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Flavor and Aroma Substances

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Extraction of flavor and aroma substances from naturally occurring raw materials is important because the compositions of flavors are often too complex to be synthesized economically. Raw materials are isolated from balsam, bark, berry, blossom, bud, fruit, grass, gum, heartwood, leaves, peel, root, seed, twig, wood, and resinous exudation. Extracts of flavor and aroma substances prepared from raw materials are termed pomade, concrete, absolute, resinoid, or tincture according to their production technique (1). In processing essential oils and natural extracts, steam distillation, solvent extraction, supercritical fluid extraction, and expression are the major methods. Steam distillation provides the essential oil, whereas solvent extraction provides both the essential oil and the oleoresins. *Oleoresins* are concentrated natural liquid flavorings that contain both volatile and nonvolatile flavor components. *Essential oils* are obtained from plant materials by steam distillation or water distillation. After condensation of the vapor phase, the oil separates from the aqueous phase and is removed. Essential oils consist of volatile, lipophilic substances that are mainly hydrocarbons or monofunctional compounds derived from the metabolism of mono- and sesquiterpenes, phenylpropanoids, amino acids, and fatty acids. *Pomades* consist of fats that contain fragrance substances and are produced by the enfleurage technique. *Concretes* are prepared by evaporation of residue substances that are extracted from fresh plant material with nonpolar solvents such as benzene, toluene, hexane, and petroleum ether, as shown in Fig. 1. Concretes contain viscous waxy compounds with volatile fragrance materials. Concretes and pomades are not completely soluble in ethanol. *Absolutes* are prepared by taking up concretes in ethanol. Compounds that precipitate on cooling are then removed by filtration. After evaporation of the ethanol, a wax-free residue, the

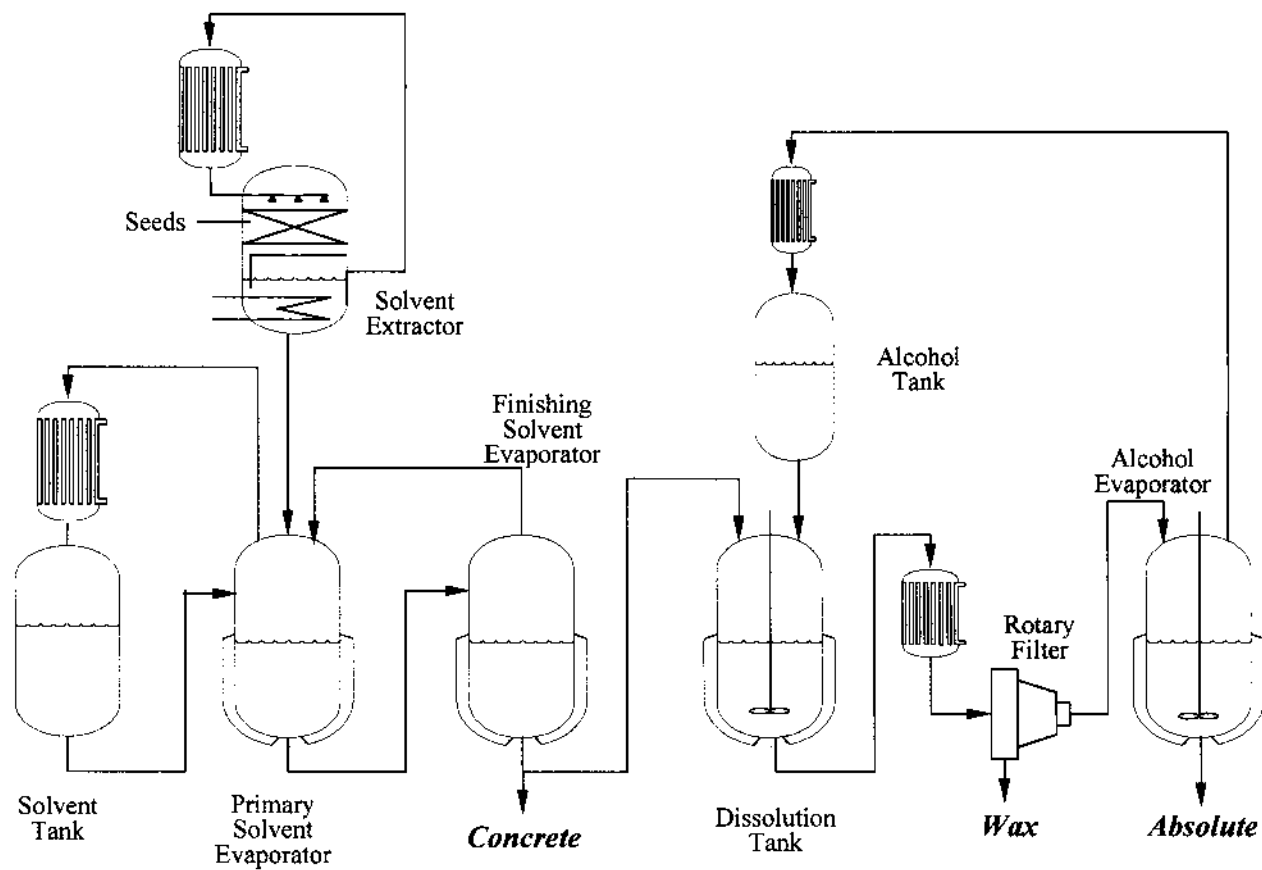


Figure 1 Solvent extraction process for concrete and absolute.

absolute, remains. Absolutes are completely soluble in ethanol. Resinoids are prepared by extracting plant exudates (balsams, oleo gum resins, natural oleoresins, and resinous products) with solvents such as methanol, ethanol, or toluene. The products are usually highly viscous to improve their flow and processing properties. *Resinoids* mainly consist of nonvolatile, resinous compounds and are primarily used for their excellent fixative properties. *Tinctures* are alcoholic solutions that are prepared by treating natural raw materials with ethanol or ethanol-water solution. They can also be obtained by dissolving other extracts in these solvents.

Extraction is still one of the most important methods for producing flavor and aroma substances and is the selective extraction of a soluble constituent from solid (solid-liquid extraction) or liquid mixtures (liquid-liquid extraction) by liquid solvents (2). In the production of natural extracts, the most impressive progress is the introduction of supercritical fluid extraction technology (Chapter 3). Characteristic applications are the extraction of caffeine from coffee or tea, or hops extraction.

I. SEPARATION PROCESSES (3)

A. Distillation

The most widely method used for producing flavor and aroma substances is distillation. There are three different processes used: steam distillation, simple boiling water distillation, and water and steam distillation, as shown in Fig. 2. In all cases, hot steam carries the most volatile compounds of the aromatic material with it and is then condensed. The resulting distillate is composed of the essential oil and water. The mixture of condensed oil and water runs into the layer separator where the lighter insoluble oil floats on the surface and accumulates slowly and from where it is drawn off periodically, as shown in Fig. 3. Some of soluble components may be lost in the water. *Steam distillation* uses an outside source of steam and no water is allowed in the still, as shown in Fig. 2a. The steam passes through the aromatic material in the distillation unit and exits into the condenser. In *simple boiling water distillation*, the plant materials are fully submerged in water and water is heated to produce steam, which contains flavor and aroma substances, as shown in Fig. 2c. This is the oldest method of distillation and the most versatile. This process works best for powders and very tough materials like seeds or roots. Production of steam by direct heating of plant material with water will result in hydrolysis and loss of fragrant esters and at least some pyrolysis of plant material. The result is low-grade oil. In *water and steam distillation*, a basket (or a perforated grid) is used for supporting the plant materials; thus, only rising steam contacts with the plant materials, while water is boiling in the still, as shown in Fig. 2b. This is the best method for distilling leafy materials, but it doesn't work well for woods, roots, seeds, and so forth.

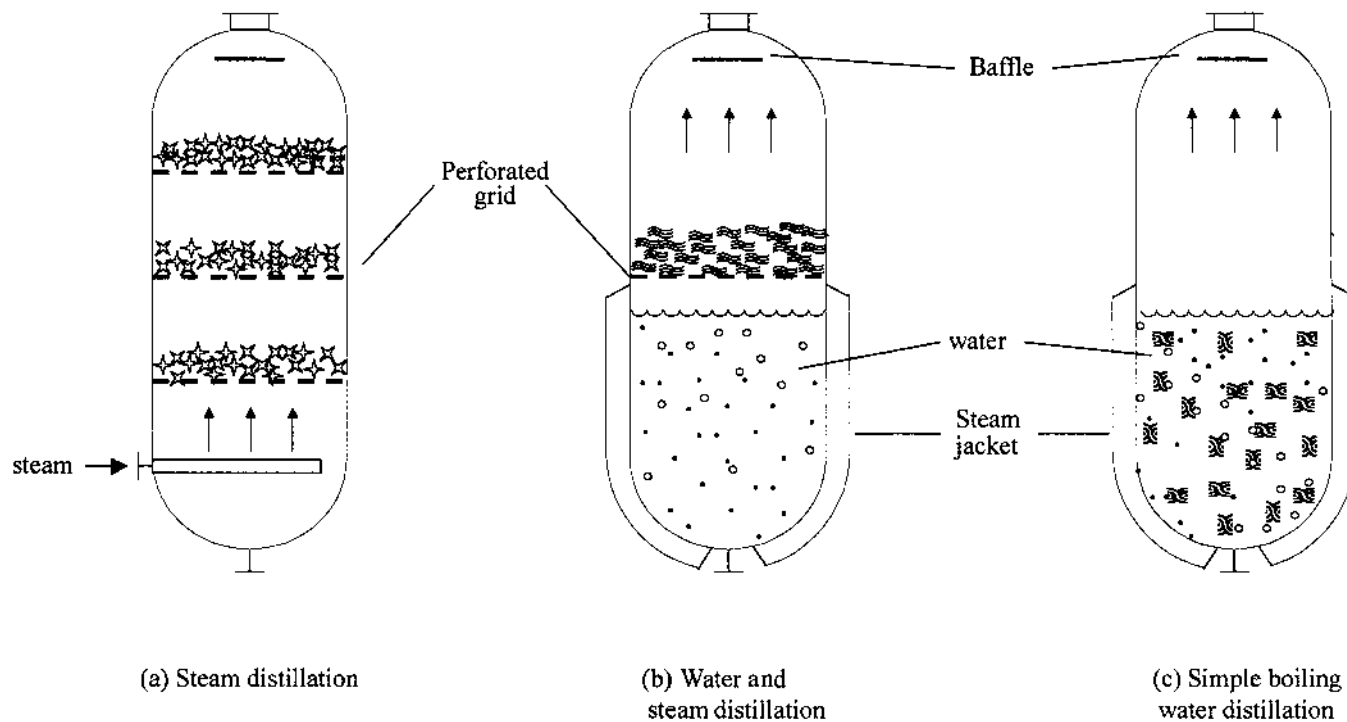


Figure 2 The different types of steam distillation.

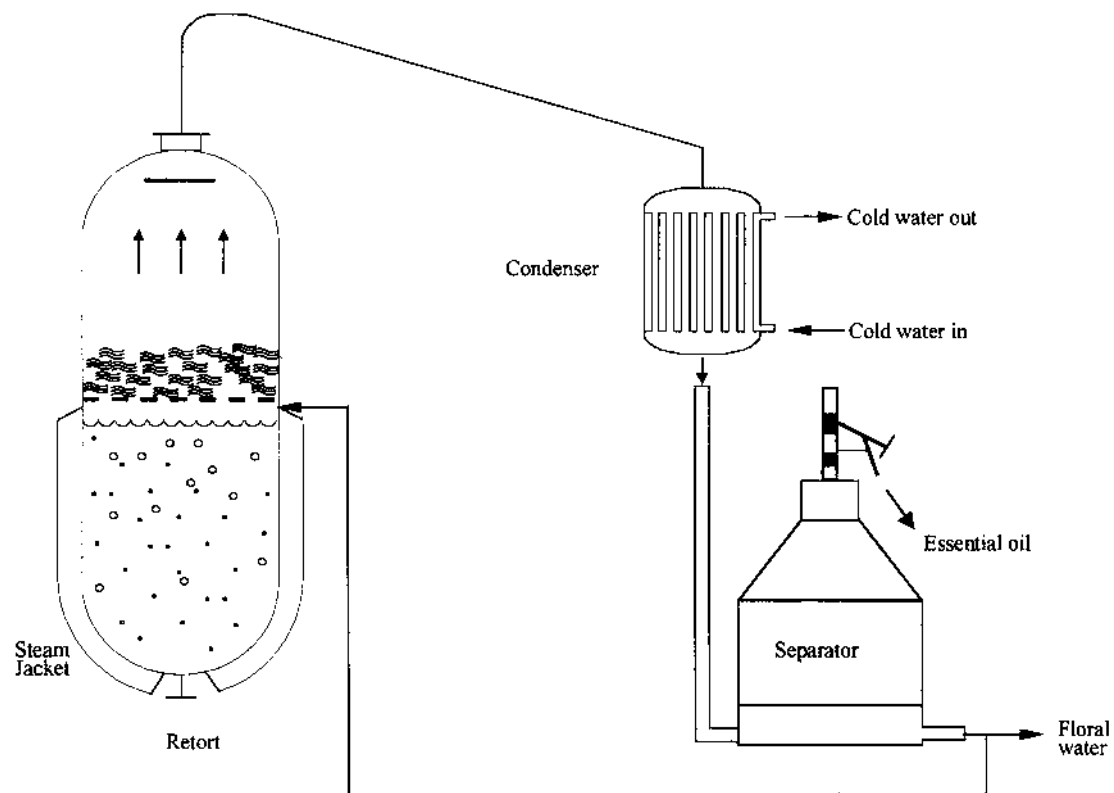


Figure 3 Steam distillation unit.

B. Solvent Extraction

Solvent extraction of the plant materials is a well-known method for the production of valuable oleoresins as well as essential oils. A solvent extracted oleoresin includes essential oil, organic soluble resins, nonvolatile fatty acids, and other plant materials, and can yield a more potent flavor profile. To capture delicate aromas like jasmine, linden blossom, and so forth, without thermal degradation, a process of solvent extraction is used.

Plant materials such as leaves, flowers, roots, or stems are dissolved into a solvent such as hexane. They become wax-like concretes. Absolute is obtained by alcohol extraction of concretes where most of the alcohol is later removed. Plant materials such as seeds are first crushed and dissolved into solvents. Hexane is the most commonly used solvent. The solvent is evaporated under vacuum to give the oil. Resinoids are resins dissolved in a solvent such as benzene or alcohol. Resins are naturally occurring solid or semisolid substances produced by plants or trees.

In general, the highest extraction yields are normally obtained compared to the other extraction methods. The solid to be extracted is placed in a basket suspended in the extraction vessel, as shown in [Fig. 4](#). Solvent fed to the boiler, is heated and distilled off. It runs from the condenser, via the reflux head, into the extraction vessel where it percolates through the solid to be extracted. Solvent loaded with extract returns, via a seal loop, to the boiler, where it evaporates again. This cycle continues until the extraction is complete.

C. Carbon Dioxide Extraction

Carbon dioxide extraction is another type of solvent extraction in which carbon dioxide is used under high pressure to extract both essential oils and oleoresins. Supercritical and liquid CO₂ can both be used as very inert, safe solvents. Liquid CO₂ fits the requirements of solvent ability and low boiling point. It is also nonflammable, inert, inexpensive, and has low toxicity. As a solvent, liquid CO₂ is highly selective, particularly toward those esters, aldehydes, ketones, and alcohols representative of aroma constituents (4). Low-temperature extraction using liquid CO₂ produces extracts that more closely resemble the aroma of the original plant materials than any process involving heating of plant materials. Some examples of commercial extraction with liquid CO₂ are as follows: anise star, cardamon, celery seed, clove bud, coffee, coriander seed, ginger Jamaican, ginger Nigerian, ginger terpeneless, hop oil, hoparome absolute, juniper berry 20%, mace, nutmeg, pepper oil black, pimento berry, and vanilla absolute.

In contrast to liquid CO₂, the solvent power of the supercritical fluid is highly dependent on its temperature and pressure. The advantage of the method, of course, is that no solvent residue remains, since at normal pressure and tempera-

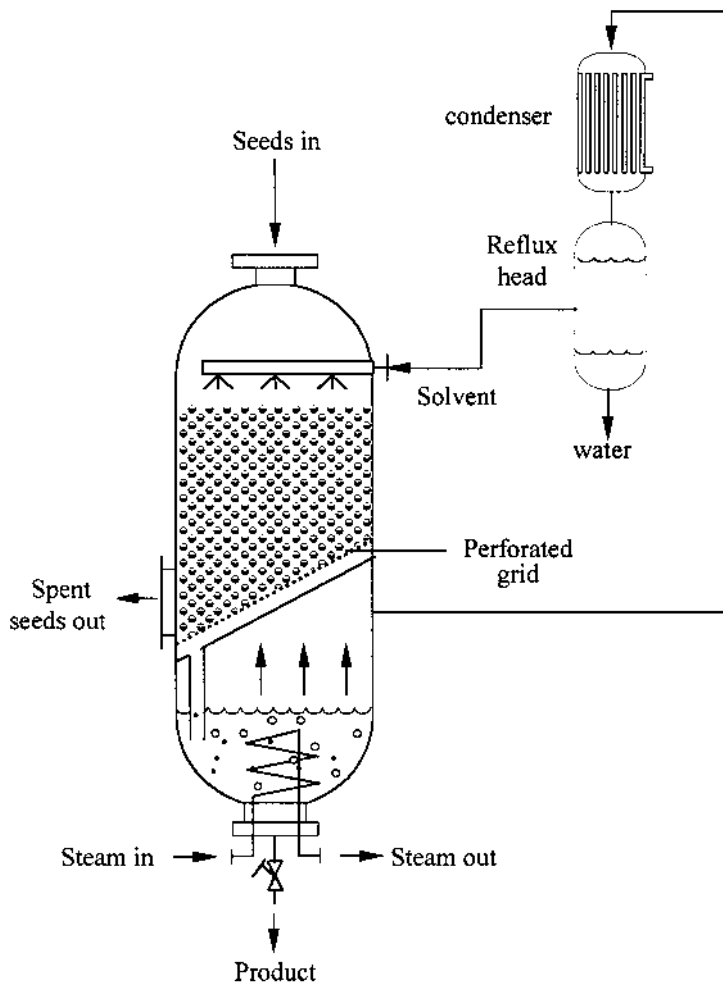


Figure 4 Single-stage extractor with solvent recycle.

ture the CO_2 simply reverts to a gas and evaporates. However, when supercritical CO_2 is used to produce flavors and aromas, some unwanted waxes, resins, and pigments are usually present simultaneously. Some examples of commercial extraction with supercritical CO_2 are as follows: celery, ginger oil, jasmine absolute, massoia oil, paprika flavor and color, pepper oil, rosemary, sage, and vanilla absolute (5, 6).

D. Cold Pressing

Cold pressing is also known as expression. In this method, the oil-containing outer layer of the fruit is pressed and filtered to yield pure essential oil. A heating stage is used to help release the oil, usually not higher than 60–80°C. The pressed citrus oils are commercially produced by expression with either hydraulic press or screw-type press, as shown in Fig. 5. A drawback to cold pressing is that recovery of oil is lower than from solvent extraction. The yields to make an essential oil from raw materials are about 2 wt% in eucalyptus, 0.7 wt% in lavender, 0.2 wt% in rosemary, 0.1 wt% in jasmine, and less than 0.05 wt% in rose.

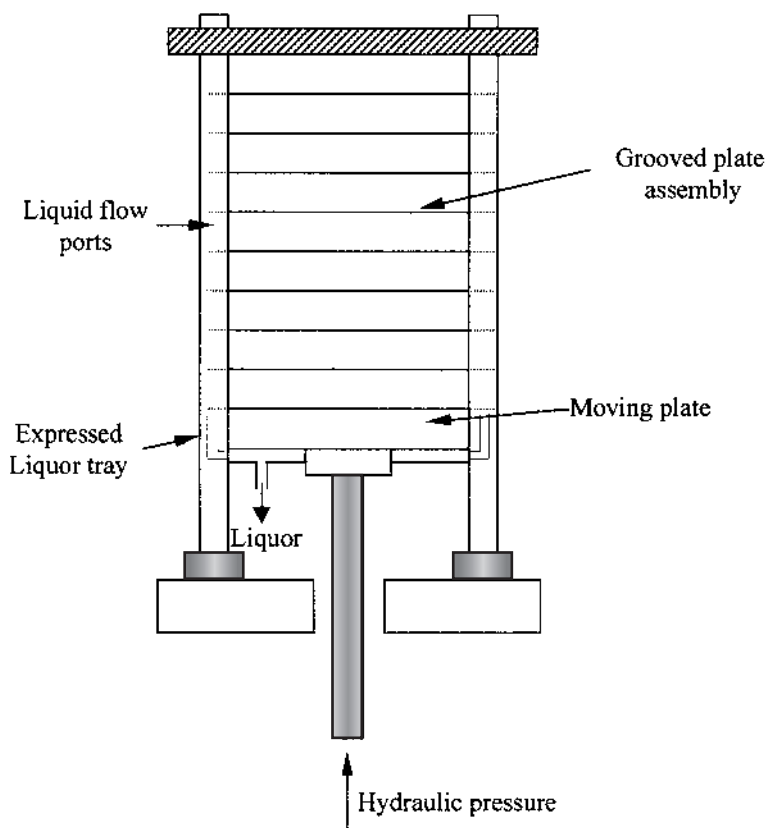


Figure 5 Plate press.

E. Enfleurage

In this technique, the flavors released by flowers are absorbed with fats for a long time. The petals of flower are spread over large sheets of glass that are covered with lard. The sheets are then pressed together. The flowers are refilled until the lard becomes fully charged. The oil is extracted by an alcohol solvent. Carrot oil is produced by using a carrot root extract macerated in vegetable oil. Carrot oil is rich in β -carotene, vitamins B, C, D, and E. It is useful as a skin rejuvenator and is recommended for treatment of dry and aging skin.

F. Maceration (Hot Enfleurage)

Maceration is one of the oldest techniques for preserving plant flavor. In this method, flowers are directly dipped in hot liquid fats that absorb essential oils. This produces pomades which consist of fats with flavor.

II. EXTRACTION SOLVENTS

The choice of solvent is the primary consideration for an extraction process, and the selectivity of the solvent is of special importance. The required solvent can be selected based on the similar polarity with the solute.

According to the Part I of the Annex of the Council Directive on the approximation of the laws of the member states on extraction solvents used in the production of foodstuffs and food ingredients (7), propane, butane, butyl acetate, ethyl acetate, ethanol, carbon dioxide, acetone, and nitrous oxide are the solvents to be used in compliance with good manufacturing practice (GMP) for all use. An extraction solvent is considered as being used in compliance with good manufacturing practice if its use results only in the presence of residues or derivatives in technically unavoidable quantities presenting no danger to human health. In Parts II and III, extraction solvent for which conditions of use are specified ([Table 1](#)).

III. APPLICATION OF SOLVENT EXTRACTION OF FLAVORS AND AROMAS (1, 3–12)

A. Anise Star

Anise star (*Illicium verum*) is so named from the star shape of its fruit. In Asia, it is often chewed in small quantities after meals to promote digestion and freshen the breath. The plant, which is cultivated in China, Indo-China, Japan,

Table 1 Parts II and III of the Annex of the Council Directive**PART II** Extraction solvents for which conditions of use are specified

Name	Condition of use (summary description of extraction)	Max. residue limits in extracted foodstuff or food ingredient
Hexane ^a	Production or fraction of fats and oils and production of co-coa butter	5 mg/kg in the fat or oil or co-coa butter
	Preparation of protein products and defatted flours	10 mg/kg in the food containing the protein products and defatted flours
	Preparation of defatted cereal germs	5 mg/kg on the defatted cereal germ
	Defatted soya products	30 mg/kg in the soya product as sold to the final consumer
Methyl acetate	Decaffeination of, or removal of irritants and bittering from coffee and tea	20 mg/kg in the coffee or tea
	Production of sugar from molasses	1 mg/kg in the sugar
Ethylmethylketone ^a	Fractionation of fats and oils	5 mg/kg in the fat or oil
	Decaffeination of, or removal of irritants and bittering from coffee and tea	20 mg/kg in the coffee or tea
Dichloromethane	Decaffeination of, removal of irritants and bittering from coffee and tea	2 mg/kg in the roasted coffee and 5 mg/kg in the tea
Methanol	For all uses	10 mg/kg
Propan-2-ol	For all uses	10 mg/kg

PART III Extraction solvents for which conditions of use are specified

Name	Max. residue limits in foodstuff due to use of extraction solvents for preparation of flavorings from natural flavoring materials (mg/kg)
Diethyl ether	2
Hexane	1 ^c
Methyl acetate	1
Butan-1-ol	1
Butan-2-ol	1
Ethylmethylketone	1 ^c
Dichloromethane	0.02

Table 1 Continued

Name	Max. residue limits in foodstuff due to use of extraction solvents preparation of flavorings from natural flavoring materials (mg/kg)
Methylpropan-1-ol	1
Propan-1-ol	1
Cyclohexane	1

^aHexane means a commercial product consisting essentially of acyclic saturated hydrocarbons containing six carbon atoms and distilling between 64°C and 70°C. The combined use of hexane and ethylmethylketone is forbidden.

^bThe presence of *n*-Hexane in this solvent should not exceed 50 mg/kg. This solvent may not be used in combination with hexane.

^cThe combined use of these two solvents is forbidden.

Source: Ref. 7.

and Philippines, is an evergreen tree up to 12 m high with a tall, slender, white trunk. Its fruit consists of 5–13 seed-shaped follicles attached to a central axis in the shape of a star. The best time to collect the seeds when they begin to turn from green to grayish brown is in the morning while the dew is still on them. Store the seeds in a tightly sealed opaque container to preserve the volatile oil. The essential oil is traditionally obtained from seeds and dry flowering tops by steam distillation, which is replaced by liquid CO₂ extraction (8% yield) or supercritical CO₂ extraction (10% yield). The essential oil is a pale yellow liquid with a warm, spicy, extremely sweet, licorice-like scent. Major components of the essential oil are *trans*-anethol, methyl chavicol, anisaldehyde, and *cis*-ocimene. It is mainly used in beverages and confectionery.

B. Beeswax

Beeswax absolute is a solid, waxy mass of pale yellow color and a very mild, sweet, oily odor, with a hay-like bodynote and a soft waxy backnote. Extraction is usually performed as a direct solvent washing of the beeswax. The most common solvents used for commercial extraction are ethanol, ether, glycol, and water. Selection of the solvent depends on the final use of the extract and on technical feasibility. The extraction yield is generally less than 1 wt%. Most active ingredients seem to be soluble in propylene glycol and ethanol. Fewer ingredients are soluble in water, but even water extracts show at least some bactericidal and fungicidal effects, as well as wound healing properties. Acetone extracts have been used for production of shampoos and lotions.

C. Calendula

Calendula (*Calendula officianalis*) oil is a herbaceous green sweet and dark brown liquid. It is obtained by solvent extraction from the flowers and contains calendulin (a yellow resin), waxes, and a small amount of volatile oil. The CO₂ extracted total of the calendula blossom is much thicker and richer than the selective extract because it contains the plant waxes and heavier phytochemicals. Calendula oil may be produced using cold pressed olive oil and infused with calendula flowers that have been dried for 24–36 h to reduce the moisture content.

D. Cardamon

Cardamon is cultivated in Guatemala, India, and Sri Lanka. It has a large, fleshy rhizome, and the alternate, lanceolate leaves are blades from 0.3 to 0.75 m long, smooth and dark green above, pale, glaucous green, and finely silky beneath. The oblong, gray cardamon (*Elettaria cardamomum*) fruit has many seeds and they are gathered just before they are ripe. The dried ripe fruits (seeds) are hand crushed rather than machine treated so as to guarantee that the precious volatile oils are never subjected to heat. Then liquid CO₂ extraction is used for avoiding heat. Traditionally it was extracted by steam distillation or solvent extraction with ethanol or acetone. Cardamon seed essential oil is a colorless or very pale yellow liquid with a sweet-spicy, warm fragrance and a woody-balsamic note. Major components are 1,8-cineole and terpinyl acetate. It is used as a spice (especially in Arab countries) for baked gingerbread, fruits, and marinades and as an ingredient of curry.

E. Chamomile German

Chamomile German (*Matricaria chamomilla*), sometimes called wild chamomile, has flower heads about 1.9 cm broad, with about 15 white, strap-shaped, reflected ray florets and numerous tubular yellow, perfect florets. Chamomile German is now cultivated extensively in Hungary, Egypt, eastern Europe, and France. The simple daisy-like white flower head that is smaller than chamomile Roman is used to extract the essential oil. Chamomile German, produced by supercritical carbon dioxide extraction, is very different from the traditional steam-distilled blue oil. The original color of the steam distilled essential oil is blue, but it becomes moderate green and finally dark brown when exposed to light and air. Since CO₂ extraction contains all the water-soluble parts of the plant, the oil is much thicker. The CO₂ extracted oil has even stronger anti-inflammatory qualities than the steam-distilled essential oil, and has a more natural, fruity odor.

F. Coffee

In decaffeinating green coffee, a solvent must be selected that extracts caffeine with high selectivity. Thus, the solvent does not extract other coffee ingredients. Moreover, the solvent employed must be completely removable from the treated coffee. Most known processes for decaffeinating green coffee employ benzene (C_6H_6), trichloroethylene ($CCl_2=CHCl$), 1,2-dichloroethane (CH_2Cl-CH_2Cl), methylene chloride (CH_2Cl_2), or chloroform ($CHCl_3$) on account of the selective dissolving capability of these solvents for caffeine.

Successful extraction of caffeine from coffee bean was achieved by the German chemist Friedrich Ferdinand Runge in 1820 following the suggestion of his friend, the poet Johann W. von Goethe. Runge investigated the components of coffee that caused his insomnia and isolated caffeine for the first time. The first commercial decaffeination process was invented by Ludwig Roselius, a German coffee importer, who founded a company, Kaffee Hag in Bremen, in 1906 with the brand Sanka. His success was based on the accidental steam treatment of ruined coffee beans. Steaming elevates the moisture content and swells the bean to facilitate the extraction of caffeine. This discovery made it possible to extract caffeine by benzene and produce decaffeinated coffee on a large scale. In the first half of the 20th century, trichloroethylene was used until it was shown to cause liver tumors in mice by the U.S. National Cancer Institute (NCI) in 1976. Since 1970s, most coffee makers have switched to other solvents, such as methylene chloride and ethyl acetate, or other types of processing to decaffeinate coffee.

The U.S. Food and Drug Administration (FDA) has authorized by regulation the use of both methylene chloride and ethyl acetate for coffee decaffeination. According to an FDA report in the *Federal Register*, most decaffeinated coffee contains less than 0.1 ppm of residual methylene chloride, 100 times less than the maximal level of 10 ppm allowed by the FDA. Under European law, the level of methylene chloride residue in decaffeinated beans must be less than 2 ppm. Since the use of the solvents has given rise to objections about health, most coffee producers no longer use methylene chloride.

In other processes, esters, ketones, light hydrocarbons, and ethers have been employed. However, esters are readily saponified, and it is difficult to sufficiently remove saponification products, i.e., acids and alcohols, from coffee. Due to their relatively high polarity ketones have insufficient selectivity for removal of caffeine. Hydrocarbons and ethers dissolve caffeine only sparingly, so that relatively high temperatures and long treating periods must be employed when these solvents are used. One of the newest decaffeination methods uses an orange peel extract. The green beans are soaked in pure water and washed with an orange peel extract to remove the caffeine.

There are four main methods to extract caffeine from coffee beans:

1. In the decaffeination process with methylene chloride, the green beans are placed in a rotating drum and soaked by steam for approximately 30 min. This treatment swells the beans, increasing their surface area and making the caffeine easier to remove. The next stage is extraction of the caffeine by methylene chloride at a temperature close to the boiling point of the solvent. Methylene chloride (CH_2Cl_2) extracts the caffeine from the coffee beans by bonding to the caffeine molecules (13). The caffeine-laden methylene chloride is drained away, and the beans are steamed for 9–12 h, evaporating the remaining solvent off the beans. Since methylene chloride actually bonds to the caffeine instead of just dissolving it, the caffeine evaporates with the solvent and does not remain in the coffee. At the final stage, air or vacuum drying removes excess moisture from the decaffeinated beans. In the indirect-contact method, sometimes called as the “water process,” the green beans soak for several hours in a water-coffee solution at a temperature near the boiling point. Gradually the solution draws the caffeine, as well as other flavors and aroma components, from the beans. The caffeine-water mixture solution is drained off and the caffeine is removed from water using methylene chloride, which absorbs the caffeine. The caffeine-free water, with all the remaining desirable flavor components, is returned to the beans. After drying the beans, most of the coffee oils and flavor elements are regained on to them. Methylene chloride itself never come in contact with the beans. The roasting and grinding process further evaporates any minute residues of methylene chloride. Although methylene chloride levels in the coffee bean are reduced to residual levels that are “legally safe,” health-conscious consumers consider these residues unacceptable. Most decaffeinated coffee producers no longer use methylene chloride because it is now strongly suspected to cause cancer in humans.

2. Ethyl acetate decaffeination is often referred to as “naturally decaffeinated” because ethyl acetate is compound found in apples, peaches, pears, orange peel, and other fruits (14). Many processes employed natural ethyl acetate obtained from the fermentation of sugar cane. However, in decaffeination a synthetic chemical is used due to high cost of natural ethyl acetate. The process is the same as in conventional methylene chloride decaffeination (direct-contact method), except that ethyl acetate replaces methylene chloride as the solvent. There are still many commercial operations using ethyl acetate extraction in practice in the world.

3. Water decaffeination is, for most people, synonymous with Swiss Water Process, which is a trademarked name. The green coffee beans are first soaked thoroughly in pure water or steam under pressure, making the caffeine soluble so that it can be drawn out easily (12). The aqueous solution is full of many desirable flavors and aroma components as well as caffeine. The solution is drained off, and the coffee thrown away, because it is now flavorless. The caffeine-rich solution is then passed through an activated carbon bed, which selectively removes the caffeine but not the flavor. This flavor-saturated solution is then

poured onto a new batch of coffee. Because the liquid is already full of flavor, this flavor-charged water doesn't extract any additional flavor from the coffee beans. It does, however, extract the caffeine. Advantage of this method is that no chemicals are used, so that no residual chemicals are left in the beans. This method successfully removes approximately 95% of the caffeine while retaining more of the flavor compounds present in the essential oils than the chemical solvent extraction. However, this method results in the loss of some other water-soluble components of coffee, such as carbohydrates. To overcome this problem, the activated carbon is pretreated with a carbohydrate, typically sucrose. This pretreatment process helps it to absorb caffeine without removing other compounds.

4. Carbon dioxide (CO₂) decaffeination uses pressurized CO₂ (a dense fluid) as a solvent to dissolve and draw the caffeine from the coffee beans, leaving the larger-molecule flavor components behind (15). Green beans are first softened by steam for higher selectivity of caffeine before loading them into an extraction vessel. Supercritical CO₂ is introduced into the vessel to dissolve the caffeine. The caffeine-laden CO₂ is then transferred to a separate scrubbing vessel where the caffeine is absorbed by water. Carbon dioxide is circulated until the caffeine content of the beans is reduced to 0.02% or less. The supercritical CO₂ is then drawn off, leaving the beans free of caffeine. In this extraction process, no residual chemicals are left in the beans but it produces the most flavorful decaffeinated coffee. The CO₂ decaffeination process is superior to other decaffeination methods because it removes caffeine while leaving the coffee's flavor compounds intact. CO₂ is a gas at normal atmospheric pressure and temperature, so it is not usually thought of as a solvent. However, under pressure it becomes a dense, liquid-like fluid. While in this liquid state, CO₂ has the ability to selectively bond with and dissolve other materials. It is this selectivity that makes CO₂ decaffeination unique. While CO₂ removes 99.9% of caffeine from coffee, it does not affect the carbohydrates (sugars, starch) and peptides (protein), which are ultimately responsible for the flavor and aroma of brewed coffee. Since carbohydrates and peptides are large polar molecules, nonpolar CO₂ extracts only the caffeine molecules, which are small nonpolar molecules. CO₂ decaffeination technology was discovered and developed at the Max Planck Institute in Germany in the 1970s. Yet this process is not widely used because of the high costs of opening a CO₂ decaffeination plant. However, as competition for sales of decaffeinated coffee increases, consumers will demand decaffeinated coffee that is processed without harmful chemicals but is full-flavored and aromatic.

G. Coriander

Coriander (*Coriandrum sativum*) is an annual herb that belongs to the carrot family (Umbelliferae). It is cultivated in East Asia, Hungary, the Mediterranean, Morocco, North America, Poland, and Russia. Coriander brown seeds, which

are sweet and vaguely reminiscent of orange peel, are used to obtain a sweet-smelling, spicy essential oil. The essential oil obtained through steam distillation of the fruits is a colorless or pale yellow liquid, and the flavor is described as mild, sweet, and spicy-aromatic yet somewhat warm and slightly burning. Coriander oil would be prepared by steam distillation of dried fruits (16). To obtain the maximal yield of essential oil and to reduce the processing time, it is necessary to crush the spice prior to distillation. The extraction yield of partially dried ripe coriander seeds by steam distillation or hydrodistillation is up to 1.7% essential and up to 20% fatty acid. Liquid CO₂ extract of seed has 3% essential oil with 50% of low molecular weight saturated solid lipids. Supercritical CO₂ oleoresin extract after separating the lipids has 1.3% volatile oil. Essential oil of coriander is used in perfumes, alcoholic beverages, baked goods, candies, ice creams, chewing gums, meats, sauces, curries, and tobacco. Demand is expected to grow due to increased consumption of ethnic foods and growth in the meat-processing industry.

H. Elemi

Elemi (*Canarium luzonicum*) is a tropical tree up to 30 m high grown in Philippines and Indonesia. It yields a resinous pathological exudation with a flesh, citrus-like, peppery odor. Although it is called a gum, it is almost entirely made up of resin and essential oil. Steam distillation has been used to prepare essential oils. Nowadays elemi essential oil is extracted by liquid CO₂ from its resin and essential oil is a colorless to pale yellow liquid with a light, fresh, balsamic-spicy, lemon-like odor. The major components of elemi oil are limonene, α -phellandrene, and sesquiterpene alcohol elemol.

I. Frankincense

Frankincense (*Boswellia carterii*), originated from Oman, Ethiopia, Somalia, South Arabia, and China, yields a natural oleo gum resin that is collected by making incisions in the bark. At first, a milky white liquid appears which then solidifies into amber or orange-brown crystals of resin. It is prepared by CO₂ extraction or steam distillation of selected oleo gum resin, and essential oil is a warm, woody, sweet balsamic, spicy fragrance with a hint of lemon.

J. Galbanum

Galbanum (*Ferula galbaniflus*), originated from the Middle East, is a large perennial herb with a smooth stem, shiny leaflets, and small flowers. It contains

resin products that exude a milky juice, a natural oleoresin. The dried resinous exudate is collected by cutting at the base of the stem or upper part of the uncovered roots. Galbanum resinoid is produced by extraction of gum with a nonpolar solvent. The essential oil is obtained from resinoid and the extraction method is turning from steam distillation to CO₂ extraction. The essential oil is a yellow liquid with a green, slightly spicy odor. Both resinoid and essential oil are used for creating green top notes.

K. Ginger

Ginger (*Zingiber officinale*), originated from China, Fiji Islands, Indonesia, Jamaica, Malaysia, Nigeria, Taiwan, and the West Indies, is a perennial herb up to 1 m high with thick, spreading, tuberous roots, which are very pungent. Ginger oil is produced by steam distillation of dried crushed rhizomes, whereas ginger oleoresin is prepared by extracting ginger rhizomes with acetone or alcohol. Ginger oil is a light yellow liquid and its major components are zingiberene (35–40%), Ar-curcumen (18%), and β -sesquiphellandrene. Ginger CO₂ extract is much more aromatic than the steam-distilled version. Like other CO₂-produced oils, ginger CO₂ seems much closer to the scent and taste of a freshly grated root of fresh ginger, rather than the scent of the dried ginger found in the steam-distilled oil. Ginger concentrates are used in beverages like ginger ale, sweet baked goods, confectionery, curry powder, meats, and cordials.

L. Heliocarrot

Heliocarrot (*Radix daucus carota*) essential oil prepared by CO₂-extracted dried carrot roots into pure jojoba oil is extremely high in β -carotene, as well as vitamins A and E. CO₂ extract is much more concentrated than many of the infused carrot root oils available on the commercial market.

M. Hop Oils

Hop oils consist principally of hydrocarbons, oxygenated compounds, and small amounts of sulfur-containing compounds. The hydrocarbons typically make up 80–90% of the total oil; the terpenes myrcene and β -pinene, and the sesquiterpenes β -caryophyllene and α -humulene are found in the largest quantities. Two of these, β -caryophyllene and α -humulene, can be easily oxidized in air, thus contributing to the oxygenated fraction of the oil as well. Other oxygenated compounds include alcohols such as linalool and geraniol and esters such as geranyl isobutyrate and methyl dec-4-enoate. Although many brewers think that esters are all fermentation byproducts, hops can contribute a number of fruity aromas, e.g., grapefruit and pineapple.

For years, oils and the hop aroma have been extracted with steam distillation. However, the heat of steam distillation changes the hop aroma profile. Both oils and α acids have been extracted with solvents such as ethanol, ether, hexane, and methylene chloride. During the extraction with hexane, highly concentrated soft resins in solution can result in a considerable uptake of hard resins. In ethanol extraction, a large amount of water-soluble components, such as inorganic salts, nitrates, and tannins, will be extracted. Heating of the extract to remove solvent markedly modifies its aroma profile. There are also concerns that some solvent remains. Recently, CO_2 has been used to extract oils and α acids without these problems (17, 18). Liquid CO_2 (typically at 6 MPa pressure and 5–10°C in extraction plants) is a relatively mild, nonpolar solvent that is highly specific for hop soft resins and oils. The low temperature and selectivity associated with liquid CO_2 extraction allows recovery of the hop oils in undamaged condition. Therefore, liquid CO_2 becomes the most selective solvent used commercially for hops and hence produces the purest whole resin and oil extract. It extracts none of the hard resins or tannins, much lower levels of plant waxes, no plant pigments, and less water and water-soluble materials. However, the yield of α acids with liquid CO_2 (89–93%) is lower than that of supercritical CO_2 (91–94%) or the organic solvents (93–96%). Above the critical point (typically at 30 MPa pressure and at 60°C in extraction plants), CO_2 has the properties of both a gas and a liquid and is a much stronger solvent. Supercritical CO_2 is more selective than the organic solvents and extracts less of the tannins and waxes and less water and water-soluble components. It does extract some of the plant pigments like chlorophyll but rather less than the organic solvents do. This modification of the hop aroma profile also applies to some extent to supercritical CO_2 extracts, which are produced at about 60°C. Supercritical CO_2 also extracts less oil than does liquid CO_2 but more than the organic solvent extracts. As mentioned, liquid CO_2 extracts are the most pure whole-resin extracts; moreover, the low-temperature extraction (5–10°C) results in an aroma profile most closely resembling that of the leaf hops from which they were prepared. The only real disadvantage of liquid CO_2 extract in comparison with the others is its higher cost resulting from the lower extraction efficiency.

N. Jasmine

Jasmine extraction is one of the most important businesses nowadays. The exotic scent of jasmine comes from the flowers of *Jasminum officinale*, which grows in Algeria, Egypt, France, India, Italy, Morocco, South Africa, Spain, and Turkey. The star-shaped, very fragrant white flowers are used to obtain jasmine absolute via the concrete. Hexane is normally used as solvent in solvent extraction. Sometimes jasmine is extracted with benzene. Multistage extraction is carried out with hexane getting richer in perfumery content with each stage. Evapo-

ration is then carried out in the falling-film evaporator until 90% of the hexane of the mother liquor is evaporated. Concentrated liquor is distilled under vacuum to obtain the final jasmine concrete. The three-stage extraction of jasmine blossoms with hexane gives a 0.3 wt% yield of concrete and the extraction of the concrete with ethanol gives a 60 wt% yield of absolute. Jasmine is the most exquisite of scents; the absolute is a deep, reddish brown liquid with a sweet, floral and exotic, slightly heady fragrance, whereas the concrete is a brown waxy mass. Even though benzyl acetate is major volatile component of jasmine oil, indole, *cis*-jasmine, and methyl jasmonate contribute strongly to the typical jasmine fragrance.

O. Linden

Linden is a deciduous tree growing to 30 m high with wide, heart-shaped leaves with a whitish down on the underside, particularly on the veins. The small, extremely fragrant white flowers grow in drooping clusters on long stalks. Linden (*Tilia vulgaris*) blossom absolute is extracted from concretes or pomades, which are produced by steam. Other methods include solvent extraction, infusion, water distillation, and CO₂ extraction. It is greenish, viscous, light, floral, and sweet.

P. Myrrh

Myrrh oil is obtained by either CO₂ extraction or steam distillation of hand-picked and selected Burseraceae oleo gum resins produced by *Balsamodendron myrrha*. CO₂-extracted myrrh (*Commiphora myrrha* grows in Northeast Africa and Arabia), a rich golden resinous liquid, contains more components of the actual myrrh beads than does the steam distilled essential oil, which is a pale yellow to amber viscid clear oil with a characteristic warm, sweet balsamic, slightly spicy-medicinal odor. The most active ingredient of the myrrh flavor is lindenstrene. Myrrh resinoid is prepared by solvent extraction of the gum with hexane. The oil, resinoid, and tincture are used in pharmaceutical products, including mouthwashes, gargles, and toothpaste; they are also used in dentistry. The oil and resinoid are used as fixatives and fragrance components in soaps, detergents, cosmetics, and perfumes, especially oriental types and heavy floral. The essential oil is also used as a flavoring in most major food categories, alcoholic and soft drinks.

Q. Nutmeg

Nutmeg (*Myristica fragrans*), which is an apricot-like fruit of an evergreen tree up to 20 m high with grayish brown smooth bark, dense foliage and small dull-yellow flowers, is cultivated in Madagascar, Indonesia, Sri Lanka,

and the West Indies. Nutmeg essential oil is obtained from the dried nutmeg seed by solvent (alcohol) extraction, steam distillation (6–16% yield), or liquid CO₂ extraction (16% yield) (19). Most active ingredients of the nutmeg flavor are sabinene, α -pinene, β -pinene, and myristicin. It is a pale yellow liquid with a pleasant, warm, spicy, aromatic odor. Nutmeg oil is used as seasonings for curries, vegetables, baked goods, and processed meats.

R. Rose

Rose concrete and rose absolute can be obtained by solvent (hexane) extraction, whereas rose essential oil is derived from steam distillation. The extraction of rose flower with steam distillation gives about 0.025 wt% yield of rose oil. The premium rose perfume is the otto or attar, which is obtained by water and steam distillation from the rose blossom (*Rosa x damascena*). A perforated grid is used for supporting the rose flowers; thus, only rising steam contacts with the plant materials while water boils in the still. The steam, which contains flavor and aroma, is condensed and collected. The waxy constituents of the rose oil that float on the water are decanted off. The lower layer water is distilled again to recover any remaining oil. Both are combined to make rose oil. Since a lot of phenyl ethyl alcohol is dissolved in the distillation water, the otto does not accurately represent the rose flower flavor. The extraction yield is generally less than 0.02 wt%. Solvent extraction is now more frequently used to extract the aroma of rose blossoms. The product of solvent (hexane) extraction is a waxy, light brown, semisolid material known as a *concrete*. The concrete has phenylethyl alcohol in the same ratio as the blossoms, so that it represents the rose flower flavor intimately. Rose absolute is obtained from the concrete by extraction with a polar solvent like alcohol. The absolute is a reddish liquid with a deep, rich, sweet, rosy-spicy, honey-like fragrance. The phenylethyl alcohol content of its volatile portion is 60–70%. Typically, solvent extraction yields about 10 times that obtained by steam distillation, in the order of 0.1–0.2% (1–2 mL concrete/kg flowers). Rose oil is used primarily as a fragrance component in pharmaceutical preparations (e.g., ointments and lotions) and is extensively used as a fragrance ingredient in perfumes, creams, and soaps. Rose oil and absolute are also used extensively as flavor ingredients in fruit-type flavors. Food products in which they are used include beverages, frozen dairy desserts, sweets, baked goods, gelatins, and puddings.

S. Rosehip

A soft golden red oil of rosehip (*Rosa rubiginosa* Germany; originated southern Andes) is obtained from its red berry-like fruits or hips by CO₂ extraction or

cold pressing process. Rosehip is a rich source of vitamin C that is made into a drink for babies and young children. Those are contained in the rosehip shell. The oil extracted from the seeds contains essential polyunsaturated fatty acids, and *trans*-retinoic acid, which is now known to promote scar healing and more youthful-looking skin.

T. Tuberose

Tuberose (*Polianthes tuberosa*) is cultivated in Egypt, India, and Morocco. Large, very fragrant, white lily-like tuberous blossoms are used to extract absolute. The solvent extracted absolute is a dark orange or brown soft paste, with a heavy, sweet-floral, sometimes slightly spicy, tenacious fragrance.

U. Vanilla

Vanilla (*Vanilla planifolia*) has been one of the most important and most publicized flavors since its discovery in Mexico. The vanilla beans of commerce are the cured, unripe fruit of *Vanilla planifolia*, Mexican or Bourbon vanilla, which is native to Mexico, Central America, and northern South America; or *Vanilla tahitensis*, Tahiti vanilla, which is native to Oceania. The principal sources of vanilla are Madagascar, the Comoros, and Reunion, which together furnish about 70–75% of the world's supply, and Mexico, Uganda, and French Polynesia. Vanilla extracts are used extensively in chocolate, dairy products (milk, ice cream, etc.), beverages (colas), baked goods, and confections. Vanilla is also used as a background note or flavor enhancer (or sweetness enhancer) to round out the flavor profiles of many food products. The type of vanilla used depends on the product, the ingredients in the base formulation, and the desired flavor profile. In solvent extraction, extracts are obtained by extracting crushed vanilla beans with a polar solvent (methanol, ethanol, acetone, or different concentrations of water/alcohol). Sometimes countercurrent extraction technique is used to obtain vanilla essential oil. Concentrated vanilla extract is made by vacuum distillation, which is often used to separate materials that might suffer thermal degradation at the higher temperatures encountered in conventional distillation. However, distillation destroys some of the aromatic substances of vanilla flavor. Solvent is removed until the desired concentration is reached. Vanilla essential oil is a viscous dark brown liquid with a rich, sweet, balsamic, vanilla-like odor. Liquid CO₂ extracted absolutes (4.5% yield) have been tried with success in high-quality ice cream and desserts. Supercritical CO₂ extraction with ethanol as a cosolvent gives essential oil (10% yield) rich in natural vanilla aroma and fine crystals of vanillin. The basic key ingredients of the vanilla extract are vanillin and phenol derivatives.

V. Violet

Violet is extracted by solvent extraction. A small, tender, perennial plant with dark green, heart-shaped leaves and fragrant violet-blue flowers are the parts of the plant (*Viola odorata*) used for preparing absolutes. The leaf absolute is an intense dark green viscous liquid with a strong green-leaf odor and a delicate floral undertone. The flower absolute is yellowish green viscous liquid with a sweet, rich, floral fragrance, characteristic of fresh flowers. Most active ingredient of the violet leaf absolute is 2-*trans*-6-*cis*-nonadienal, which is responsible for the flavor.

W. Tolu Balsam

Tolu balsam is formed after injuries in the trunk of *Myroxylon balsamum* tree, native of the jungles of northern South America, particularly, in Colombia, Honduras, Peru, and Venezuela. The balsam is a brown, orange-brown, or dark yellowish brown mass. It is brittle when cold, and the fracture is glass-like or flint-like. Its odor is sweet balsamic, cinnamic in type, faintly floral, and with a backnote of vanillin. The fresh balsam is soft and sticky, but exposure to the air makes it hard and brittle, more like resin, with a crystalline appearance. The resinoid is prepared by extraction of the balsam, while essential oil is obtained by distillation of the balsam. Tolu balsam absolute is used mainly as a fixative in citrus colognes, oriental perfumes, chypres, and floral bases.

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