is of the highest quality and will obtain the highest price. Cleaning should remove all the foreign matter that lowers the quality and endangers the sale. Sieves, grading tables, flotation tanks and screens can all be used to ensure that the quality standards are met and an even line of high quality spice is obtained.

5.7 Packaging

Processed plant materials should be packaged as quickly as possible to prevent deterioration of the product and as a protection against exposure to pest attacks and other sources of contamination. Continuous in-process quality control measures should be implemented to eliminate substandard materials, contaminants and foreign matter prior to and during the final stages of packaging. Processed plant materials should be packaged in clean, dry boxes, sacks, bags or other containers in accordance with standard operating procedures and national and/or regional regulations of the producer and the end-user countries. Materials used for packaging should be non-polluting, clean, dry and in undamaged condition and should conform to the quality requirements for the plant materials concerned. Fragile plant materials should be packaged in rigid containers. Whenever possible, the packaging used should be agreed upon between supplier and buyer. Reusable packaging material such as jute sacks and mesh bags should be disinfected and thoroughly dried prior to reuse, so as to avoid contamination by previous contents. Packaging materials should be stored in a clean and dry place that is free from pests and inaccessible to livestock, domestic animals and other sources of contamination.

A label affixed to the packaging should clearly detail the product name of the spice, the plant name, the place of production, the harvest date and the names of the grower and the processor, and quantitative information. The label should also contain information indicating quality approval and comply with other national and/or regional labeling requirements. The label should bear a number that clearly identifies the production batch. Additional information about the production and quality of the plant materials may be added in a separate certificate, which is clearly linked to the package carrying the same batch number. Records should be kept of batch packaging, and should include the product name, place of origin, batch number, weight, assignment number and date. They should be retained for a period of three years or as required by national and regional authorities.

The International Trade Centre (UNCTAD/WTO) has produced a packaging manual (1999) for dried herbs and spices (ISBN 92-9137-114-9) and this reviews products and relevant packaging standards; explains various types of packaging methods and packaging materials used for handling and storage of such products; outlines current trends and highlights health, safety and environmental issues affecting spice packaging (www.intracen.org). There is continuing development with packaging materials and an example is CTMP (Chemi-Thermo-Mechanical Pulp) board which is aluminium-free but has aroma –barrier properties. There is also an increasing usage of irradiation by importing countries to sterilize herbs and spices and this requires special packaging by the exporting processors. The American Society for Testing and Materials has a standard guide (F1640-03) for packaging materials for foods to be irradiated and a standard guide (F1885-04) for irradiation of dried spices, herbs, and vegetable seasonings to control pathogens and other organisms (www.astm.org). The International Atomic Energy Agency also lists packaging approved in the USA and in the UK, for the packaging and irradiation of food (www.iaea.org/icgfi/packaging-dat-usa.pdf, and www.iaea.org/icgfi/packaging-dat-uk.pdf). Some specific packaging requirements for major spice crops are detailed below.

5.7.1 Packaging for Seeds and fruits

Vanilla, for most of the world trade, has grades of whole and split beans which are subdivided according to length into various sizes between 12 and 26cm and then put into bundles, each containing 70-100 beans and weighing between 150-200g. These are packed into wax-lined cardboard boxes that hold 20-40 bundles. Beans remaining from the grading and sorting, such as short or broken beans, are bulked together and loosely packed into boxes. **Cardamom,** when dried, needs to be kept in polypropylene bags to ensure the flavour components are retained and to prevent re-adsorption of moisture, mould growth and reduce insect pests. A sealing machine with a timer will aid efficient bagging.

Cloves when bagged should be stored in cool, clean dry buildings. Sound, properly dried cloves are relatively free from storage pests. Clove oils should be stored in full, airtight containers, and remain sealed until required. Bulk oil is usually transported in 200 litre metal drums.

Nutmeg & mace is graded according to size, and the bigger the mace, the better the premium. After drying, the nutmeg seeds are put into bags and transported to the processing factory for kernel separation and grading. After grading, nutmeg is bagged, labeled and fumigated prior to export. Nutmegs are usually packed in double-layered linen, jute, sisal or woven bags. If other packaging is used, care should be taken to avoid materials that might lead to sweating and mould development. Mace follows a similar process but there is a need for three months curing before bagging and fumigation and top quality mace is packaged in plastic bags.

Chillis (Capsicums, Chilli peppers and Paprika) that have been dried should be stored in airtight containers away from sunlight as air and light accelerates the rate of bleaching. Chillies should be stored in polyethylene bags or packs and can be stored for a year in a cool, dry and dark place.

5.7.2 Packaging for Leaves and stems

It is essential that all material is dry to below 10% moisture content. The leaves and stems of dried herbs should be stored in cool, dark and dry areas of low humidity and polyethylene bags or packs used.

5.7.3 Packaging for Flowers and buds

Saffron stigma, when dried and graded, should be stored in airtight containers, in a cool dry place out of the light.

5.7.4 Packaging for Roots and Rhizomes

Ginger when fresh should be stored in polyethylene bags with 2% ventilation to prevent dehydration and mould development. Ginger rhizome for bulk shipping can be packed in jute sacks, wooden boxes or lined corrugated cardboard boxes. Processed, dry ginger should be packaged in laminated bags that have low oxygen permeability, and stored in a cool dry environment.

Turmeric is mostly traded as whole rhizome and then processed into powder or oleoresin. The colour constituents of turmeric deteriorate with light, and to a lesser extent under heat and oxidative conditions. Ground turmeric should be stored in UV protective packaging and a cool dry environment.

5.7.5 Packaging for Bark, Wood and Resins

Cinnamon and Cassia quills are graded on colour and pressed into cylindrical bales in jute cloth or corrugated cardboard cartons. Cinnamon and cassia, especially if ground, require polypropylene packaging and polyethylene is not recommended as the flavour components diffuse through it.

5.8 Storage

There is a need for quality storage both on-farm and off-farm, with cool stores and warehousing facilities linked to post-harvest crop management. Spices deteriorate rapidly in adverse conditions and should be stored in well-prepared and maintained storage facilities. It is essential the moisture level of the spice to be stored is at a safe level prior to storage. This is usually below 10% moisture. The storehouses should be damp-proof, vermin-proof and bird-proof and where possible have controlled ventilation and devices to control humidity and temperature. A dehumidifier fitted to a storage room, by keeping the atmosphere always dry, can eliminate mould and insect attacks. The room should be fumigated before storage, the walls whitewashed regularly and the facility kept dry.

Fumigation against pest infestation should be carried out only when necessary, and should be carried out by licensed or trained personnel. Only registered chemicals authorized by the regulatory authorities of the source country and the countries of intended end-use should be used. All fumigation, fumigation chemicals, and dates of application should be documented. When freezing or saturated steam is used for pest control, the humidity of the materials should be checked after treatment. Some specific examples for major spices are described below.

Pepper has a steady loss of aroma compounds that will be faster in poor storage conditions. Polyethylene-lined gunny bags or laminated HDPE (high density polyethylene) are ideal for pepper storage. Care should be taken with pepper storage to avoid aroma spoilage by other spices in close proximity.

Clove quality is affected by prolonged storage which reduces oil content and may also dull the colour. Oil composition and the ratio of constituents of cloves can change in storage, with the rate and extent of change dependent on the production method.

Nutmeg & mace should not be ground until required because of the loss of volatile constituents when in uncontrolled storage. Incorrectly stored nutmeg oil may also undergo significant composition changes if exposed to high ambient temperatures. Unprotected powders and oil can also absorb unpleasant odours and powders should be stored in sealed containers.

Chillis (Capsicums, Chilli peppers and Paprika) fruit, to ensure storage without mould should be close to 10% moisture or below.

Turmeric dried rhizomes are usually chemically treated or fumigated before storage to prevent insect and fungal infestation. Rhizomes stored in a cool chamber have less disease, rot and pest damage and less sprouting, compared to underground pit storage or heaps out doors.

5.9 Processing

5.9.1 Grinding and separating

Grinding an herb or spice to a specified particle size using standardised sieve apertures is a normal processing activity. Grinding gives easier mixing in the final food product and aids the dispersion of flavour throughout the food. A food manufacturer will have specific particle size requirements and the processor will have to mill the herb or spice through sieves that will obtain the fineness required. There are specific examples.

White pepper is produced by removing the pericarp (fruit wall) from ripe pepper fruits, and then grinding. White pepper is traditionally prepared by steeping ripe fruits in water for a few days, rubbing to remove the pericarp, washing and drying. The berries that are beginning to ripen are put into bags and soaked in water to soften the pericarp, which is then washed off and the seeds dried in the sun. The quality of the water used for soaking the berries is important, as pepper soaked in muddy or dirty water may be discoloured or have foreign odours. Soaking tanks and clean water produces pepper of higher quality. For black pepper, berries are harvested when mature green, de-spiked and dried in the sun. For both black and white pepper, the quality of the product is dependent on the weather, as almost all the pepper is sun-dried. Efforts to improve quality by cleaning out foreign matter, stalks, and light berries by simple sieves and blowers reduce the amounts transported and increase the value. Ground pepper is obtained by grinding pepper with equipment like a hammer-mill. The pepper is first fluidised for the removal of extraneous matter and then passed through screens. Specifications for a mill and grinder are available at:

http://www.fao.org/inpho/isma?m=equipment&txt=spice&i=INPhO&p=SimpleSearchDetail&lang=en&op=or&n=2

Cardamom capsules should be sorted into size classes and different size sieves will allow different grades to be separated as well as the separation of split and insect infested capsules. In addition to the green cardamom capsules, there is a bleached cardamom product that is creamy white or golden yellow in colour. Bleaching can be undertaken with dried capsules or freshly harvested capsules. The bleaching of fresh capsules is undertaken by soaking for one hour in 20% potassium metabisulphite solution containing 1% hydrogen peroxide solution to degrade the chlorophyll. On drying these capsules yield a golden yellow colour. The bleaching of dry capsules can be undertaken by a number of methods viz sulphur bleaching, potassium metabisulphite with hydrochloric acid and hydrogen peroxide, hydrogen peroxide, or the traditional method by steeping in soap-nut water. The quality requirements vary depending on the end use and are related to moisture level, cleanliness, content of sub-standard product, extraneous matter, appearance and colour, for example if the processor values the extractives, volatile oil and specific ingredients. There are specific quality standards for India and Sri Lanka. Although cardamom is usually sold in the form of dried capsules, cardamom is also processed into various products such as seeds, powder, oil, oleoresin, and encapsulated flavour. Cardamom seeds are obtained by decorticating the capsules by use of a plate mill. The ratio of seeds to husk is 30:70. The storage of cardamom seed needs care to maintain the essential oil and boxes lined with aluminum foil are favoured. Cardamom as a powder gives the maximum flavour to the food products but the disadvantage is that it loses aroma quality by the loss of the volatiles.

Nutmegs are grouped under three broad quality classes. Sound: nutmegs that are mainly used for grinding and for oleoresin extraction. Substandard: nutmegs that are used for grinding, oleoresin extraction and essential oil distillation; and poor quality nutmegs for essential oil distillation. The shelling of nutmegs can be undertaken by hand or machine, and care is necessary to prevent bruising of the kernels. Cracking the shell is often undertaken by machine that can be a centrifugal type in which the rotary motion of the machine forces the nut to be thrown at high speed against the inside of the drum. Once the cracking is complete, the nuts are sorted when whole kernels are separated from broken pieces. Floatation in water is used to remove unsound kernels, as these kernels are lighter than water and float. Sound kernels can be sorted on their quality and size and separated from broken kernels. Sizing can be carried out using different mesh sized sieves. Sorted kernels are bagged, labeled and fumigated for export.

Capsicums, Chilli peppers and Paprika, colour retention is improved by the application of fat–soluble anti-oxidants and the addition of these antioxidants is more effective after curing than before and in the ground spice rather than whole pods. Cayenne pepper is prepared by grinding chillis through a 40-mesh sieve. The spice should be a uniform fine powder, orange to dark red with a hot biting taste. Paprika pepper is a relatively coarse bright to brilliant red powder with a spicy and only mildly pungent flavour.

Saffron stigmas are graded on colour, bitterness and aroma, and the ISO 3632-1 classification divides the filaments into four categories depending on % floral waste and % extraneous matter and on the assay results for colour, bitterness and aroma. The processor will sell different categories based on grading.

Turmeric, as a dried rhizome has a rough dull outer surface with scales and root bits. Smoothing and polishing the outer surface by manual or mechanical rubbing improve the appearance. Manual polishing consists of rubbing the dried turmeric on a dried surface. The mechanical methods can be a hand-operated barrel drum or power-operated drums. The turmeric rhizomes are rotated and the polishing occurs with abrasion against the metal mesh of the drum and mutual rubbing of the rolling rhizomes. In India the yield of polished turmeric from the untreated rhizome varies from 15-25%.

5.9.2 Extraction of essential oils

The extraction of essential oils from plant material can be achieved by a number of different methods and these are shown in the generalised flow diagram (Figure 4). There are five main methods of extraction:

- Expression
- Hydro- or water-distillation.
- Water and steam distillation

- Steam distillation
- Solvent extraction

For each method there may be many variations and refinements and the extraction may be conducted under reduced pressure (vacuum), ambient pressure or excess pressure. The choice of extraction method will depend on the nature of the material, the stability of the chemical components and the specification of the targeted product.

Flowers are generally solvent-extracted and not steam distilled with the exception of rose, ylang ylang and orange blossom. In some applications an isolate or essential oil fraction is preferred to the total oil. Terpeneless oils (eg bay oil) and folded citrus oils (a concentrated oil produced by removing unwanted compounds from the whole oil) are well-known examples of fractionated essential oils with better quality than the whole oil. Sometimes, fractionation is used to reduce undesirable notes. This is the case for antheole-containing essential oils from anise, star anise and fennel. Other processing steps may be applied to reduce instability of certain oils (eg lemon oil which is known to be unstable in soft drinks due to the level of citral). The production of some special oils, oleoresins, absolutes and concretes requires much greater technologically-advanced facilities, labour skills and safety systems. These processing facilities are generally beyond the capability of the small individual producer. The high capital cost and highly-skilled labour skill requirements of a supercritical carbon dioxide extraction plant also limits the widespread application of this extraction process except for large flavour, fragrance or pharmaceutical manufacturers. Expression is used exclusively for the extraction of citrus oil from the fruit peel, because the chemical components of the oil are easily damaged by heat. Citrus oil production is now a major by-product process of the juice industry.

Distillation is still the most economical method of extracting essential oil from spices and aromatic plant material. The main advantage of distillation is that it can generally be carried out with some very simple equipment, close to the location of plant production. Even in relatively remote locations large quantities of material can be processed in a relatively short time. Distillation is less labour intensive and has a lower labour skill requirement than solvent extraction. Adopting the simplest or cheapest extraction method however, may prove to be false economy because of low yield, poor or highly variable oil quality and low market value. Water distillation is the simplest of the three distillation methods. The plant material is mixed directly with water in a still pot. A perforated grid may be inserted above the base of the still pot to prevent the plant material settling on the bottom and coming in direct contact with the heated base of the still and charring (Figure 7). Water distillation is probably the simplest and cheapest method of extracting essential oils, but the quality of the oil has the greatest potential to be modified due to the effects of direct heating and the water contact.

- The water present in the still must always be more than enough to last the duration of the distillation, other wise the plant material can over-heat and char.
- It is very easy for still 'off-notes' to be generated, since some components of the oil are more susceptible to chemical change and oxygenated componets tend to dissolve in the still water so their complete extraction is not possible.
- The plant material must be kept agitated as the water boils otherwise it may settle in the bottom of the still and become damaged by the heating. Chopping or grinding the material into fine particles may help to keep the material dispersed in the water.
- Some plant materials like cinnamon bark contain high levels of mucilages and as these are leached out the viscosity of the water increases and there is a high risk of charring.
- The stills tend to be small and therefore it will take a long time to accumulate much oil and each batch may be highly variable containing better quality oil mixed with poor quality.

- Water distillation is a slower extraction process than the other two distillation types and therefore less energy efficient.
- The only advantage of water distillation is the cost of the equipment tends to be extremely low and the designs of the stills, condensers and oil separator are simple so they can operate and be maintained in very remote locations.

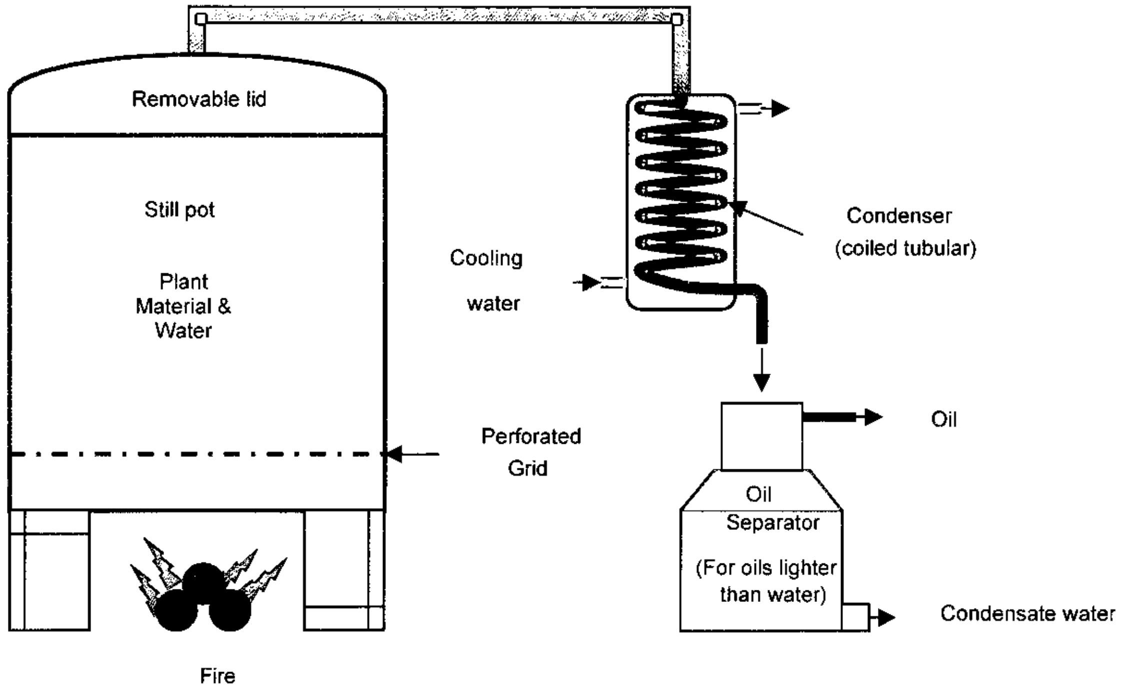


Figure 7: Diagrammatic representation of water distillation unit where the plant material is suspended in the water.

The water-distilled oils are commonly darker in colour and have stronger still 'off-note' odours than oils produced by the other methods, and therefore tend to be of the lowest value. The disadvantages of the water distillation method would generally outweigh the advantages except for local market use.

In steam-and-water distillation the basic still design is very similar to that of water distillation (Figure 8). The plant material is packed into the still pot sitting on a grill or perforated plate above the boiling water. The capacity of the still pot volume is reduced but it may be possible to achieve a high packing density because the plant material is not suspended in the water. The advantages of steam and water distillation over water distillation are as follows:

- Higher oil yield.
- Oil component less susceptible to change due to wetness and thermal conductivity of the still from the heat source.
- The effect of refluxing is minimised.
- Oil quality more reproducible.
- Faster process so more energy efficient.

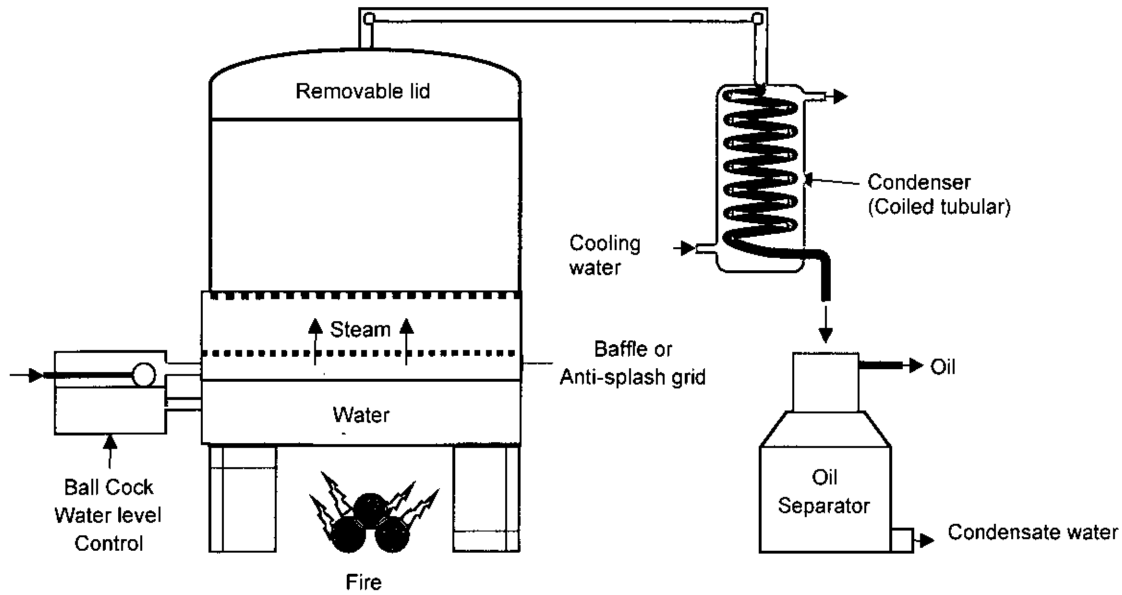


Figure 8: Diagrammatic representation of a steam and water distillation unit with a baffle to prevent direct water contact with the plant material on the perforated grid.

Steam distillation is the process of distilling plant material with the steam generated outside the still in a stand-alone boiler (Figure 9).

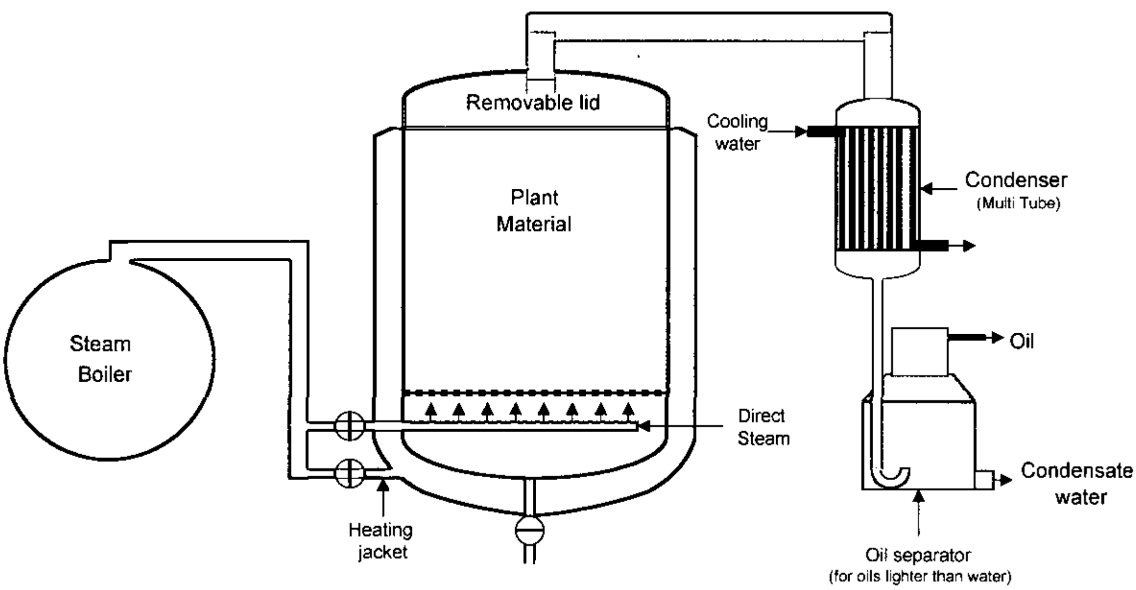


Figure 9: Diagrammatic representation of steam distillation unit.

As in the steam-and-water distillation system the plant material is supported on a perforated grid above the steam inlet. The advantages and disadvantages of steam distillation are as follows:

- The amount of steam and the quality of the steam can be controlled.
- Lower risk of thermal degradation as temperature generally not above 100 °C.
- Most widely used process for the extraction of essential oils on a large scale.
- Throughout the flavour and fragrance supply industry it is the standard method of extraction.
- There is a much higher capital requirement and with low-priced oils the pay back period can be over 10 years.
- Requires higher level of technical skill and fabrication and repairs and maintenance require a higher level of skill.
- Many variations of the process exist, e.g. batch, hydrodiffusion, maceration distillation, mobile stills and continuous distillation process.

When designing a distillation system a number of issues must be considered:

Site

- Availability of adequate water
- Energy source: electricity, boiler fuel
- Easy transport access
- Skilled and unskilled labour
- Close proximity to plant material
- Access to fabricators and machine shop for repairs
- Environmental zoning, plant waste and waste water discharge

Distillation Charge

(the amount of plant material that can be processed in a single cycle)

- Size of the still
- Plant species and oil content
- Daily volume and condition of plant material and frequency of supply
- Distance of the plant material production to still and how it will be transported
- Required pretreatment (chopping, crushing, powdering, maceration)
- Time taken to charge and discharge the still
- Storage capacity of plant material prior to distilling incase of poor weather
- Disposal of waste plant material after distillation

Still

- Design determined by distillation method; seek professional advice
- Ideally constructed of stainless steel
- Size determined by capacity of boiler
- Distillation time affected by height of the charge, flow rate and pressure of steam
- Easy to charge and discharge

Boiler

- Should produce enough steam to adequately remove the oil from the plant material
- Low pressure (saturated steam) or pressurised (dry steam)
- Best to measure output of home made or commercial boiler (condensing steam for set time) to determine capacity
- Seek professional advice on design and access for repairs and maintenance

Condenser

- The role of the condenser is to change the oil and water vapour back to a liquid
- Two main types: coiled tube or multitube
- Multitube difficult to make, needs running water, but has good heat transfer, efficient water use and no pressure build up
- Coiled tube easy to make, just needs a tank of water and sparse use of running water, but has poor heat transfer, risk of high pressure build up during distillation and poor use of water

Oil Separator

- Design of separator depends on density of the oil (if <1, oils are lighter than water and float; if >1, oils heavier than water and sink). Only a few wood and root oils are heavier than water
- Large enough capacity to allow the oil particles to form droplets and readily separate from the water (recommended at least a 4 minute retention time in the separator before out flow)
- Controlling temperature can be used to improve separation
- Seek professional advice on design as poor separation affects all the effort of distillation to extract oil

Storage

- System to filter separated oil
- Storage in suitable containers that exclude light
- Method to remove dissolved water (filtered bed of anhydrous sodium sulfate or chilling)
- Removal of residual still notes and dissolved oxygen (bubbling stream of nitrogen or allow oil to breathe and topping drum to over flowing to remove all air)

Where possible the still vessel condenser and separator should be fabricated from stainless steel. In developing countries access to specialist fabricators, and equipment and skills for maintenance and repair, should be of primary consideration in the design of the distillation system. Seeking professional advice is also critical.

Having an efficient separator in an important item of the distillation process. To put a lot of effort into distilling the oil is self-defeating if the separator recovery process is less than adequate. The majority of essential oils float on water i.e. their specific gravity is less than 1, but there are a few of the wood and root oils that are heavier than water. Separation of oils whose density is close to that of water or where the oil contains one major component whose density is greater than 1, while the other components have a density less than 1, is more difficult. The design and operation of the separator needs to be specific to the oil being extracted [4].

In addition to steam distillation, specific crops, particularly the high priced spices, are now also extracted by solvents and carbon dioxide as this provides standardized extracts of high quality, free from contaminants. Super critical fluid or gaseous extraction methods are becoming more common because of the problem of solvent residues in food. The following examples demonstrate different management needs for specific spice crops.

Vanilla is extracted by two main methods, a percolation method and the oleoresin method. The percolation method consists of circulating a solvent solution of ethanol and water 35-50:65-50 (v/v), over and through the beans, under vacuum. This process may take 48-72 hours and at completion a vanillin solution about four-fold strength can be obtained. The oleoresin method consists of pulverising whole beans and then circulating ethanol over the beans under vacuum at about 45°C. The excess alcohol is removed by evaporation. This process takes about 8-9 days, but by using this process, approximately 10-fold strength vanillin may be obtained. Commercially natural vanillin is sold as a dilute ethanol extract. Post-extraction processing includes filtration or centrifuging to aid clarification and aging for a year follows this.

Pepper essential oil recovery, as an industrial process involves the flaking of the black pepper using roller mills and placing this material in a distillation basket. Dry steam is passed through the ground pepper and the oil present in the pepper is vaporized. This mixture is cooled in the condenser and the oil collected using an oil/water separator. It is possible to make essential oils to different flavour specifications by blending oils from different grades of pepper. The oleoresin offers considerable advantages over whole or ground spice in that they are uniform in composition and strength. Contaminants are absent and thus oleoresins can be added to any food after adjusting the flavour concentration. Oleoresin extraction represents the total flavour and aroma of pepper by the extraction of ground pepper using solvents like ethanol, acetone, ethyl dichloride or ethyl acetate.

Clove bud oil is obtained by hydro- or steam distilling whole or broken buds and is now commonly extracted in the country of origin. Leaf oil is extracted on-site, again using hydro- or steam distillation. A typical charge of 1000kg of dry leaves yields <25kg of crude oil, over a 4-6 hour distillation. The distilling method and distillation time affect both the oil yield and characteristics: e.g. combined water and steam distilling produces more oil than steam alone. Using water and steam for four hours gave the highest oil yield of 3% while steam alone produced oils lower in eugenol.

Nutmeg oleoresins, obtained by solvent extraction from the dried spice of nutmeg, are used in colourings and flavourings in the food industry and are a direct competitor of the dried spice. Nutmeg butter that contains between 25-40% of fixed oil is obtained by expression, usually by hot manual pressing. Nutmeg butter is a highly aromatic, orange-coloured fat. Poor quality nutmegs are used for nutmeg butter production. The seed of nutmeg contains 8%-15% of essential oil obtained by steam distillation. Nutmeg oil is a colourless, pale yellow or pale green liquid with an odour and taste of the spice. During distillation exposure to the vapours should be kept to a minimum due to the toxicity of the essential oil compounds.

Capsicums, Chilli peppers and Paprika dried fruits are ground and solvent extracted to obtain the oleoresin. The fruits must be free of other plant material and have a moisture level less than 8% and fineness of grinding is critical to oleoresin yield and quality. Supercritical fluid extraction produces oleoresins whose pungency and organoleptic characteristics are close to the original fruit. Oleoresins reflect the parent material and vary in pungency and colour. Oleoresins have replaced powders in the food processing industry.

Cinnamon & Cassia bark produces two oils, a superior type derived from the inner bark and a lower quality from broken quills, chips and bark. Hydro distillation or steam distillation of chips, featherings and quillings produce cinnamon bark oil or Chinese cassia oil. Bark to be distilled for oil should be kept dry as dampness encourages mould or fermentation that directly affects oil composition. The leaves left after trimming the cut stems, as well as those obtained from pruning, provide the raw material for production of cinnamon leaf oil. The leaves are usually allowed to dry for a few days before distillation. Cinnamon and cassia oils, which have variation in quality because of geographical origins of the source material, are both normally rectified to provide oils of a more uniform composition.

Allspice–Pimento leaves may be fresh, or dried and stored for 2-3 months prior to steam distilling, with little effect on oil yield or phenol content. Yield from dried leaves is 0.5-3% and fresh leaves 0.3-1.25%. Modern stills taking a 1-2 t charge are used, with an approximate 4-hour distilling run. The oil is stored in stainless steel drums. Berry oil is obtained by crushing berries immediately prior to loading, and steam distilling for about 10 hours with cohobation (repeated distillation). The total oil yield is 3.3-4.5%. The organoleptic properties of the berry oil vary with production area and chemotype variation exists in the species. The oil content of ginger rhizomes is dependent on cultivar and a volatile oil content up to 4.4% is quoted. Poor post-harvest handling or distilling can substantially reduce the important pungent compounds.

6 Overall Losses

The major losses in post-harvest and production are dependent on many factors. Poor harvesting methods with immature crop product, disease- or pest-contaminated material, or rotten and damaged material, all encourage crop losses. There is a need to have facilities such as artificial driers and dry storage to minimise the problem of rainfall interrupting the crop drying. The consequences of poor drying and storage multiply into microbial invasion, which can have disastrous results on the potential sale and can lead to rejection of the crop. Poor processing methods, creating damage, can lead to loss of quality and losses, while poor storage facilities can also lead to losses to pests and to quality. Failure to comply with legislative requirements at the port of entry can also lead to rejection of a consignment. The cost of these losses is progressively greater as the products move through the post-harvest chain. This is why it is important to keep information flowing with the marketplace so that an informed decision (such as, not to harvest a crop) can be made before investing in processing, packaging and transport.

Bearing these issues in mind, strategic marketing decisions can be made where a new crop may be targetted to an affluent urban market within the growing country in order to establish the industry securely. In some cases, marketing to an international supermarket chain within the growing country requires compliance with international export standards. Once the production and post-harvest system is established to meet these criteria, most of the barriers to growing for export have already been overcome.

7 Pest control

Pest control is targeted at reducing the losses associated with pest feeding and spoilage or micro-organism invasion and contamination. Rodent control is a continuing problem but sanitation and clean practices, aided by well-built storage facilities and the strategic use of baits, help keep the problem in control. Storage insects can also bring significant damage to the stored crop. Good quality storage facilities that can be cleaned and fumigated before the harvest will help pest management. There is on-going strategic management fumigation needed in storage facilities. As noted previously, cleaning and packaging after drying can assist in pest control. Micro-organism spoilage often starts in the field, or with contaminated equipment and is carried from the field to the store. High humidity is the crucial factor encouraging fungal infection. The drying of the crop and moisture control in the storage facility is of primary importance in controlling fungal invasion. The use of preventative measures such as sterilizing equipment or disinfecting with antiseptic solutions all aid in reducing fungal outbreaks. Only properly trained personnel, wearing appropriate protective clothing (such as overalls, gloves, helmet, goggles, face mask), should apply agrochemicals.

7.1 Pest species

Pests can be general to stored produce or specific to a crop [13]. Common stored product pests such as the drug store beetle or the tobacco borer beetle attack stored ginger. A range of storage pests and particularly the nutmeg weevil eats stored nutmeg and mace. Spice beetle and cigarette beetle attack chillis during storage. Rats also have a great liking for chillis and the storage method should protect against this pest. Chilli and paprika spice is vulnerable to contamination from mould toxins particularly the aflatoxins. Vanilla is prone to mite attack that encourages spoilage. Fumigation can be needed with severe invasion. Harvesting management and fermentation practice can be critical to keeping mites under control.

7.2 Relative status of major pest species

Spice and herb crops, because of their essential oil content, have an enhanced ability to keep pest invasion to a minimum provided the crop has been dried to correct specification and stored in temperature and humidity controlled conditions. A major problem can be rodents or fungal invasion but these are secondary causes due to inferior facilities and less than ideal management. Produce which has field insect contamination can be extracted for essential oil production and provided these oils are stored in clean sealed drums in a cool environment, there is little likelihood of pest spoilage.

7.3 Pest control methods

The usual principles of pest and disease control apply. Pest and disease pressure should be minimised before harvest. Grading restricts the passage of pests and diseases into the stored product. Many micro-organisms are effectively controlled by the low moisture content of well-dried herbs and spices making further chemical treatment unnecessary, as long as strict attention is paid to the maintenance of a dry product through effective packaging. For example, in chillis, using an integrated strategy best controls aflatoxins. Initially disease in the field needs to be controlled by preventing insect damage to the fruit. At harvest, diseased and damaged fruit should be removed to prevent the source of moulds. Fruit should be processed immediately after harvest or stored under refrigeration. During processing, conditions need to be constantly controlled to ensure the moisture content is always below 11% and moulds cannot grow.

Two physical processing methods are effective for the control of pests in spices: the use of microwaves and ionising radiation. Microwaves penetrate the food and are converted to heat in areas of high water content. Ionisation treatments consist of exposing the dried spices to gamma radiation or X-rays. The doses used and permitted on food never render the products radioactive and ionisation does not leave any residues. For example, there are several methods available to sterilize dried pepper including hot air or steam, gamma irradiation, chemical or microwave use. Gamma irradiation is considered to be a superior method for sterilization and insect disinfestations due to its ability to treat pepper that has been pre-packed. As irradiation is a cold process the loss of volatile or flavour components is overcome, and this process does not leave harmful residues.

As noted previously (section 1.5), pest contamination in spices will always be identified by the importing country and can lead to consignment rejection or reduced prices because of extra processing. The FDA Technical Bulletin Number 5 on macro-analytical methods for spices, condiments, flavours, and crude drugs details the procedures to quantify the contamination (http://www.cfsan.fda.gov/~dms/mpm-5.html).

8 Economic and Social Considerations

8.1 Overview of costs and losses

Herbs, spices and essential oils suffer the problems inherent in commodity trading. The market demand and price for agricultural production can be greatly affected by global crop growing conditions, the amount of stored product from the past, and the changing market demand driven by consumer preference and by manufacturing formulators. The market can be cyclical, moving from under-supply to over-supply as a result of price and crop productivity. Large fluctuations in price can make the crop uneconomic and in some cases perennial crops may be left unharvested until the commodity price rises to make harvesting and processing economic. More processing of herbs, spices and essential oils in the producing countries would aid greater price stability in the market place by providing contracts to growers and processors and enable the countries of origin to move higher up the processing chain away from the raw commodity trade and attain higher prices. The market state and prices paid for spices can be viewed on a number of websites and two examples are www.spizes.com or www.indianspices.com.

8.2 Major problems: Maintenance of Quality Standards

One major problem for the industry is to ensure quality standards are maintained by growing and processing clean, high quality spice that has no adulteration or contamination. This requires a concerted effort by the growers, processors, and traders to make certain that the products are of the highest standard to meet food hygiene requirements. There is a need to identify the problem areas (e.g. drying methods, or storage) that can have a significant effect on the quality outcome. The adoption of a hazard analysis and critical control point (HACCP) system which focuses on prevention rather than relying mainly on end-product testing, would seem to be a worthwhile advance. The HACCP system provides a science-based and systematic approach to identify specific hazards, and measures for their control, It ensure the safety of foods. There is a need for the production and processing stages for each crop to have individual HACCP procedures developed and adopted to ensure quality standards and to provide an insight into the most hazardous areas likely to affect spice quality (http://www.fao.org/docrep/005/Y1579E/y1579e03.htm).

A different but very real problem for developing countries is the temptation to invest effort in production of a novel niche crop such as a particular spice because of its high price, not realising how small the market is and how much the price may drop as the production rises. Successful niche marketing of high-value crops requires constant information flow from the market to the grower and vice versa.

8.3 Proposed improvements

The herb and spice and essential oil industry should adopt a HACCP system, specific to a crop, to help identify the main areas of hazard to food safety and quality in the production chain. There is a need to provide financial assistance to grower co-operatives or businesses to build infrastructure such as crop driers or processing equipment, to ensure high quality post-harvest methods. In addition, there is a need to encourage investment by governments, aid agencies or multi-national companies into state-of-the-art processing factories in the developing countries.

It is imperative that growers of niche products such as herbs, spices and essential oils are part of an integrated system which links their production to a particular anticipated (or contracted) market. It is critical to decide in advance whether production is aimed at urban consumers in the same country; an industrial processor in a neighbouring country; or affluent consumers in a distant country. Different investments are appropriate depending on these target markets; and all aspects of the post-harvest chain need to be in place before production begins. This includes the processing and transportation infrastructure and, importantly, systems for rapid and efficient information flow to and from the market.

8.4 Gender aspects

Niche marketing of minor crops such as herbs, spices and essential oils provides enormous potential for generating improved incomes for rural women. The relatively high value and low weight of the products means they are suited for small-scale production and processing operations which can be organised to work around other farming and domestic duties which often traditionally fall on women. Medium-scale processing operations can be established at village level, ensuring maximal retention of the value of the crop in those rural areas.

Unfortunately there may be many negative social factors to overcome: for example, farm advisors may recommend diversification into niche crops without recognising that women's time is not infinitely elastic. An assessment of their existing workload is required to ensure survival is not already filling their day. Also, social factors will determine whether there is any improvement in the financial status of women from participation in the spice trade; frequently, men, regardless of their contribution to the work, control household cash income and in some countries banks may not be able to lend to women.

Finally it is important to note that the appeal of growing a cash crop has often been found to differ between men and women. Men seem to be more willing to make risky cash cropping decisions than women, who generally prefer to ensure there is sufficient food to feed the family first. In very poor communities or unreliable environments, the consequences of such risks may be disastrous. Diversified farming choices are required to help ensure that a local community will not be left without food if a risky cash crop fails to generate income.

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Appendix I: Spice and Essential Oil Products and their Growing Regions

Table 1: Spice and Essential oil crop products from fruits and seeds for world climate zones (Köppen's)

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Abelmoschus moschatus	Ambrette	Malvaceae	Perennial shrub	Seeds	EO, A, C	Aw
Aegle marmelos	Bael, Bengal Quince	Rutaceae	Perennial tree	Fruit rind, Flowers	EO	Aw, Bs
Aframomum angustifolium	Madagascar cardamom	Zingiberaceae	Perennial herb	Fruit,Seeds	S	Aw
Aframomum hanburyi	Cameroon cardamom	Zingiberaceae	Perennial herb	Fruit,Seeds	S	Aw
Aframomum koranima	Korarima cardamom	Zingiberaceae	Perennial herb	Fruit,Seeds	S	Aw
Aframomum. melegueta	Grains of Paradise	Zingiberaceae	Perennial herb	Fruit,Seeds	S	Aw
Allium schoenoprasum	Chive	Alliaceae	Perennial herb	All parts	S, EO, O	Aw, Ar, Bs, Cs, Do, Dc, Df, Dw, E
Amomum aromaticum	Bengal cardamom	Zingiberaceae	Perennial herb	Fruit, Seed	S, EO	Aw
Amomum kepulaga	Round cardamom	Zingiberaceae	Perennial herb	Fruit, Seed	S, EO	Aw
Amomum krervanh	Cambodian cardamom	Zingiberaceae	Perennial herb	Fruit, Seed	S, EO	Aw
Amomum subulatum	Nepal cardamom	Zingiberaceae	Perennial herb	Fruit capsule	S, EO	Aw,
Amomum tsao-ko	Tsao-ko cardamom	Zingiberaceae	Perennial herb	Fruit, Seed	S, EO	Aw
Amomum villosum	White cardamom	Zingiberaceae	Perennial herb	Fruit, Seed	S, EO	Aw, Ar
Anethum graveolens	Dill	Apiaceae	Annual herb	Leaves, Seeds	S, EO, O, C, A	Aw, Bs, Cs, Do, Dc, Df, Dw, E
Anethum sowa	Indian Dill	Apiaceae	Annual herb	Seeds	S, EO, O, C, A	Aw, Bs, Cs, Do, Dc, Df, Dw, E
Angelica archangelica	Angellica	Apiaceae	Biennial herb	Roots, Seeds	S, EO, O, C, A	Bs, Do, Dc, Df, Dw, E
Apium graveolens	Celery	Apiaceae	Biennial herb	Aerial parts, Seeds	S, EO, O	Aw, Bs, Cs, Do, Dc, Df, Dw, E
Artocarpus heterophyllus	Jackfruit	Moracaea	Perennial tree	Fruit, Seed	S	Aw, Ar, Cf, Cs, Cw
Averrhoa belimbi	Bilimbi	Oxalidaceae	Perennial tree	Fruit	S	Aw, Ar
Averrhoa carambola	Carambola	Oxalidaceae	Perennial tree	Fruit	S	Aw, Ar
Berberis vulgaris	Barberry	Berberidaceae	Perennial shrub	Fruit	S	Do, Dc
Borago officinalis	Borage	Boraginaceae	Annual herb	Flowers, Seed	S, A, E	Bs, Cs, Do, Dc, Df, Dw
Brassica carinata	Abysinnian mustard	Brassicaceae	Annual herb	Seed	S	Aw, Cf
Brassica juncea	Indian mustard	Brassicaceae	Annual/perennial herb	Seed	S	Aw, Bs, Cs, Do
Brassica nigra	Black Mustard	Brassicaceae	Annual herb	Seed	S, EO, A	Bs, Do, Dc, Df, Dw

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Bunium persicum	Black caraway	Apiaceae	Perennial herb	Root,Seed	S, EO	Bs, Bw, Dc, E*
Bursera penicillata	Elemi gum	Burseraceae	Perennial tree	Fruit husk,Seed, Wood	EO	Aw, Ar*
Canarium ovatum	Pilinut	Burseraceae	Perennial tree	Seed fruit stems	EO, O	Aw, Ar
Capsicum annuum	Peppers	Solanaceae	Annual shrub	Fruits	S, O	Aw, Ar, Cf, Cs, Cw
Capsicum frutescens	Cayenne pepper	Solanaceae	Annual shrub	Fruits	S, O	Aw, Ar, Bs, Cf, Cs, Cw
Carum carvi	Caraway	Apiaceae	Biennial herb	Seeds	S, EO, O	Cs, Do, Dc, Df, Dw
Citrofortunella X microcarpa	Calamondin	Rutaceae	Perennial tree	Fruit	S	Aw, Ar, Cf, Cs, Cw
Citrullus colocynthis	Colocynth	Cucurbitaceae	Annual vine	Seed	S	Aw, Ar, Bs, Cs, Do
Citrus aurantifolia	Lime	Rutaceae	Perennial tree	Fruit rind	EO	Aw, Ar, Cf, Cs, Cw
Citrus aurantium	Sour Orange	Rutaceae	Perennial tree	Flowers, Fruit rind, Leaves,	EO	Aw, Bs, Cf, Cs, Cw
Citrus bergamia	Bergamot orange	Rutaceae	Perennial tree	Fruit rind	EO	Aw, Ar, Bs, Cf, Cs
Citrus limon	Lemon	Rutaceae	Perennial tree	Fruit rind	S, EO	Aw, Bs, Cf, Cs, Cw
Citrus paradisi	Grapefruit	Rutaceae	Perennial tree	Seed	EO	Aw, Ar, Bs, Cs
Citrus reticulata	Mandarine orange	Rutaceae	Perennial tree	Fruit rind	EO	Aw, Bs, Cf, Cs, Cw
Citrus sinensis	Sweet Orange	Rutaceae	Perennial tree	Fruit rind, Flowers, Seed	EO	Aw, Ar, Bs, Cf, Cs, Cw
Coffea arabica	Arabian coffee	Rubiaceae	Perennial tree	Seed	S, EO	Aw, Cf, Cw
Coffea canephora	Coffee	Rubiaceae	Perennial tree	Seed	S, EO	Aw
Coriandrum sativum	Coriander	Apiaceae	Annual herb	Fruits, Leaf	S, EO, O, E	Aw, Bs, Cs, Do, Dc
Cuminum cyminum	Cumin	Apiaceae	Annual herb	Fruits	S, EO, O, E	Aw, Cs
Daucus carota	Carrot	Apiaceae	Biennial herb	Seeds	EO, E	Aw, Bs, Cs, Do, Dc, Df, Dw
Dipteryx odorata	Tonka tree	Fabaceae	Perennial tree	Seeds	A	Aw, Ar
Elettaria cardamomum	Cardamom	Zingiberaceae	Perennial herb	Fruit capsule	S, EO, O,E	Aw, Ar, Cs
Eruca vesicaria	Rocket	Brassicaceae	Annual herb	Leaves, Seed	S	Bs, Cs
Foeniculum vulgare	Fennel	Apiaceae	Biennial herb	Seeds	S, EO, E	Aw, Bs, Cs, Do, Dc, Df, Dw
Garcinia cambogia	Cambodge	Clusiaceae	Perennial Tree	Fruit	S	Aw, Ar*
Garcinia indica	Kokam	Clusiaceae	Perennial tree	Bark, Fruit	S, E	Aw, Ar*
Glycine max	Soya bean	Fabaceae	Annual herb	Fruit	S	Aw, Bs, Cs
Hibiscus sabdariffa	Roselle	Malvaceae	Annual herb	Flowers, Fruit	S	Aw, Ar, Bs
Ilicium verum	Star Anise (baldian)	Iliciaceae	Perennial tree	Fruits	S, EO	Aw, Ar, Cf*
Juniperus communis	Juniper	Cupressaceae	Perennial shrub	Fruits	S, EO	Cs, Do, Dc, E, F
Laurus nobilis	Bay Laurel	Lauraceae	Perennial tree	Leaves, Berry	S, EO, O	Aw, Ar, Bs, Cs, Do, Dc, Dw

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Levisticum officinale	Lovage	Apiaceae	Perennial herb	Aerial parts, Seeds, Roots	S, EO	Do, Dc, Dw
Litsea cubeba	Cubeba	Lauraceae	Perennial tree	Fruits	EO	Aw, Ar Cf*
Luvunga scandens	Luvunga	Rutaceae	Perennial shrub	Fruits	EO	Aw, Ar Cf*
Lycopersicon esculentum	Tomato	Solanaceae	Annual herb	Fruits	S	Aw, Ar, Bs, Cf, Cs, Cw, Do, Dc, Df, Dw
Monodora myristica	Jamacia nutmeg	Annonaceae	Perennial tree	Aril, Seeds	E	Aw, Ar*
Moringa oleifera	horseradish tree	Moringaceae	Perennial tree	Roots, Leaves, Fruit, Seed	S	Aw, Bs, Cs
Morus alba	Mulberry	Moraceae	Perennial tree	Leaves , Fruit	EO	Aw, Bs, Cf, Cs, Do
Myrica gale	Bog myrtle	*Myricaceae*	Perennial shrub	*Leaves , Fruit*	*S*	*Dc, Do, E**
Myristica argentea	Papuan nutmeg	Myristicaceae	Perennial tree	Kernal, Aril	S	Aw, Ar *
Myristica fragrans	Nutmeg	Myristicaceae	Perennial tree	Kernal, Aril	S, EO, O	Aw, Ar
Myrrhis odorata	Sweet Cicely	Apiaceae	Perennial herb	Foliage, Seeds	S, EO	Dc, Do, E *
Nasturtium officinale	Water cress	Brassicaceae	Perennial herb	Leaves , Seed	S	Aw, Ar, Bs, Cf, Cs, Cw, Do, Dc, Df, Dw
Nigella damascena	Damas black cumin	Ranunculaceae	Annual herb	Seeds	S	Aw, Bs, Cs *
Nigella sativa	Black cumin	Ranunculaceae	Annual herb	Seeds	S	Aw, Bs, Cs
Ocimum gratissimum	Clove basil	Lamiaceae	Perennial shrub	Fruit calyx	EO	Aw, Ar*
Olea europaea	Olive	Oleaceae	Perennial tree	Fruit, Seed	S, E	Ar, Bs, Cs
Papaver somniferum	Poppy	Papaveraceae	Annual herb	Seeds	S	Aw, Ar, Bs, Cs, Do, Dc, Df, Dw
Perilla frutescens	Perilla	Lamiaceae	Annual herb	Seeds	S, EO	Cf, Dc*
Petroselinum crispum	Parsley	Apiaceae	Biennial herb	Aerial parts, Seed	EO	Aw, Ar, Bs, Cf, Cs, Cw, Do, Dc, Df, Dw, E
Pimenta dioica	Allspice	Myrtaceae	Perennial tree	Fruits, Leaves	S, EO, O	Aw, Ar
Pimpinella anisum	Anise	Apiaceae	Annual herb	Fruits	S, EO	Aw, Bs, Cs, Do
Pinus pinea	Stone pine	Pinaceae	Perennial tree	Seeds	S	Bs, Cs
Piper longum	Indian pepper	Piperaceae	Perennial vine	Fruits	S, EO, O	Aw, Ar*
Piper nigrum	Pepper	Piperaceae	Perennial vine	Fruits	S, EO, O	Aw, Ar
Piper species	Pepper	Piperaceae	Perennial shrubs/vines	Fruits	S. EO	Aw, Ar*
Prunus dulcis	Almond	Rosaceae	Perennial tree	Seed kernel	S, EO, O	Bw, Bs, Cs, Do, Dc, Df, Dw
Prunus mahaleb	Mahaleb cherry	Rosaceae	Perennial tree	Seeds	S	Cf, Dc, Do*
Psidium guajava	Guava	Myrtaceae	Perennial tree	Fruit, Leaves	EO	Aw, Ar, Bs, Cf, Cs, Cw
Punica granatum	Pomegranate	Punicaceae	Perennial tree	Seed	S	Aw, Ar, Bs, Cf, Cs, Cw
Sambucus nigra	Elder	Caprifoliaceae	Perennial tree	Flowers, fruit	S	Aw, Cs, Cw, Do, Dc
Schinus molle	Pepper tree	Anacardiaceae	Perennial tree	Fruit Leaves	S, EO	Aw, Bs, Cf, Cs, Cw
Schinus terebenthifolius	Brazillian pepper	Anacardiaceae	Perennial tree	Fruit	S	Aw, Ar , Cf *

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Sesamum indicum	Sesame	Pedaliaceae	Annual herb	Seeds	S, E	Aw, Bs, Cf, Cs, Cw
Sinapis alba	White mustard	Brassicaceae	Annual herb	Seed	S	Bs, Do, Dc, Df, Dw, E
Smyrnium olusatrum	Alexanders	Apiacea	Biennial herb	Leaves, Seed	S	Bs, Cs, Do*
Tamarindus indica	Tamarind	Cesalpiniaceae	Perennial tree	Fruits	S	Aw, Bs, Cf, Cs
Trachyspermum copticum	Ajowan caraway	Apiaceae	Annual herb	Fruits	S, EO	Bs, Cs*
Trigonella caerulea	Blue fenugreek	Fabaceae	Annual herb	Leaf, Seed	S	Bs, Cf, Cs, Dc, Do*
Trigonella foenum-graecum	Fenugreek	Fabaceae	Annual herb	Seed	S, EO, O	Aw, Bs, Cs, Do
Vanilla planifolia	Vanilla	Orchidaceae	Perennial herb	Fruits	S, EO, R, E,	Aw, Ar
Xylopia aethiopica	Ethiopian pepper	Annonaceae	Perennial tree	Fruit	S	Aw*
Zanthoxylum piperitum	Sichuan pepper	Rutaceae	Perennial tree	Fruits	S, EO	Aw, Cf*

[1]*The product classification used is: A: absolute; C: concrete; E: extract; EO: essential oil; R: resin; S: spice (or herb).*

[2]*The climate biome classifications as per FAO website (http://ecocrop.fao.org) are: Ar: tropical wet, Aw: tropical wet & dry, Bw: desert or arid, Bs: steppe or semiarid, Cf: subtropical humid, Cs: subtropical dry summer, Cw: subtropical dry winter, Dc: temperate continental, Df: temperate with humid winters, Do: temperate oceanic, Dw: temperate with dry winters, E: boreal. When the species did not have a biome requirement listed on the FAO ecocrop web site, this was estimated by the authors and acknowledged with an asterisk.*

Table 2: Spice and Essential oil crop products from leaves and stems for world climate zones (Köppen's)

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Abies alba	Silver Fir	Pinaceae	Perennial tree	Leaves	EO,	Do, Dc
Abies balsamea	Balsam Fir	Pinaceae	Perennial tree	Leaves	EO, R	Do, Dc, E
Acinos alpinus	Alpine calamint	Lamiaceae	Perennial herb	Leaves	EO	Bs, Cs, Dc, Do*
Acinos suaveolens	'Mint'	Lamiaceae	Perennial herb	Leaves	EO	Bs, Cs, Dc, Do*
Aeolanthus gamwelliae	Nindi	Lamiaceae	Perennial herb	Aerial parts	EO	Aw, Ar
Agastache foeniculum	Anise hyssop	Lamiaceae	Perennial herb	Aerial parts	EO	Do, Dc
Agastache rugosa	Korean mint	Lamiaceae	Perennial herb	Aerial parts	S, EO	Dc, E*
Agathosma betulina	Buchu	Rutaceae	Perennial shrub	Leaves	EO	Cf*
Agathosma crenulata	Buchu Long Leaf	Rutaceae	Perennial shrub	Leaves	EO	Cf*
Allium ascalonicum	Shallot	Alliaceae	Perennial herb	leaf/Bulb	S	Aw, Ar, Bs, Cf, Cs, Cw, Do, Dc, Df, Dw
Allium fistulosum	Welsh onion	Alliaceae	Perennial herb	Leaf, bulb	S	Aw, Cf, Do, Dc, E
Allium porrum	Leek	Alliaceae	Biennial herb	Leaves	S, EO	Cf, Cs, Do, Dc*
Allium tuberosum	Chinese chives	Alliaceae	Perennial herb	Leaves	S	Aw, Ar, Bs, Cf, Cs, Cw, Do, Dc, Df, Dw, E
Aloysia triphylla	Lemon verbena	Verbenaceae	Perennial shrub	Leaves	S, EO, O, C, A	Aw, Cs, Do
Anethum graveolens	Dill	Apiaceae	Annual herb	Leaves, Seeds	S, EO, O, C, A	Aw, Bs, Cs, Do, Dc, Df, Dw, E
Anthriscus cerefolium	Chervil	Apiaceae	Annual herb	Aerial parts	S, EO	Bs, Do
Apium graveolens	Celery	Apiaceae	Biennial herb	Aerial parts, Seeds	S, EO, O	Aw, Bs, Cs, Do, Dc, Df, Dw, E
Artemisia abrotanum	Southernwood	Asteraceaee	Perennial shrub	Leaf	S	Bs, Do, Dc, Df, Dw
Artemisia absinthium	Wormwood	Asteraceae	Perennial herb	Aerial parts	EO	Do, Dc
Artemisia annua	sweet wormwood	Asteraceae	Annual herb	Aerial parts	EO	Aw, Bs, Cf, Cs, Do, Dc, Df, Dw*
Artemisia dracunculus	Russian tarragon	Asteraceae	Perennial herb	Aerial parts	S, EO, O	Bw, Bs, Cs, Do, Dc, Df, Dw
Artemisia herba-alba	Wormwood	Asteraceae	Perennial shrub	Aerial parts	EO	Bs, Bw, Cs*
Artemisia maritima	Sea wormwood	Asteraceae	Perennial shrub	Aerial parts	EO	Cf, Cs*
Artemisia pallens	Davana	Asteraceae	Perennial shrub	Aerial parts	EO	Aw, Ar*
Artemisia vulgaris	Mugwort	Asteraceae	Perennial herb	Aerial parts	S, EO	Cf, Cs, Dc, Do, E*
Balsamita major	Costmary	Asteraceae	Perennial herb	Aerial parts	EO	Bs, Cs, Dc, Do*
Chamaecyparis obtusa	Hinoki Cypress	Cupressaceae	Perennial tree	Leaves, Wood	EO	Cf*
Cinnamomum burmannii	Indonesian Cassia	Lauraceae	Perennial tree	Leaves, Bark	S, EO	Ar
Cinnamomum camphora	Camphor	Lauraceae	Perennial tree	Leaves, Wood	S, EO	Aw, Ar, Cf, Cs, Cw
Cinnamomum cassia	Chinese cinnamon	Lauraceae	Perennial tree	Leaves	S, EO	Ar, Cf, Cw

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Cinnamomum loureirii	Vietnamese Cassia	Lauraceae	Perennial tree	Leaves , Bark	S, EO	Aw, Ar, Cf
Cinnamomum tamala	Indian Cassia	Lauraceae	Perennial tree	Leaves, Bark	S, EO	Aw, Ar*
Cinnamomum verum	Cinnamon	Lauraceae	Perennial tree	Leaves, Bark	S, EO, O	Ar, Cf
Cistus ladaniferus	Labdanum	Cistaceae	Perennial shrub	Aerial parts	EO, E	Bs, Cs*
Clausena anisata	Clausena	Rutaceae	Perennial tree	Leaves	EO	Aw, Ar*
Cnicus benedictus	Blessed thistle	Asteraceaee	Annual herb	Aerial parts	S, EO	Cs, Do, Dc, Df, Dw
Conyza canadensis	Horse weed	Asteraceae	Annual herb	Aerial parts	EO	Do, Dc
Coriandrum sativum	Coriander	Apiaceae	Annual herb	Fruits, Leaf	S, EO, O, E	Aw, Bs, Cs, Do, Dc
Crithmum maritimum	Samphire (sea fennel)	Apiaceae	Perennial herb	Leaf	S, EO	Do
Cupressus sempervirens	Italian Cypress	Cupressaceae	Perennial tree	Leaves, Bark	EO	Cs, Do
Cymbopogon citratus	Lemon Grass	Poaceae	Perennial herb	Leaves	EO	Aw, Ar, Cs
Cymbopogon flexuosus	Lemon Grass	Poaceae	Perennial herb	Leaves	EO	Aw, Ar, Cf
Cymbopogon jwarancusa	Lemon Grass	Poaceae	Perennial herb	Leaves	EO	Aw, Bs*
Cymbopogon martinii	Ginger Grass	Poaceae	Perennial herb	Leaves	EO	Aw, Ar*
Cymbopogon nardus	Citronella (Sri Lanka)	Poaceae	Perennial herb	Leaves	EO	Aw, Ar, Cs
Cymbopogon pendulus	Lemon Grass	Poaceae	Perennial herb	Leaves	EO	Aw, Ar*
Cymbopogon winterianus	Citronella (Indonesia)	Poaceae	Perennial herb	Leaves	EO	Aw, Ar*
Dimocarpus longan	Longan	Sapindaceae	Perennial tree	Leaves, Flowers	S	Aw, Ar, Cf, Cw
Elsholtzia ciliata	Vietnamese balm	Lamiaceae	Annual herb	Aerial parts	EO	Aw, Bs, Cf, Cs, Do*
Eriocephalus punctulatus	Cape chamomile	Asteraceae	Perennial shrub	Leaves	EO	Bs, Cf*
Eruca vesicaria	Rocket	Brassicaceae	Annual herb	Leaves, Seed	S	Bs, Cs
Eucalyptus citriodora	Spotted Gum	Myrtaceae	Perennial tree	Leaves	EO	Aw, Cf, Cs, Cw
Eucalyptus globulus	Blue Gum	Myrtaceae	Perennial tree	Leaves	EO	Cf, Cs, Cw, Do
Gaultheria procumbens	Wintergreen	Ericaceae	Perennial shrub	Leaf	S, EO	Bs, Cf, Dc*
Geranium macrorrhizum	Cranesbill	Geraniaceae	Perennial herb	Leaves, Roots	EO	Cf, Cs, Dc, Do*
Glechoma hederacea	Ground Ivy	Lamiaceae	Perennial herb	Leaves	S	Cs, Do, Dc
Hedeoma pulegioides	American pennyroyal	Lamiaceae	Perennial shrub	Aerial parts	EO	Cf, Dc*
Houttuynia cordata	Tsi	Saururaceae	Perennial herb	Leaves	S	Aw, Ar, Cf*
Hyssopus officinalis	Hyssop	Lamiaceae	Perennial shrub	Aerial parts	S, EO,	Bs, Cs, Do, Dc

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Ilex paraguariensis	Mate	Aquifoliaceae	Perennial tree	Leaves	S, EO	Aw, Cf, Cw
Juniperus virginiana	Eastern Red cedar	Cupressaceae	Perennial tree	Heartwood, Leaves	EO	Cf, Dc, Do*
Laurus nobilis	Bay Laurel	Lauraceae	Perennial tree	Leaves, Berry	S, EO, O	Aw, Ar, Bs, Cs, Do, Dc, Dw
Lavandula angustifolia	Lavander	Lamiaceae	Perennial shrub	Aerial parts	EO	Bs, Cs, Do, Dc, Df, Dw
Lavandula intermedia	Lavandin	Lamiaceae	Perennial shrub	Aerial parts	EO	Bs, Cs
Lepidium sativum	Cress	Brassicaceae	Perennial herb	Aerial parts	S	Aw, Bs, Cf, Dc, Do*
Levisticum officinale	Lovage	Apiaceae	Perennial herb	Aerial parts, Seeds, Roots	S, EO	Do, Dc, Dw
Lindera benzoin	Spice bush	Lauraceae	Perennial shrub	Leaves, Twigs	S, EO	Cf, Dc*
Lippia graveolens	Mexican sage	Verbenaceae	Perennial shrub	Leaves	S, EO	Aw, Ar, Bs*
Marrubium vulgare	Horehound	Lamiaceae	Perennial shrub	Leaf	S, EO	Cf, Cs, Cw, Do, Dc, Df, Dw
Matricaria chamomilla	Chamomile	Asteraceae	Annual herb	Leaves, Flowers	EO	Cs, Do, Dc, Df, Dw
Melaleuca quinquenervia	Cajeput	Myrtaceae	Perennial tree	Leaves	EO	Aw, Ar, Cf
Melissa officinalis	Lemon Balm	Lamiaceae	Perennial herb	Aerial parts	S, EO	Bs, Cs, Do, Dc, Df, Dw
Mentha aquatica	Bergamot mint	Lamiaceae	Perennial herb	Aerial parts	EO	Dc, Do*
Mentha arvensis	Japanese mint	Lamiaceae	Perennial herb	Aerial parts	EO	Aw, Ar, Bs, Cf, Cs, Cw, Do, Dc, Df, Dw
Mentha piperita	Peppermint	Lamiaceae	Perennial herb	Aerial parts	EO	Aw, Ar, Cf, Cs, Cw, Do, Dc, Df, Dw
Mentha pulegium	European pennyroyal	Lamiaceae	Perennial herb	Aerial parts	EO	Bs, Cs, Do, Dc, Df, Dw
Mentha x spicata	Spearmint	Lamiaceae	Perennial herb	Aerial parts	EO	Aw, Ar, Cf, Cs, Cw, Do, Dc, Df, Dw
Monarda citriodora	Lemon Bergamot	Lamiaceae	Annual herb	Aerial parts	EO	Cf*
Monarda didyma	Bergamot	Lamiaceae	Perennial herb	Aerial parts	EO	Cf, Dc, Do*
Monarda punctata	Horsemint	Lamiaceae	Perennial herb	Aerial Parts	EO	Bw, Cf, Dc*
Morus alba	Mulberry	Moraceae	Perennial tree	Leaves , Fruit	EO	Aw, Bs, Cf, Cs, Do
Murraya koenigii	Curry leaf	Rutaceae	Perennial tree	Leaf	S	Aw
Myrica gale	Bog myrtle	Myricaceae	Perennial shrub	Leaves , Fruit	S	Dc, Do, E*
Narcissus poeticus	Poet's Narcissus	Liliaceae	Annual herb	Aerial parts	C, A	Cs, Cf, Dc, Do*
Nasturtium officinale	Water cress	Brassicaceae	Perennial herb	Leaves , Seed	S	Aw, Ar, Bs, Cf, Cs, Cw, Do, Dc, Df, Dw
Nepeta cataria	Catnip	Lamiaceae	Perennial shrub	Aerial parts	S, EO	Bs, Do, Dc, Df, Dw
Ocimum basilicum	Sweet basil	Lamiaceae	Annual herb	Leaves, Bark	EO	Aw, Ar, Cf, Cs, Cw, Do

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Ocimum tenuiflorum	Holy basil	Lamiaceae	Perennial shrub	Aerial parts	EO	Aw, Cs
Ocotea quixos	American cinnamon	Lauraceae	Perennial tree	Aerial parts	S	Aw, Ar*
Origanum majorana	Sweet marjoram	Lamiaceae	Perennial shrub	Aerial parts	EO	Cs, Do, Dc
Origanum vulgare	Oregano	Lamiaceae	Perennial shrub	Aerial Parts	EO, O, E	Bs, Cs, Do*
Pandanus amaryllifolius	Pandan leaves	Pandanaceae	Perennial tree	Leaf	S	Aw, Ar*
Pelargonium capitatum	Geranium	Geraniaceae	Perennial herb	Aerial parts	EO, C, A.	Bs, Cf*
Pelargonium graveolens	Geranium, rose	Geraniaceae	Perennial shrub	Aerial parts	EO, C, A.	Cs, Do
Petroselinum crispum	Parsley	Apiaceae	Biennial herb	Aerial parts, Seed	EO	Aw, Ar, Bs, Cf, Cs, Cw, Do, Dc, Df, Dw, E
Peumus boldus	Boldo	Monimiaceae	Perennial tree	Leaves	S, EO	Cs*
Pimenta racemosa	Bay Rum tree	Myrtaceae	Perennial tree	Leaves	EO, O	Aw, Ar
Pinus spp.	Pine	Pinaceae	Perennial tree	Heartwood, Needles Resin	EO, R, O, E	Bs, Bw, Cf, Cs, Cw, Dc, Df, Do, Dw, E*
Piper betle	Betle	Piperaceae	Perennial shrub	Leaves	S, EO	Aw, Ar
Pistacia lentiscus	Pistacia	Anacardiaceae	Perennial tree	Leaves, Resin	S, R, A	Cs, Do
Plectranthus amboinicus	Mexican mint	Lamiaceae	Perennial herb	Leaves	S	Aw, Ar*
Pogostemon cablin	Patchouli	Lamiaceae	Perennial herb	Leaves	EO, C, E	Aw, Ar
Polygonum hydropiper	Water pepper	Polygonaceae	Annual herb	Leaves	S	Aw, Bs, Cf, Do, Dc, E
Polygonum odoratum	Vietnamese coriander	Polygonaceae	Perennial herb	Leaves	S	Aw, Ar*
Portulaca oleracea	Purslane	Portulacaceae	Annual herb	Leaves	S	Aw, Ar, Cf, Cs, Cw
Rosmarinus officinalis	Rosemary	Lamiaceae	Perennial shrub	Aerial parts	S, EO	Bs, Cs, Do, Dc, Df, Dw
Ruta graveolens	Rue	Rutaceae	Perennial shrub	Leaves, Flowers, Fruits	EO	Aw, Bs, Cs, Do
Ruta montana	Mountain rue	Rutaceae	Perennial shrub	Leaves, Flowers, Fruits	S, EO	Cs, Dc, Do*
Salvia lavandulifolia	Spanish sage	Lamiaceae	Perennial herb	Aerial parts	EO	Bs, Cs, Do*
Salvia officinalis	Dalmatian Sage	Lamiaceae	Perennial shrub	Aerial parts	S, EO	Aw, Bs, Cs, Do, Dc, Df, Dw
Salvia sclarea	Clary sage	Lamiaceae	Perennial herb	Aerial parts	EO	Cs, Do, Dc, Df, Dw
Sanguisorba minor	Salad burnet	Rosaceae	Perennial herb	Leaves	S	Bs, Cf, Cs, Cw
Santolina chamaecyparissus	Lavender cotton	Asteraceae	Perennial shrub	Leaves	EO	Cs, Do
Satureja hortensis	Summer savory	Lamiaceae	Annual herb	Aerial parts	EO	Bs, Cs, Do, Dc, Df, Dw
Satureja montana	Winter savory	Lamiaceae	Perennial shrub	Aerial parts	EO	Cs, Do, Dc, Df, Dw

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Satureja viminea	Jamaican savory	Lamiaceae	Perennial shrub	Aerial parts	EO	Aw, Ar*
Skimmia laureola	Skimmia	Rutaceae	Perennial shrub	Leaves	EO	Bs, Cf*
Smyrnium olusatrum	Alexanders	Apiacea	Biennial herb	Leaves, Seed	S	Bs, Cs, Do*
Syzygium cumini	Jambolan	Myrtaceae	Perennial tree	Leaves	EO	Aw, Ar, Cf, Cs, Cw
Tanacetum vulgare	Tansy	Asteraceae	Perennial herb	Aerial parts	EO	Cs, Do
Thuja occidentalis	White Cedar	Cupressaceae	Perennial tree	Leaves	EO	Dc, E*
Thymus capitatus	Conehead thyme	Lamiaceae	Perennial shrub	Aerial parts	S, EO	Bs, Cs*
Thymus satureioides	Red thyme	Lamiaceae	Perennial shrub	Aerial parts	S, EO	Bs, Cs*
Thymus serpyllum	Wild thyme	Lamiaceae	Perennial shrub	Aerial parts	S, EO	Bs, Cs, Do, Dc
Thymus vulgaris	Common Thyme	Lamiaceae	Perennial shrub	Aerial parts	S, EO	Aw, Ar, Bs, Cs, Do, Dc, Df, Dw
Thymus zygis	Spanish Thyme	Lamiaceae	Perennial shrub	Aerial parts	S, EO	Bs, Cs, Do*
Trigonella caerulea	Blue fenugreek	Fabaceae	Annual herb	Leaf, Seed	S	Bs, Cf, Cs, Dc, Do*
Tsuga canadensis	Canada hemlock	Pinaceae	Perennial tree	Leaves	EO	Cf, Dc, E*
Tsuga heterophylla	Western hemlock	Pinaceae	Perennial tree	Leaves	EO	Do, E*
Verbena officinalis	vervain	Verbenaceae	Perennial herb	Aerial parts	S, EO	Cs, Do, Dc
Viola odorata	Violet	Violaceae	Perennial herb	Leaves, Flowers	A	Bs, Cf, Cs, Dc, Do*
Vitex negundo	Chaste tree	Verbenaceae	Perennial tree	Leaves, Stems, Bark	EO	Aw, Ar*

[1]The product classification used is: A: absolute; C: concrete; E: extract; EO: essential oil; R: resin; S: spice (or herb)

[2]The climate biome classifications as per FAO website (http://ecocrop.fao.org) are: Ar: tropical wet, Aw: tropical wet & dry, Bw: desert or arid, Bs: steppe or semiarid, Cf: subtropical humid, Cs: subtropical dry summer, Cw: subtropical dry winter, Dc: temperate continental, Df: temperate with humid winters, Do: temperate oceanic, Dw: temperate with dry winters, E: boreal. When the species did not have a biome requirement listed on the FAO ecocrop web site, this was estimated by the authors and acknowledged with an asterisk.

Table 3: Spice and Essential oil crop products from flowers and buds for world climate zones (Köppen's)

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Acacia dealbata	Silver Wattle	Fabaceae	Perennial tree	Flowers	O, C, A	Cf, Cs, Cw, Do
Acacia farnesiana	Cassie	Fabaceae	Perennial tree	Flowers	EO, C, A	Aw, Bs, Cs
Achillea millefolium	Yarrow (milfoil)	Asteraceae	Perennial herb	Flowers	EO	Cs, Do
Alpinia zerumbet	Shell Ginger	Zingiberaceae	Perennial herb	Rhizomes, Flowers	S, EO, O	Aw, Ar*
Borago officinalis	Borage	Boraginaceae	Annual herb	Flowers, Seed	S, A, E	Bs, Cs, Do, Dc, Df, Dw
Boronia megastigma	Boronia	Rutaceae	Perennial shrub	Flowers	O, A, E	Cs, Cf*
Cananga odorata	Ylang ylang	Annonaceae	Perennial tree	Flowers	EO	Aw, Ar
Capparis spinosa	Caper	Capparaceae	Perennial shrub	Buds , Flowers	S	Bs, Cs, Do, Dc
Chamaemelum nobile	Roman chamomile	Asteraceaee	Perennial herb	Flowers	EO	Bs, Cs, Do, Dc, Df, Dw
Citrus aurantium	Sour Orange	Rutaceae	Perennial tree	Flowers, Fruit rind, Leaves,	EO	Aw, Bs, Cf, Cs, Cw
Convallaria majalis	Lily of Valley	Liliaceae	Perennial herb	Flowers	EO, A	Do, Dc, E
Crocus sativus	Saffron	Iridaceae	Annual corm	Stigma	S	Cs, Do, Dc
Dianthus caryophyllus	Carnation	Caryophyllaceae	Perennial herb	Flowers	A	Cs, Dc, Do*
Dimocarpus longan	Longan	Sapindaceae	Perennial tree	Leaves, flowers	S	Aw, Ar, Cf, Cw
Etlingera elatior	Torch ginger	Zingiberaceae	Perennial herb	Flower bud	S	Aw, Ar
Helichrysum italicum	Curry Plant; Immortelle	Asteraceae	Perennial herb	Flowers	EO	Bs, Cs*
Hibiscus sabdariffa	Roselle	Malvaceae	Annual herb	Flowers, Fruit	S	Aw, Ar, Bs
Humulus lupulus	Hops	Cannabaceae	Perennial vine	Flowers	EO, E	Bs, Cf, Cs, Cw, Do, Dc, Df, Dw
Hyacinthus orientalis	Hyacinth	Liliaceae	Perennial herb	Flowers	A, E	Cs, Dc, Do*
Jasminum auriculatum	Jasmine	Oleaceae	Perennial shrub	Flowers	C, A, E	Aw, Ar*
Jasminum grandiflorum	Catalonian Jasmine	Oleaceae	Perennial shrub	Flowers	C, A, E	Aw, Bs, Cs*
Jasminum officinale	Jasmine	Oleaceae	Perennial shrub	Flowers	C, A, E.	Aw, Ar*
Jasminum sambac	Arabian Jasmine	Oleaceae	Perennial shrub	Flowers	C, A, E	Aw, Ar*
Lonicera caprifolium	Honeysuckle	Caprifoliaceae	Perennial shrub	Flowers	EO	Cs, Do, Dc
Lonicera japonica	Japanese honeysuckle	Caprifoliaceae	Perennial shrub	Flowers	EO, E	Cs, Do, Dc*
Matricaria chamomilla	Chamomile	Asteraceae	Annual herb	Leaves, Flowers	EO	Cs, Do, Dc, Df, Dw
Michelia champaca	Champaka	Magnoliaceae	Perennial tree	Flowers	A, EO	Aw, Cw, Do, Dc, Df, Dw
Myroxylon Pereira	Balsam of Peru	Fabaceae	Perennial tree	Flowers	EO	Aw, Ar *

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Myrtus communis	Myrtle	Myrtaceae	Perennial shrub	Flowers	S, EO	Bs, Cs, Do
Origanum onites	Pot marjoram	Lamiaceae	Perennial shrub	Flowers	EO	Cs, Do, Dc, Df, Dw
Osmanthus fragrans	Sweet olive	Oleaceae	Perennial shrub	Flowers	C, A, E	Aw, Ar*
Pandanus tectorius	Pandanus	Pandanaceae	Perennial tree	Flower	A, EO	Aw, Ar*
Polianthes tuberosa	Tuberose	Agavaceae	Bulbous Perennial	Flowers	EO, A	Aw, Cs, Bs
Ribes nigrum	Black currant	Grossulariaceae	Perennial shrub	Flower buds	A, E	Bs, Do, Dc, Df, Dw, E
Rosa centifolia	Rose	Rosaceae	Perennial shrub	Flowers	EO, A, E	Bs, Cs, Dc, Do*
Rosa damascena	Damask Rose	Rosaceae	Perennial shrub	Flowers	EO, A, E	Bs, Cs, Dc, Do*
Rosa rugosa	Turkestan rose	Rosaceae	Perennial shrub	Flowers	EO, A, E	Bs, Cs, Dc, Do*
Ruta graveolens	Rue	Rutaceae	Perennial shrub	Leaves, Flowers, Fruits	EO	Aw, Bs, Cs, Do
Ruta montana	Mountain rue	Rutaceae	Perennial shrub	Leaves, Flowers, Fruits	S, EO	Cs, Dc, Do*
Sambucus nigra	Elder	Caprifoliaceae	Perennial tree	Flowers, Fruit	S	Aw, Cs, Cw, Do, Dc
Syringa vulgaris	Lilac	Oleaceae	Perennial tree	Flowers	EO, A	Cs, Dc, Do*
Syzygium aromaticum	Clove	Myrtaceae	Perennial tree	Flower Buds,Leaves	S, EO, O, C, A, E	Aw, Ar, Cs
Tagetes erecta	Mexican Marigold	Asteraceae	Annual herb	Flowers	EO	Aw, Bs, Cs, Cf, Do, Dc*
Tagetes minuta	Wild marigold	Asteraceae	Annual herb	Flowers	EO, C, A	Aw, Bs, Cs, Cf, Do, Dc*
Tagetes patula	French marigold	Asteraceae	Perennial herb	Flowers	EO	Aw, Bs, Cs, Cf, Do, Dc*
Tropaeolum majus	Nasturtium	Tropaeolaceae	Annual herb	Flowers	S	Cs, Do
Viola odorata	Violet	Violaceae	Perennial herb	Leaves, Flowers	A	Bs, Cf, Cs, Dc, Do*

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[2]The climate biome classifications as per FAO website (http://ecocrop.fao.org) are: Ar: tropical wet, Aw: tropical wet & dry, Bw: desert or arid, Bs: steppe or semiarid, Cf: subtropical humid, Cs: subtropical dry summer, Cw: subtropical dry winter, Dc: temperate continental, Df: temperate with humid winters, Do: temperate oceanic, Dw: temperate with dry winters, E: boreal. When the species did not have a biome requirement listed on the FAO ecocrop web site, this was estimated by the authors and acknowledged with an asterisk.

Table 4: Spice and Essential oil crop products from roots and rhizomes for world climate zones (Köppen's)

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product oil	Product[1]	Climate Zone[2]
Acorus calamus	Sweet Flag	Acoraceae	Perennial herb	Rhizomes	EO, E	Aw, Ar, Bs, Cf, Cs, Cw, Dc
Allium ascalonicum	Shallot	Alliaceae	Perennial herb	Leaf/Bulb	S	Aw, Ar, Bs, Cf, Cs, Cw, Do, Dc, Df, Dw
Allium cepa	Onion	Alliaceae	Biennial herb	Bulbs	S, EO, O,	Aw, Ar, Bs, Cf, Cs, Cw, Do, Dc, Df, Dw
Allium fistulosum	Welsh onion	Alliaceae	Perennial herb	Leaf, Bulb	S	Aw, Cf, Do, Dc, E
Allium sativum	Garlic	Alliaceae	Biennial herb	Bulbs	S, EO, O	Aw, Ar, Cf, Cs, Cw, Do, Dc, Df, Dw, E
Allium ursinum	Wild garlic	Alliaceae	Bulbous perennial	Bulb, Leaf	S	Do*
Alpinia galanga	Greater galanga	Zingiberaceae	Perennial herb	Rhizomes, Leaves	S, EO, O	Aw, Ar
Alpinia officinarum	Lesser Galanga	Zingiberaceae	Perennial herb	Rhizomes	S, EO, O	Aw, Ar
Alpinia zerumbet	Shell Ginger	Zingiberaceae	Perennial herb	Rhizomes, Flowers	S, EO, O	Aw, Ar*
Angelica archangelica	Angellica	Apiaceae	Biennial herb	Roots, Seeds	S, EO, O, C, A	Bs, Do, Dc, Df, Dw, E
Armoracia rusticana	Horse radish	Brassicaceae	Perennial herb	Roots	S	Bs, Cs, Do, Dc, E*
Asarum canadense	Wild ginger	Aristolochiaceae	Perennial herb	Roots	S, EO	Cf, Dc, E*
Bunium persicum	Black caraway	Apiaceae	Perennial herb	Root,Seed	S, EO	Bs, Bw, Dc, E*
Curcuma longa	Turmeric	Zingiberaceae	Perennial herb	Rhizomes	S, EO, O, E	Aw, Ar, Cs
Curcuma zedoaria	Zedoary	Zingiberaceae	Perennial herb	Rhizomes	S, EO	Aw, Ar
Cyperus longus	Galingale	Cyperaceae	Perennial herb	Roots	S	Aw, Bw, Bs, Cf, Cs
Cyperus rotundus	Cypriol	Cyperaceae	Perennial herb	Rhizomes, Roots	EO	Aw, Ar, Bs, Cs, Cw
Cyperus scariosus	Cypriol	Cyperaceae	Perennial herb	Rhizomes, Roots	EO	Aw, Ar, Bs*
Geranium macrorrhizum	Cranesbill	Geraniaceae	Perennial herb	Leaves, Roots	EO	Cf, Cs, Dc, Do*
Inula helenium	Elecampane	Asteraceae	Perennial herb	Rhizomes	EO, E	Bs, Cs, Dc, Do*
Iris germanica	German Iris	Iridaceae	Perennial herb	Rhizomes	EO,	Cs, Do
Iris pallida	Florentine Orris	Iridaceae	Perennial herb	Rhizomes	EO,	Cs, Do*
Kaempferia galanga	Galangal	Zingiberaceae	Perennial herb	Rhizome	S	Aw, Ar, Cf
Moringa oleifera	Horseradish tree	Moringaceae	Perennial tree	Roots, Leaves, Fruit, Seed	S	Aw, Bs, Cs
Narcissus jonquilla	Jonquil	Liliaceae	Annual herb	Roots, Rhizomes	C, A	Cs, Cf, Dc, Do*
Nardostachys chinensis	Spikenard	Valerianaceae	Perennial herb	Roots, Rhizomes	EO	Aw, Cw*
Nardostachys jatamansi	Spikenard	Valerianaceae	Perennial herb	Roots, Rhizomes	EO	Aw, Cw*
Panax ginseng	Ginseng	Araliaceae	Perennial herb	Root	S	Cf, Do, Dc
Sassafras albidum	Sassafras	Lauraceae	Perennial tree	Root bark	EO	Cf, Dc

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product oil	Product[1]	Climate Zone[2]
Saussurea lappa	Costus	Asteraceae	Perennial herb	Roots	EO	Bs
Valeriana officinalis	Valerian	Valerianaceae	Perennial herb	Roots, Rhizomes	EO	Do, Dc
Vetiveria zizanoides	Vetiver	Poaceae	Perennial herb	Roots	EO, R	Aw, Ar, Cw*
Wasabia japonica	Wasabi	Brassicaceae	Perennial herb	Rhizomes	S	Cf, Do*
Zingiber officinale	Ginger	Zingiberaceae	Perennial herb	Rhizomes	S, EO, A, O, E	Aw, Ar, Cf

[1]*The product classification used is: A: absolute; C: concrete; E: extract; EO: essential oil; R: resin; S: spice (or herb).*

2The climate biome classifications as per FAO website (http://ecocrop.fao.org) are: Ar: tropical wet, Aw: tropical wet & dry, Bw: desert or arid, Bs: steppe or semiarid, Cf: subtropical humid, Cs: subtropical dry summer, Cw: subtropical dry winter, Dc: temperate continental, Df: temperate with humid winters, Do: temperate oceanic, Dw: temperate with dry winters, E: boreal. When the species did not have a biome requirement listed on the FAO ecocrop web site, this was estimated by the authors and acknowledged with an asterisk.

Table 5: Spice and Essential oil crop products from barks, wood and resins for world climate zones (Köppen's)

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Acacia senegal	Gum arabic	Fabaceae	Perennial tree	Resin, Seeds	R	Aw, Ar, Bw, Bs
Amyris balsamifera	Sandlewood	Rutaceae	Perennial tree	Wood	EO	Aw*
Aniba canelilla	Rosewood	Lauraceae	Perennial tree	Bark	S, EO	Ar*
Aniba rosaeodora	Rosewood	Lauraceae	Perennial tree	Bark	S, EO	Ar*
Anogeissus latifolia	Ghatti gum	Combretaceae	Perennial tree	Gum	R	Aw, Ar, Cf, Cs, Cw
Boswellia carteri	Frankincense	Burseraceae	Perennial tree	Secretion from bark	R, EO	Bs, Bw*
Boswellia serrata	Indian Frankincense	Burseraceae	Perennial tree	Secretion from bark	R, EO	Aw, Bs
Bursera penicillata	Elemi gum	Burseraceae	Perennial tree	Fruit husk, Seed, Wood	EO	Aw, Ar*
Canarium indicum	Java olive	Burseraceae	Perennial tree	Resin	R, E	Aw, Ar
Canarium luzonicum	Elemi oil	Burseraceae	Perennial tree	Secretion from bark , Resin	EO	Aw, Ar*
Canella alba	Wild cinnamon	Canellaceae	Perennial tree	Bark	S, EO	Aw, Ar
Cedrus deodara	Cedar	Pinaceae	Perennial tree	Wood	EO	Cs
Chamaecyparis obtusa	Hinoki Cypress	Cupressaceae	Perennial tree	Leaves, Wood	EO	Cf*
Cinnamomum burmannii	Indonesian Cassia	Lauraceae	Perennial tree	Leaves, Bark	S, EO	Ar
Cinnamomum camphora	Camphor	Lauraceae	Perennial tree	Leaves, Wood	S, EO	Aw, Ar, Cf, Cs, Cw
Cinnamomum loureirii	Vietnamese Cassia	Lauraceae	Perennial tree	Leaves , Bark	S, EO	Aw, Ar, Cf
Cinnamomum tamala	Indian Cassia	Lauraceae	Perennial tree	Leaves, Bark	S, EO	Aw, Ar*
Cinnamomum verum	Cinnamon	Lauraceae	Perennial tree	Leaves, Bark	S, EO, O	Ar, Cf
Commiphora africana	African myrrh	Burseraceae	Perennial tree	Bark	S	Aw, Bw, Bs
Commiphora erythraea	Opopanax	Burseraceae	Perennial tree	Resin	R, EO	Aw, Bw, Bs*
Commiphora molmol	Myrrh	Burseraceae	Perennial tree	Resin	R	Aw, Bw, Bs*
Copaifera officinalis	Copaiba	Fabaceae	Perennial tree	Resin	R, O	Aw, Ar*
Cupressus sempervirens	Italian Cypress	Cupressaceae	Perennial tree	Leaves, Bark	EO	Cs, Do
Ferula assa-foetida	Asafetida	Apiaceae	Perennial herb	Root exudate	S, R	Bs, Bw, Cs
Ferula gummosa	Galbanum	Apiaceae	Perennial herb	Root exudate	S, R	Bs, Bw, Cs*
Galipea officinalis	Angostura	Rutaceae	Perennial tree	Bark	E	Aw, Ar*

Species	Common Name	Family	Habit	Plant part(s) used as source(s) of product	Product[1]	Climate Zone[2]
Garcinia indica	Kokam	Clusiaceae	Perennial tree	Leaf, Bark, Fruit	S, E	Aw, Ar*
Juniperus virginiana	Eastern Red cedar	Cupressaceae	Perennial tree	Heartwood, Leaves	EO	Cf, Dc, Do*
Liquidambar styraciflua	Sweet gum	Hamamelidaceae	Perennial tree	Secretion from bark	R, EO	Aw, Cf, Cs
Ocimum basilicum	Sweet basil	Lamiaceae	Annual herb	Leaves, Bark	EO	Aw, Ar, Cf, Cs, Cw, Do
Ocotea pretiosa	Brazillian sassafras	Lauraceae	Perennial tree	Wood	EO	Aw, Ar*
Picrasma excelsa	Quassia	Simaroubaceae	Perennial tree	Wood	E	Aw, Ar*
Pinus spp.	Pine	Pinaceae	Perennial tree	Heartwood, Needles	EO, R, O, E	Bs, Bw, Cf, Cs, Cw, Dc, Df, Do, Dw, E*
Pistacia lentiscus	Pistacia	Anacardiaceae	Perennial tree	Leaves, Resin	S, R, A	Cs, Do
Santalum album	Sandlewood	Santalaceae	Perennial tree	Heartwood	EO	Aw, Bs
Sassafras albidum	Sassafras	Lauraceae	Perennial tree	Root bark	EO	Cf, Dc
Styrax benzoin	Benzoin	Styracaceae	Perennial tree	Secretion from bark	R, EO	Aw, Ar
Vitex negundo	Chaste tree	Verbenaceae	Perennial tree	Leaves, stems, bark	EO	Aw, Ar*

[1]The product classification used is: A: absolute; C: concrete; E: extract; EO: essential oil; R: resin; S: spice (or herb).

[2]The climate biome classifications as per FAO website (http://ecocrop.fao.org) are: Ar: tropical wet, Aw: tropical wet & dry, Bw: desert or arid, Bs: steppe or semiarid, Cf: subtropical humid, Cs: subtropical dry summer, Cw: subtropical dry winter, Dc: temperate continental, Df: temperate with humid winters, Do: temperate oceanic, Dw: temperate with dry winters, E: boreal. When the species did not have a biome requirement listed on the FAO ecocrop web site, this was estimated by the authors and acknowledged with an asterisk.

Appendix II: Trade in Spices and Essential Oils

Table 6: Total global imports of herbs and spices, 1998-2002.

Item	1998 Quantity (tons)	1998 Value (US$ 000)	1999 Quantity (tons)	1999 Value (US$ 000)	2000 Quantity (tons)	2000 Value (US$ 000)	2001 Quantity (tons)	2001 Value (US$ 000)	2002 Quantity (tons)	2002 Value (US$ 000)
Pepper whole	170,586	838,729	204,015	952,941	209,838	861,364	224,948	482,472	236,999	403,136
Pepper crushed/ ground	20,213	87,052	21,519	95,659	23,743	95,624	20,760	70,918	25,079	73,943
Capsicum	222,807	372,043	243,330	387,395	252,965	388,212	294,368	424,034	323,688	451,855
Vanilla	5,245	80,468	4,795	73,025	4,284	108,163	4,412	240,183	5,015	308,086
Cinnamon whole	62,434	127,348	69,686	123,496	71,529	106,648	68,874	107,165	76,981	104,052
Cinnamon, crushed /ground	9,831	17,100	9,291	15,570	10,456	17,371	10,961	16,380	13,567	20,306
Cloves whole/stem	51,266	52,962	45,543	89,937	49,969	148,273	53,256	209,716	28,151	122,627
Nutmeg/mace/ cardamom	43,133	157,757	36,952	228,972	40,798	270,604	39,883	253,381	42,330	229,452
Spice seeds	168,861	201,005	174,960	175,742	202,066	207,148	182,619	249,314	195,564	200,916
Ginger (except preserved)	170,709	150,235	174,965	173,093	204,708	196,590	231,383	190,280	230,744	141,536
Thyme/saffron/bay leaves	12,393	82,140	12,959	81,200	15,305	78,912	17,621	79,783	16,996	79,476
Spices, mixtures	158,177	268,879	146,538	286,763	163,609	290,797	237,613	296,105	180,491	313,806
World Total	**1,095,655**	**2,435,718**	**1,144,553**	**2,683,793**	**1,249,270**	**2,769,706**	**1,386,698**	**2,619,731**	**1,375,605**	**2,449,191**

Source: COMTRADE, UNSO, cited in [21]

Table 7: Top three exporting countries by type of spice in value and percentage share (2002)

Item	Export Value ('000 of US$)	First	$ Value	%	Second	$ Value	%	Third	$ Value	%
Pepper Whole	403,136	Indonesia	92,297	22.89	Vietnam	88,472	21.95	Brazil	53,119	13.18
Pepper crushed/ ground	73,943	India	10,271	13.89	Germany	8,175	11.06	Indonesia	7,637	10.33
Capsicum	451,855	China	109,285	24.19	India	57,399	12.70	Spain	40,298	8.92
Vanilla	308,086	Madagascar	196,878	63.90	Indonesia	32,640	10.59	Comoros	16,133	5.24
Cinnamon whole	104,052	Sri Lanka	46,205	44.41	China	24,547	23.59	Indonesia	18,131	17.42
Cinnamon, crushed / ground	20,306	Indonesia	5,493	27.05	Brazil	3,607	17.76	China	2,514	12.38
Cloves, whole / stem	122,627	Madagascar	27,085	22.09	Brazil	25,612	20.89	Indonesia	16,359	13.34
Nutmeg / mace / cardamom	229,452	Guatemala	104,152	45.39	Indonesia	42,292	18.43	India	17,900	7.80
Spice seeds	200,916	Syria Arab Rep.	43,093	21.45	India	34,339	17.09	Turkey	26,155	13.02
Ginger (except preserved)	141,536	China	76,985	54.39	Thailand	23,804	16.82	Taiwan	6,706	4.74
Thyme / saffron / bay leaves	79,476	Iran Islamic Rep.	24,100	30.32	Spain	20,115	25.31	Turkey	8,713	10.96
Spice, mixtures	313,806	India	43,648	13.91	Germany	28,830	9.19	France	16,479	5.25

Source: COMTRADE, UNSO, cited in [21]

Table 8: The Main Spice Exporting Countries by value ('000 US$) 1998-2002

Exporting Country	1998 Value	1999 Value	2000 Value	2001 Value	2002 Value
China	189,861	225,041	223,455	263,948	244,365
Madagascar	64,909	74,599	165,617	239,960	226,578
Indonesia	354,069	321,792	384,891	281,422	219,001
India	306,575	401,782	303,563	247,437	208,918
Guatemala	60,467	92,242	108,739	116,407	107,513
Brazil	119,161	109,388	104,188	112,594	105,801
Vietnam	85,142	155,399	143,038	101,178	103,316
Sri Lanka	80,117	75,225	74,064	77,987	83,876
Others	1,175,417	1,228,325	1,262,151	1,178,798	1,149,823
Total	**2,435,718**	**2,683,793**	**2,769,706**	**2,619,731**	**2,449,191**

Source: COMTRADE, UNSO, cited in [21]

Table 9: Traded quantities and values of some essential oils. NB: data are from pre-1993.

Essential oil	Species	Family	Volume (t)	Value (US$000)	Value/ton (US$000)
Orange	*Citrus sinensis*	Rutaceae	26,000	58500	2.3
Cornmint	*Mentha arvensis*	Lamiaceae	4,300	34400	8.0
Eucalyptus cineole-type	*Eucalyptus globulus, E. polybractea*	Myrtaceae	3,728	29800	8.0
Citronella	*Cymbopogon species*	Poaceae	2,830	10800	3.8
Peppermint	*Mentha x piperita .*	Lamiaceae	2,367	28400	12.0
Lemon	*Citrus limon .*	Rutaceae	2,158	21600	10.0
Eucalyptus citronellal-type	*Eucalyptus citriodora .*	Myrtaceae	2,092	7300	3.5
Clove leaf	*Syzygium aromaticum*	Myrtaceae	1,915	7700	4.0
Cedarwood (US)	*Juniperus virginiana .*	Cupressaceae	1,640	9800	6.0
Litsea cubeba	*Litsea cubeba .*	Lauraceae	1,005	17100	17.0
Sassafras (Brazil)	*Ocotea pretiosa*	Lauraceae	1,000	4000	4.0
Lime distilled (Brazil)	*Citrus aurantifolia*	Rutaceae	973	7300	7.5
Native spearmint	*Mentha spicata .*	Lamiaceae	851	17000	20.0
Cedarwood (Chinese)	*Chamaecyparis funebris*	Cupressaceae	800	3200	4.0
Lavandin	*Lavandula intermedia*	Lamiaceae	768	6100	7.9
Sassafras (Chinese)	*Cinnamomum micranthum*	Lauraceae	750	3000	4.0
Camphor	*Cinnamomum camphora*	Lauraceae	725	3600	5.0
Coriander	*Coriandrum sativum .*	Apiaceae	710	49700	70.0
Grapefruit	*Citrus paradisi*	Rutaceae	694	13900	20.0
Patchouli	*Pogostemon cablin*	Lamiaceae	563	6800	12.1
Scotch spearmint	*Mentha gracilis*	Lamiaceae	530	10600	20.0
Lavender	*Lavandula angustifolia .*	Lamiaceae	362	7200	19.9
Rosemary	*Rosmarinus officinalis .*	Lamiaceae	295	3500	11.9
Sweet fennel	*Foeniculum vulgare*	Apiaceae	255	7700	30.2
Dill weed	*Anethum graveolens .*	Apiaceae	114	800	7.0
Clary sage	*Salvia sclarea .*	Lamiaceae	70	5600	80.0
Spike lavender	*Lavandula latifolia*	Lamiaceae	64	1000	15.6
Marjoram	*Origanum majorana .*	Lamiaceae	62	1200	19.4
Ocimum	*Ocimum gratissimum*	Lamiaceae	50	800	16.0
Basil	*Ocimum basilicum .*	Lamiaceae	43	2800	65.1
Sage	*Salvia officinalis .*	Lamiaceae	35	1800	51.4
Armoise	*Artemisia herba-alba*	Asteraceae	32	1100	34.4
Celery seed	*Apium graveolens .*	Apiaceae	30	1500	50.0
Thyme	*Thymus species .*	Lamiaceae	29	1500	51.7
Caraway	*Carum carvi .*	Apiaceae	29	1000	34.5
Bitter fennel	*Foeniculum vulgare*	Apiaceae	28	700	25.0
Anise	*Pimpinella anisum.*	Apiaceae	26	700	26.9
Ajowan	*Trachyspermum copticum*	Apiaceae	25	300	12.0
Indian dill seed	*Anethum sowa.*	Apiaceae	25	100	4.0
European dill seed	*Anethum graveolens*	Apiaceae	23	200	8.7
Cumin	*Cuminum cyminum .*	Apiaceae	15	900	60.0
Tagetes	*Tagetes minuta .*	Asteraceae	12	1200	100.8

Essential oil	Species	Family	Volume (t)	Value (US$000)	Value/ton (US$000)
Tarragon	*Artemisia dracunculus .*	Asteraceae	10	800	80.8
Carrot seed	*Daucus carota .*	Apiaceae	9	1230	139.8
Parsley seed	*Petroselinum crispum*	Apiaceae	8	1162	140.0
Roman chamomile	*Anthemis nobilis.*	Asteraceae	6	3600	600.0
Wormwood	*Artemisia absinthum.*	Asteraceae	6	200	33.3
Angelica root	*Angelica archangelica*	Apiaceae	4	3080	700.0
Blue chamomile	*Chamomilla recutita*	Asteraceae	4	2200	511.6
Parsley herb	*Petroselinum crispum*	Apiaceae	4	560	140.0
Asafoetida	*Ferula assafoetida.*	Apiaceae	3	1035	345.0
Wild chamomile	*Chamaemelum species*	Asteraceae	2	<0.1	
Muhuhu	*Brachylaena hutchinsii*	Asteraceae	2	<0.1	
Lovage root	*Levisticum officinale .*	Apiaceae	2	1600	800.0
Wild thyme	*Thymus pulegioides.*	Lamiaceae	2	100	50.0
Monarda (geraniol type)	*Monarda fistulosa*	Lamiaceae	2	40	20.0
Hyssop	*Hyssopus officinalis .*	Lamiaceae	2	32	17.8
Perilla	*Perilla frutescens*	Lamiaceae	2	1800	1200.0
Lovage herb	*Levisticum officinale .*	Apiaceae	2	712	474.7
Savory	*Satureja montana .*	Lamiaceae	2	90	60.0
Artemisia martima	*Artemisia maritima .*	Asteraceae	1	<0.1	
Davana	*Artemisia pallens*	Asteraceae	1	300	300.0
Lovage seed	*Levisticum officinale .*	Apiaceae	0.9	unknown	
Angelica seed	*Angelica archangelica*	Apiaceae	0.8	880	1100.0
Yarrow	*Achillea millefolium .*	Asteraceae	0.8	88	110.0
Celery herb	*Apium graveolens*	Apiaceae	0.8	60	75.0
Artemisia afra	*Artemisia afra*	Asteraceae	0.8	51	68.0
Artemisia annua	*Artemisia annua .*	Asteraceae	0.6	16	26.7
Santolina	*Santolina chamaecyparissus .*	Asteraceae	0.3	unknown	
Helichrysum	*Helichrysum italicum*	Asteraceae	0.3	81	270.0
Ammoniac gum	*Dorema ammoniacum*	Apiaceae	0.2	unknown	
Catnip	*Nepeta cataria .*	Lamiaceae	0.1	unknown	
Elecampane	*Inula helenium.*	Asteraceae	0.1	unknown	
Monarda (thymol type)	*Monarda citriodora*	Lamiaceae	0.1	5	50.0
Ocimum canum	*Ocimum canum*	Lamiaceae	0.1	5	50.0
Melissa	*Melissa officinalis .*	Lamiaceae	0.1	4	40.0
Balsamite	*Chrysanthemum balsamita .*	Asteraceae	0.1	3.5	35.0
Ereocephalus	*Ereocephalus punctulatus*	Asteraceae	0.05	unknown	
Pteronia	*Pteronia incana*	Asteraceae	0.05	unknown	
Artemisia vestita	*Artemisia vestita*	Asteraceae	0.05	unknown	
Ninde	*Aeollanthus gamwelliae*	Lamiaceae	<0.05	unknown	
American pennyroyal	*Hedeoma pulegioides*	Lamiaceae	<0.05	unknown	
Tansy	*Tanacetum vulgare .*	Asteraceae	<0.05	unknown	

Source: [22]

Appendix III: Quality Assurance and Standards

Table 10: International Organization for Standardization (ISO) spice and essential oil quality standards

ISO Number	Standards Title	Species
ISO 7357:1985	Oil of calamus -- Determination of cis-beta-asarone content	*Acorus calamus*
ISO 5559:1995	Dehydrated onion	*Allium cepa*
ISO 5560:1997	Dehydrated garlic	*Allium sativum*
ISO 4733:1981	Oil of cardamom	*Amomum spp.*
ISO 10622:1997	Large cardamom	*Amomum subulatum*
ISO 3525:1979	Oil of amyris	*Amyris balsamifera*
ISO 3761:1997	Oil of rosewood, Brazilian type	*Aniba rosaeodora* or *Aniba parviflora*
ISO 3760:2002	Oil of celery seed	*Apium graveolens*
ISO 6574:1986	Celery seed	*Apium graveolens*
ISO 10115:1997	Oil of tarragon, French type	*Artemisia dracunculus*
ISO 7926:1991	Dehydrated tarragon	*Artemisia dracunculus*
ISO 3063:1983	Oil of ylang-ylang	*Cananga odorata*
ISO 3523:2002	Oil of cananga	*Cananga odorata, forma macrophylla*
ISO 10624:1998	Oil of elemi	*Canarium luzonicum*
ISO 7540:1984	Ground (powdered) paprika	*Capsicum annuum*
ISO 7542:1984	Ground (powdered) paprika (Capsicum annuum	*Capsicum annuum*
ISO 3513:1995	Chillies Determination of Scoville index	*Capsicum spp.*
ISO 972:1997	Chillies and capsicums, whole or ground (powdered) -- Specification	*Capsicum spp.*
ISO 7543-1:1994	Chillies and chilli oleoresins - Determination of total capsaicinoid content	*Capsicum spp.*
ISO 7543-2:1993	Chillies and chilli oleoresins - Determination of total capsaicinoid content	*Capsicum spp.*
ISO 7541:1989	Ground (powdered) paprika -total natural colouring matter content	*Capsicum spp.*
ISO 5561:1990	Black caraway and blond caraway, whole	*Carum carvi*
ISO 8896:1987	Oil of caraway	*Carum carvi*
ISO 3216:1997	Oil of cassia, Chinese type	*Cinnamomum aromaticum*
ISO 11025:1998	Oil of cassia, Chinese type -Determination of trans-cinnamaldehyde content	*Cinnamomum cassia*
ISO 6538:1997	Cassia, Chinese type, Indonesian type and Vietnamese type	*Cinnamomum spp.*
ISO 6539:1997	Cinnamon, Sri Lankan type, Seychelles type and Madagascan type	*Cinnamomum verum*
ISO 3524:2003	Oil of cinnamon leaf, Sri Lanka type	*Cinnamomum zeylanicum*
ISO 3519:1997	Oil of lime, obtained by distillation	*Citrus aurantifolia*
ISO 3809:2004	Oil of lime (cold pressed), Mexican type obtained by mechanical means	*Citrus aurantifolia*
ISO 3809:1987	Oil of lime, Mexico obtained by mechanical means	*Citrus aurantiifolia*
ISO 8901:2003	Oil of bitter orange petitgrain, cultivated	*Citrus aurantium .*
ISO 3517:2002	Oil of neroli	*Citrus aurantium spp. Aurantium*
ISO 3064:2000	Oil of petitgrain, Paraguayan type	*Citrus aurantium ssp. Aurantium*
ISO 9844:1991	Oil of bitter orange	*Citrus aurantium ssp. Aurantium*
ISO 8900:1987	Oil of bergamot petitgrain	*Citrus aurantium ssp. bergamia*
ISO 3520:1998	Oil of bergamot	*Citrus aurantium. subsp. bergamia*

ISO Number	Standards Title	Species
ISO 8899:2003	Oil of lemon petitgrain	*Citrus limon*
ISO 855:2003	Oil of lemon obtained by expression	*Citrus limon* .
ISO 3528:1997	Oil of mandarin, Italian type	*Citrus reticulata*
ISO 8898:2003	Oil of mandarin petitgrain	*Citrus reticulata*
ISO 3140:1990	Oil of sweet orange, obtained by mechanical treatment	*Citrus sinensis*
ISO 3516:1997	Oil of coriander fruits	*Coriandrum sativum*
ISO 2255:1996	Coriander, whole or ground (powdered)	*Coriandrum sativum.*
ISO/TS 3632-1:2003	Saffron Part 1: Specification	*Crocus sativus*
ISO/TS 3632-2:2003	Saffron Part 2: Test methods	*Crocus sativus*
ISO 9301:2003	Oil of cumin seed	*Cuminum cyminum*
ISO 6465:1984	Whole cumin - Specification	*Cuminum cyminum*
ISO 9843:1991	Oil of cedarwood	*Cupressus funebris*
ISO 9843:2002	Oil of cedarwood, Chinese type	*Cupressus funebris*
ISO 5566:1982	Turmeric --Colouring power -- Spectrophotometric method	*Curcuma longa*
ISO 5562:1983	Turmeric, whole or ground (powdered) -- Specification	*Curcuma longa*
ISO 3217:1974	Oil of lemongrass	*Cymbopogon citratus*
ISO 4718:1981	Oil of lemongrass	*Cymbopogon flexuosus*
ISO 4718:2004	Oil of lemongrass	*Cymbopogon flexuosus*
ISO 4727:1988	Oil of palmarosa	*Cymbopogon martinii*
ISO 3849:2003	Oil of citronella, Sri Lankan type	*Cymbopogon nardus*
ISO 3848:2001	Oil of citronella, Java type	*Cymbopogon spp.*
ISO 882-1:1993	Cardamom Part 1: Whole capsules	*Elettaria cardamomum*
ISO 882-1:1993	Cardamom - Part 1: Whole capsules	*Elettaria cardamomum*
ISO 882-2:1993	Cardamom - Part 2: Seeds	*Elettaria cardamomum*
ISO 3044:1997	Oil of eucalyptus citriodora	*Eucalyptus citriodora*
ISO 770:2002	Crude or rectified oils of Eucalyptus globulus	*Eucalyptus globulus*
ISO 14716:1998	Oil of galbanum	*Ferula galbaniflua*
ISO 7927-1:1987	Fennel seed, whole or ground (powdered) -- Part 1: Bitter fennel seed	*Foeniculum vulgare*
ISO 11023:1999	Liquorice extracts - Determination of glycyrrhizic acid content	*Glycyrrhiza glabra*
ISO 3714:1980	Oil of pennyroyal	*Hedeoma pulegioides*
ISO 9841:1991	Oil of Hyssop	*Hyssopus officinalis*
ISO 11016:1999	Oil of star anise, Chinese type	*Illicium verum*
ISO 11178:1995	Star anise	*Illicium verum*
ISO 7377:1984	Juniper berries	*Juniperus communis*
ISO 8897:1991	Oil of juniper berry	*Juniperus communis*
ISO 4725:1986	Oil of cedarwood, Texas	*Juniperus mexicana*
ISO 4724:1984	Oil of cedarwood, Virginia	*Juniperus virginiana*
ISO 6576:1984	Laurel - Whole and pounded leaves	*Laurus nobilis*
ISO 3045:1974	Oil of bay	*Laurus nobilis*
ISO 3054:2001	Oil of lavandin Abrial, French type	*lavandin Abrial*
ISO 3515:2002	Oil of lavender	*Lavandula angustifolia*
ISO 8902:1999	Oil of lavandin Gross, French type	*Lavandula angustifolia x Lavandula latifolia*
ISO 4719:1999	Oil of spike lavender, Spanish type	*Lavandula latifolia*
ISO 11019:1998	Oil of roots of lovage	*Levisticum officinale*
ISO 3214:2000	Oil of Litsea cubeba	*Litsea cubeba*

ISO Number	Standards Title	Species
ISO 4730:1996	Oil of Melaleuca, terpinen-4-ol type	*Melaleuca*
ISO 9776:1999	Oil of Mentha arvensis, partially dementholized	*Mentha arvensis var. piperascens*
ISO 5563:1984	Dried peppermint	*Mentha piperita*
ISO 856:1981	Oil of peppermint, France, Italy, United Kingdom and USA	*Mentha piperita*
ISO 3033:1988	Oil of spearmint	*Mentha spicata*
ISO 2256:1984	Dried mint (spearmint)	*Mentha spicata*
ISO 3215:1998	Oil of nutmeg, Indonesian type	*Myristica fragrans*
ISO 6577:2002	Nutmeg, whole or broken, and mace, whole or in pieces	*Myristica fragrans*
ISO 11043:1998	Oil of basil, methyl chavicol type	*Ocimum basilicum*
ISO 11163:1995	Dried sweet basil	*Ocimum basilicum*
ISO 590:1981	Oil of brazilian sassafras	*Ocotea pretiosa*
ISO 10620:1995	Dried sweet marjoram	*Origanum majorana*
ISO 10620:1995	Dried sweet marjoram	*Origanum majorana*
ISO 7925:1999	Dried oregano - Whole or ground leaves	*Origanum vulgare*
ISO 4731:1978	Oil of geranium	*Pelargonium spp.*
ISO 3527:2000	Oil of parsley fruits	*Petroselinum sativum*
ISO 973:1999	Pimento (allspice) , whole or ground	*Pimenta dioica*
ISO 4729:1984	Oil of pimento leaf	*Pimenta dioica*
ISO 3043:1975	Oil of pimento berry	*Pimenta dioica*
ISO 3045:2004	Oil of bay	*Pimenta racemosa*
ISO 3475:2002	Oil of aniseed	*Pimpinella anisum*
ISO 7386:1984	Aniseed	*Pimpinella anisum*
ISO 21093:2003	Oil of dwarf pine	*Pinus mugo*
ISO 11020:1998	Oil of turpentine, Iberian type	*Pinus pinaster*
ISO 3756:1976	Oil of cubeb	*Piper cubeba*
ISO 10621:1997	Dehydrated green pepper	*Piper nigrum*
ISO 10621:1997	Dehydrated green pepper	*Piper nigrum*
ISO 959-1:1998	Pepper, whole or ground Part 1: Black pepper	*Piper nigrum*
ISO 959-2:1998	Pepper, whole or ground - Part 2: White pepper	*Piper nigrum*
ISO 3061:1979	Oil of black pepper	*Piper nigrum*
ISO 11027:1993	Pepper and pepper oleoresins -Piperine content	*Piper nigrum*
ISO 11162:2001	Peppercorns (Piper nigrum L.) in brine	*Piper nigrum*
ISO 5564:1982	Black pepper, white pepper, whole or ground - Determination of piperine	*Piper nigrum*
ISO 3757:2002	Oil of patchouli	*Pogostemon cablin*
ISO 9842:2003	Oil of rose	*Rosa x damascena*
ISO 11164:1995	Dried rosemary	*Rosmarinus officinalis*
ISO 1342:2000	Oil of rosemary	*Rosmarinus officinalis*
ISO 3526:1991	Oil of sage	*Salvia lavandulifolia*
ISO 11165:1995	Dried sage	*Salvia officinalis*
ISO 9909:1997	Oil of Dalmatian sage	*Salvia officinalis*
ISO 7356:1985	Oils of thujone-containing Artemisia and oil of sage	*Salvia officinalis*
ISO 3518:2002	Oil of sandalwood	*Santalum album*
ISO 7928-1:1991	Savory - Part 1: Winter savory	*Satureja montana*
ISO 7928-2:1991	Savory-- Part 2: Summer savory	*Satureja montana*
ISO 3141:1997	Oil of clove leaves	*Syzygium aromaticum*
ISO 3142:1997	Oil of clove buds	*Syzygium aromaticum*
ISO 3143:1997	Oil of clove stems	*Syzygium aromaticum*

ISO Number	Standards Title	Species
ISO 2254:1980	Cloves, whole and ground (powdered) -- Specification	*Syzygium aromaticum*
ISO 2254:1980	Cloves, whole and ground (powdered) -- Specification	*Syzygium aromaticum*
ISO 14717:1999	Oil of origanum, Spanish type	*Thymbra capitata*
ISO 4728:2003	Oil of Spanish wild marjoram	*Thymus mastichina*
ISO 6754:1996	Dried thyme	*Thymus vulgaris .*
ISO 14715:1999	Oil of thyme containing thymol, Spanish type	*Thymus zygis*
ISO 6575:1982	Fenugreek, whole or ground (powdered) -- Specification	*Trigonella foenum-graecum*
ISO 5565-1:1999	Vanilla - Specification	*Vanilla fragrans*
ISO 5565-2:1999	Vanilla - Test methods	*Vanilla fragrans*
ISO 4716:2002	Oil of vetiver	*Vetiveria zizanioides*
ISO 13685:1997	Ginger and its oleoresins - the main pungent components	*Zingiber officinale*
ISO 1003:1980	Spices and condiments - Ginger, whole, in pieces, or ground	*Zingiber officinale*

Table 11: Spice quality specifications available on the world-wide web.

Site	Specification
The National Institute of Agricultural Marketing (NIAM), Jaipur: www.niam.gov.in/download/17.pdf	ASTA Cleanliness Specifications For Spices, Seeds And Herbs (Revised and effective June 15, 1996) Defect action level prescribed by USFDA for spices U.S. pesticides tolerances for spices in ppm Proposed ESA specification on spices Annex: ESA-individual product specifications Cleanliness specification for spices in Germany, Netherlands, UK *and as per ESA (maximum limits)* Maximum pesticides residues limits in Germany, Netherlands & United Kingdom Commercial specification for chilli Commercial specification for coriander Commercial specification for fennel Commercial specification for ginger Commercial specification for pepper Commercial specification for turmeric
Spices Board India: www.indianspices.com/html/s1491qua.htm	European Spice Association specifications of quality minima for herbs and spices ESA *Quality* Minima spices whole form American Spice Trade Association (ASTA) cleanliness specifications for spices and herbs Cleanliness specification for spices in major importing countries (Germany, Netherlands & UK), Maximum pesticides residues limits in Netherlands & United Kingdom Maximum residue levels fixed for spices as per the German *legislation* Pesticide residue limits prescribed by Spain U.S. Pesticide tolerances for spices in ppm The maximum limits for pesticide residues in certain spices (PPM) in Japan General microbiological specification - Germany & Netherlands
International Pepper Community (IPC): www.ipcnet.org/quality.htm	Summary of legislation on aflatoxins in ESA Member countries and other major importing countries (Austria, Belgium, Germany, Denmark, Netherlands, Switzerland, UK, Spain, Sweden, Finland, Italy, France, USA) *Grades of whole pepper, black & white* IPC Grades of Treated Black and White, Whole Pepper IPC Manual of Methods of Analysis IPC Code of Hygienic Practices for Pepper and Other Spices
European Standards: www.cenorm.be/catweb/cwen.htm	ASTA's Cleanliness specifications For Spices, Seeds and Herbs (Effective April 28, 1999) European Spice Association specifications of quality minima for herbs and spices (Revised in May 2003 during ESA *Meeting*) Quality requirements of pepper in Japan (All Nippon Spices Association/ANSA) On line catalogue for individual EU countries

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