Chapter 6

Vegetable Oils and Fats

U7: General Introduction

Unlike dyes, essences and spices, vegetable oils and fats (also known as fixed or expressed oils) have stimulated little exploration and exploitation because of their abundance, universality and substitution or interchangeability. Their demand has, however, increased considerably in recent times with their use as a raw material for expanding industries. Our dependence on fatty oils can be expected to increase further owing to the constant depletion of non-renewable mineral resources.

Oils, fats and waxes have been in use since prehistoric times. Probably the fats initially used by man were of animal origin such as tallow, obtained from cattle and sheep and grease from pigs. The fats were separated from the other tissues by 'rendering', a process involving heating either in the presence (wet rendering) or absence of water (dry rendering). The art of recovering vegetable oils from the oil-bearing materials with the help of primitive mills was known to the ancient Chinese and Hindus much earlier than in any other parts of the world. The old Chinese oil presses were driven by manpower, while the primitive Indian extractor known as the *ghani*, *chekku* or *kolhu* was driven by bullocks. Even today, the *ghani* is still being used in remote rural areas of India and operates on the principle of a pestle rotating in a mortar, generally made of wood.

The ancient Egyptians and Phoenicians used vegetable oils for food and for anointing their bodies. As early as 1400 BC, Egyptian chariot wheels were lubricated with axle greases consisting of fats and lime. From the Egyptians and Phoenicians, the knowledge of the use of fats and oils spread to the Hebrews and thence to the Greeks. Homer mentions oil as an aid to weaving, and Pliny talks about hard and soft soaps. Today these oils and fats are put to endless uses, too numerous to mention.

Like carbohydrates, fats and oils contain only carbon, hydrogen and oxygen but in a different proportion, having a relatively very low percentage of oxygen. Vegetable oils and fats are triglycerides of complex organic fatty acids. Naturally occurring fats are usually mixtures of triglycerides of various fatty acids with a general formula represented as:

$$\begin{array}{l} CH_2\text{—}COOR_1 \\ \;| \\ CH\text{—}COOR_2 \\ \;| \\ CH_2\text{—}COOR_3 \end{array}$$

R1, R2 and R3 represent the carbon chains of the different fatty acids. Most commonly, each fatty acid radical is different. The most infrequent type of fat is the one in which all the fatty acid molecules are identical. The fatty acids are of two principal kinds, saturated and unsaturated. The common saturated fatty acids in fats are palmitic and stearic, the former being the most abundant in vegetable fats. The common unsaturated fatty acids are oleic (one double bond), linoleic (two double bonds) and linolenic acids (three double bonds).

The most important fatty acids are given in Table 6.1 along with their empirical formulae.

Table 6.1 Important fatty acids with empirical formulae

Saturated acids		*Unsaturated acids*	
Acids	*Empirical formula*	*Acid*	*Empirical formula*
Capric	$C_{10}H_{20}O_2$	Oleic	$C_{18}H_{34}O_2$
Lauric	$C_{12}H_{24}O_2$	Linoleic	$C_{18}H_{32}O_2$
Myristic	$C_{14}H_{28}O_2$	Linolenic	$C_{18}H_{30}O_2$
Palmitic	$C_{16}H_{32}O_2$	Ricinoleic	$C_{18}H_{34}O_3$
Stearic	$C_{18}H_{36}O_2$	Erucic	$C_{22}H_{42}O_2$

Oils, fats and waxes are very similar in their composition. Oils are liquid at ordinary room temperature whereas fats are solid or nearly solid. In general, the triglycerides of unsaturated fatty acids are liquid, and glycerides of saturated fatty acids with 12 or more carbon atoms are solid at ordinary temperatures. Coconut oil, palm oil, palm kernel oil, cocoa butter and shea butter are examples of fats. Coconut oil, a liquid in the tropical climate, is solid in temperate regions.

Waxes, on the other hand, are fatty acid esters of monohydroxy alcohols, unlike oils. They are found mostly as protective coverings on the surfaces of the leaves and stems, and greatly reduce the loss of water through transpiration. Waxes are very rarely found within living plant cells. Amongst the most valuable to mankind are carnauba and candelilla waxes.

Vegetable oils differ from volatile or essential oils (also designated as ethereal oils) in a number of important respects: a). they do not volatilise at ordinary room temperatures; b). they cannot be distilled without being decomposed; c). they leave a permanent greasy stain on paper; d). being glycerides, they form soaps with alkali; e). they lack strong taste and odour of essential oils and may become rancid on long exposure to air.

Box 6.1 Unsaturated fatty acids and their role in human nutrition

Monounsaturated fatty acids (MUFA) have a single double bond in their structure (for example, olive oil, mustard oil, groundnut oil) while polyunsaturated fatty acids (PUFA) have more than one double bonds in their chemical configuration (for example, sunflower oil, safflower oil, soya bean oil, corn oil, etc.). Sesame or *til* oil and rice bran oil are a mixture of both PUFA and MUFA.

Essential fatty acids (EFA) are those fatty acids which the human body is not capable of synthesizing. They must be supplemented in the diet as they are essential for normal growth of the body, especially the brain, heart, blood vessels, nerves and the skin. EFAs strengthen the immune or defense system and lubricate the joints. Two EFAs* that are known to be important for humans are as follows:

- *Alpha-linolenic acid* or abbreviated as ALA (an omega-3-fatty acid): It regulates many health challenges like heart diseases, arthritis, blood pressure, sudden cardiac death and depression. They raise the good cholesterol (HDL), making arteries more flexible. They also reduce the production of triglycerides in the body, thus helping in the regulation of blood pressure.
- *Linoleic acid* or abbreviated as LA (an omega-6-fatty acid): It is the building block for certain hormones like prostaglandins that protect against heart diseases, strokes, blood clots, high blood pressure and strengthen central nervous system.

Some of the food sources of omega-3 to -6 fatty acids are fish and shellfish (such as salmon, mackerel and sardines), flaxseed or linseed oil (containing approximately 55 per cent ALA), nuts (almonds, cashews and walnuts), hempseed oil, soya oil, canola (rapeseed) oil, palm oil, sunflower oil, safflower oil and pumpkin seeds. Four major oils (palm, soya bean, rapeseed and sunflower) provide more than 100 million metric tonnes annually, contributing more than 32 million metric tonnes of n-6 linoleic acid and 4 million metric tonnes of n-3 alpha-linolenic acid.

In India, we commonly use flaxseeds in the form of dry chutney. They are roasted on a low flame till they splutter, then cooled and dry grind with some dry coconut (*gari*), roasted peanuts, garlic flakes, salt and pepper. One tablespoon a day is a healthy addition to the diet. The chutney powder can be eaten with *khakhra* or chapattis or is sprinkled over *raita* or salad.

Hydrogenated oils (*vanaspati ghee*) should be avoided for cooking as the fatty acids (PUFA and MUFA) get converted into artery-clogging *trans* fatty acids, and they also lack vitamins E and A. Many of the commercially prepared baking items, such as biscuits, cookies, buns, rolls, croissants; *namkeen*; sweets, such as *gulab jamun*, cakes, pastries and chips as snacks for children are all made of *vanaspati*

Classification of Vegetable Oils

Vegetable oils, according to their ability to absorb oxygen from the atmosphere, are classified into three main groups–non-drying oils, semi-drying oils and drying oils.

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* Arachidonic acid (AA, sometimes called ARA, with a formula C20H32O2) is a counterpart to the saturated arachidic acid found in the peanut oil. It is a type of omega-6 polyunsaturated fatty acid, present in the phospholipids of membranes of human body cells and is one of the most abundant fatty acids in the brain, muscles and liver. It is primarily derived from red meats as well as egg yolks, organ meats and fish oil. The human body needs AA for the repair and growth of skeletal muscle tissue. In a true sense, it is not one of the essential fatty acids because our body can synthesise it from linoleic acid in the liver, but it does become 'essential' if there is a deficiency of linoleic acid or if the body is incapable of converting linoleic acid to arachidonic acid. It has great potential as an anabolic body-building supplement in today's athlete's nutritional arsenal to increase lean body mass and strength, however, too much of it can be very harmful. Little or no AA is found in common plants, but it can be used as a dietary supplement in the processed foods, especially for vegans or vegetarians. The fungus *Mortierella alpina* is a rich source of ARA, and is being exploited commercially.

- ***Non-drying oils:***

These oils remain liquid at normal temperatures and are incapable of forming elastic films even after long exposure to air as they do not react with atmospheric oxygen. They are largely glycerides of saturated acids and oleic acid, with little or no linoleic and linolenic acid. The iodine number* is less than 100. The non-drying oils never undergo oxidation to form a film, hence, are of no use in the paint, varnish or lacquer industry, but are very useful in the manufacture of soaps, as lubricants and as food. These oils are found notably in plants of tropical regions. Groundnut, palm, olive, castor, rapeseed and almond oils are a few important examples.

- ***Semi-drying oils:***

These are intermediate between the drying and non-drying oils, and are characteristic of having large amounts of linoleic and saturated acids but no linolenic acid. The semi-drying oils absorb atmospheric oxygen slowly, producing only a soft film after prolonged exposures to air (they never form a tough elastic film as is the case of drying oils). The iodine number is between 100 and 130. Oils included in this category are cottonseed, sesame, sunflower, corn and croton.

- ***Drying oils:***

These oils are fairly rich in glycerides of the unsaturated fatty acids, particularly linoleic and linolenic, with few oleic compounds. Such oils readily absorb oxygen on exposure to air and form a tough, elastic but resistant film. They are, therefore, very important as solvents for pigments in the paint and varnish industries. Drying oils have a high iodine number, more than 130. Temperate plants notably linseed, soya bean, tung, safflower and hempseed are the important types included under this category.

Location of Oils

Vegetable oils and fats are located in the form of small insoluble droplets within the plant cells. They occur predominantly in seeds, most commonly in the endosperm and cotyledons. In most of the cereals, however, the fat occurs almost exclusively in the embryo. Olive and palm oils are two important examples that are obtained from the fleshy pericarp of the fruit. Less frequently, oils and fats are extracted from the roots, stems and foliage.

* EXTRACTION

Methods of Obtaining Oils

Crude vegetable oils and fats are extracted from the oil-bearing cells by either of the following methods; rendering, mechanical pressure or solvent extraction. Rendering, as mentioned before, is chiefly used for recovering oils from animal fats, such as carcasses, but sometimes it is also practised in the extraction of palm oil in parts of Africa. The mechanical expression is by far the most common method of extraction.

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* Iodine number is the number of grams of iodine or iodine compounds absorbed by 100 grams of fat. The oil with higher iodine numbers readily absorb atmospheric oxygen and forms a tough and durable film.

Prior to extraction, extraneous materials such as twigs, leaves, stones and tramp materials are removed by screening and passage over magnets. After cleaning, the seed coats (hulls) are removed with the help of specially designed decorticating machines (decorticators) and thereafter the kernels are reduced to thin flakes.

- ***Mechanical expression:***

It involves the application of pressure to the oil-bearing tissues to squeeze out the fat. This is accomplished either by hydraulic pressing or screw pressing. In hydraulic press, the flaky material is usually placed in sacks or wrapped in strong cloth or filter cloth that holds back the residual mass as the oil strains through it. The hot expression is more common and involves the preheating of kernels with steam to allow the lipids to escape from the cells. In the cold expression, the kernels are merely pressed without resorting to steaming. As a result of pre-cooking, the oil is rendered more labile giving a higher yield but the quality is relatively inferior. There is often a considerable difference in price and use of cold-pressed and hot-pressed oils of the same plant.

- ***Solvent extraction:***

As the name implies, this process employs a solvent to leach out the oil and is the only practical method for recovering oils from tissues having a relatively low proportion of oil. Sometimes even the press cake (left during mechanical expression) is subjected to solvent extraction to retrieve the last traces of oil. This method is quite effective but expensive. A number of solvents can be used, including gasoline, benzene, carbon disulphide, petroleum ether and chlorinated hydrocarbons. The solvent must have access to all oil-bearing cells. The fatty oils are freed from the extracting solvents by distillation. The cake mass obtained during solvent extraction contains only one per cent or less of oil as compared to four to seven per cent in the mechanical pressing.

The crude oils often contain impurities such as water, dirt, cellular material, free fatty acids and phosphatides, pigments, odiferous compounds, such as an aldehyde, ketone, hydrocarbons and essential oils. The oils must, therefore, be subjected to a refining process to rid them of all the impurities.

The albuminoid fraction of the crude vegetable oil is removed through coagulation by heating. Free fatty acids are removed by agitation with sodium hydroxide. In some cases, bleaching or deodorisation is also practised.

Keeping Quality of Oilseeds and Vegetable Oils and Fats

Some seeds, if they are not bruised, can be stored for years without any change in the fat due to the presence of substances that tend to prevent autooxidation. The most common naturally occurring antioxidant is vitamin E (tocopherol). Vegetable fats usually contain appreciable amounts of tocopherol, while animal fats are relatively poor. In addition to antioxidants, other compounds are present that have practically no antioxidant property but increase the activity of a true antioxidant. These are referred to as synergists. Phosphatides function as antioxidants and may also enhance the activity of other antioxidants. Sesamol is an antioxidant contained only in sesame oil whereas gossypol is present in crude cottonseed oil.

Unfortunately, both the antioxidant and synergist are sometimes partly or wholly removed from fats and oils during the refining process and, therefore, these fats and fat-containing foods tend to deteriorate and develop an unpleasant odour and flavour. Fats in the early stages of autoxidation are edible but unpalatable. However, later both the odour and flavour become so repulsive that they cannot be eaten. Rancidity, as it is known, is due to the breakdown of glycerides into free fatty acids, aldehyde, ketones, etc. In order to increase their stability, antioxidants must be added to refined oils.

Although the main purpose of hydrogenation of oils is to produce more valuable plastic fats, the hydrogenated fats are generally many times more stable than the oils from which they are produced, that is, they are less likely to become rancid.

PRODUCTION

Of the many plants that produce vegetable oils, only about 12 species are commercially important and nearly 90 per cent of the total world's supply comes from them. The total oilseed production in the world (2012–13) was estimated at 474 million tonnes from a cropped area of 258.9 million hectares of land. The United States was by far the largest producer, accounting for 93.3 million tonnes. Brazil ranked second with 84 MT, followed by China (59.6 MT), Argentina (53.6 MT) and India (36.8 MT). The combined share of these five countries from the global production was around 69 per cent. The other leading oilseed producers in the order of ranking were the Ukraine, Russia, Indonesia, Paraguay, France and Australia. The ten top oilseed exporting nations were Brazil, the US, Canada, Argentina, Australia, the Ukraine, Uruguay, China and India. Soya bean is the leading oilseed crop produced globally with 267.8 MT of the world's total (with a share of more than 55 per cent of the total), followed by the rapeseed crop. The other major edible oilseed crops are cotton-seed, oil palm, groundnut, sesame, sunflower, coconut, safflower, olive, linseed, castor-seed and tung seed oil.

The global 'vegetable oil' production during the same period was around 186. 5 million tonnes. The palm and palm kernel oils ranked first with 56 233 000 tonnes (around 30 per cent share), followed by the second important soya bean oil with 42 558 000 tonnes – both accounted for roughly 61 per cent of the total world production. Rapeseed and sunflower seed oils were at the third and fourth positions with an output of 25 047 000 (15 per cent share) and 13 942 000 (9 per cent share), respectively – all the four vegetable oils together represented 85 per cent of the market. The major oil-producing countries were Indonesia, Malaysia, China, the EU-27, the US, Argentina and Brazil.

Besides, niger seed, *Guizotia abyssinica* (L.f.) Cass.; safflower, *Carthamus tinctorius* L. (both of Asteraceae); tobacco seed oil, *Nicotiana* spp. (Solanaceae) and poppy seed oil, *Papaver somniferum* L. (Papaveraceae) are produced locally in comparatively smaller quantities. Many others are obtained from trees growing wild in various parts of India and elsewhere, for example, mahua, [*Diploknema butyracea* (Roxb.) H.J. Lam. (syn. *Madhuca butyracea* (Roxb.) Macb.] (Sapotaceae); neem or margosa tree, *Azadirachta indica* A. Juss. (Meliaceae) and pongam, *Pongamia pinnata* (L.) Pierre (Fabaceae).

UTILISATION OF VEGETABLE OILS AND FATS

Vegetable oils and fats have a wide-range of uses, as food, for industrial purposes and also in the pharmaceuticals.

The contribution of fats and other lipids to our daily diet is great: a). they are the highly concentrated reserve of energy as they contain very little oxygen. All fats have a high caloric value as compared to that of carbohydrates and proteins. One gramme of fat will supply approximately nine calories whereas a gramme of carbohydrate or protein produces about four; b). fats and other lipids have a role in the satiety value of a food, that is, they give a feeling of satisfaction and delays the onset of hunger as fats retard the rate at which the food leaves the stomach; c).fats add flavour and variety to foods and make meals palatable and satisfying; d). fats act as solvents for the fat-soluble vitamins such as vitamins A, D, E, K and provitamin A.

Many of these oils, for example, olive, groundnut, soya bean, corn and cottonseed are used as cooking oils, and also in the manufacture of oleomargarine. The oleomargarine consists of about 80 per cent refined and hydrogenated oil, some 14-16 per cent cultured whole or skimmed milk together with small amounts of emulsifying agents such as lecithin and monoglycerides, salt, vitamin A and benzoate of soda.

The residue left after the extraction of oil, known as oil-cake, is often rich in protein and, therefore, can be incorporated into livestock feed and occasionally in human food. However, some oil-cakes, for example, castor, linseed and tung contain toxic constituents that make them unsuitable for feeding purposes but may be used as nitrogenous fertilisers.

Oils and fats are nowadays employed in the manufacture of many non-edible products such as paints, varnishes and lacquers, and as components in linoleum and oilcloth, soaps, detergents, candles, plastics, synthetic fibres, printer's ink, artificial leather, polishes, cosmetics and lubricants.

Fixed oils and fats such as castor and croton oils are used pharmaceutically for their soothing properties.

Groundnut, Peanut or Monkey-nut

***Arachis hypogaea* L. (n = 20)**
Family: Fabaceae

Like the bambara groundnut of West Africa (*Voandzeia* spp.), all species of *Arachis* are geocarpic, that is, their fruits ripen under the ground (Figure 6.1). A native of Brazil, it became widely distributed throughout South America at an early date. In the sixteenth century, the Portuguese brought them from Brazil to West Africa and the Spaniards took these across the Pacific to the Philippines from where they were introduced to China, Japan, Malaysia, India and Madagascar. The plant is now extensively cultivated in tropical and subtropical regions all over the world and also in the warm temperate regions. India is by far the largest producer, but most of the crop is consumed locally, and only a very little enters the world trade.

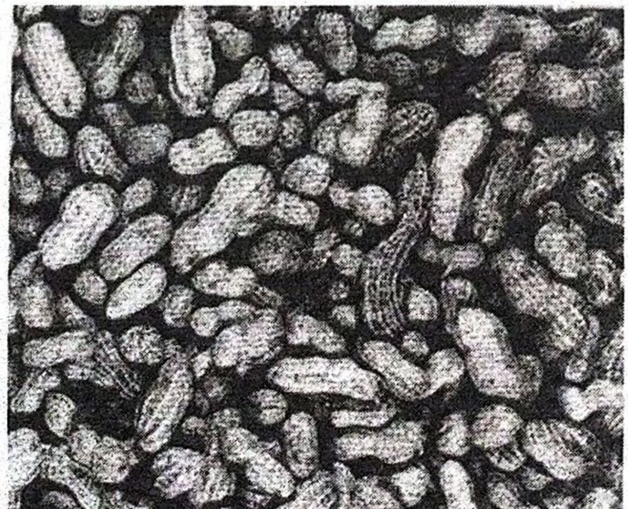

Figure 6.1 Different types and sizes of groundnut (*Arachis hypogaea*) pods.

olive oil. In India, a very high percentage of the total production of groundnut oil is now used for the manufacture of '*vegetable ghee*' by hydrogenation. Lower grade oil is employed in the manufacture of soaps, lubricants and illuminants. The residue, left after oil extraction, is a high-protein livestock feed. Sometimes the cake is used as manure. The best quality cake may be ground into flour for human consumption as it is a protein-rich-food supplement. The green haulms make excellent fodder.

A new synthetic textile fibre 'ardil' is manufactured from peanut protein. The fibres are cream coloured and have a wool-like texture. The shells are used as boiler fuel or to produce a particle-board for building purposes.

Medicinally, the oil is used as a laxative and emollient. In recent years, there has been great interest in the production of mycotoxin (aflatoxin) from *Aspergillus flavus* Link., which grows rapidly on moist peanut cake. It is known to possess an extreme toxicity to mammals, having a carcinogenic property.

Rape Seeds, Mustard Seeds and Relatives

***Brassica* spp. (x = 8, 9, 10, 11)**
Family: Brassicaceae

The genus *Brassica* contributes many species of considerable economic importance. It includes over 150 species of annual, biennial or rarely perennial herbs, mostly native to the north temperate parts of the Old World, especially the Mediterranean region. There are perhaps three centres of genetic diversity: Europe, central and southern Asia and China. The different species have spread to the subtropics and tropics as cold-season crops. The cultivated *Brassica* species may be divided into two distinct types; the vegetable types and the oilseed types, the former comprising cabbage, cauliflower, broccoli, turnip and rutabaga. Those extensively cultivated for the extraction of oil are *Brassica napus* L. and *B. juncea* (L.) Czern. and Coss. in China and Japan; *B. napus* and *B. praecox* Waldst. and Kit. in Europe and America; and *B. juncea* and probably *B. napus* in Russia and the Mediterranean region. In India, the principal oilseed or oleiferous crops are *B. campestris* and *B. juncea*. *Eruca vesicaria* subsp. *sativa*, another cruciferous plant, is a minor oilseed crop, grown mainly in Punjab and yields 'jamba oil'. Three distinct varieties have evolved from *B. campestris* in India; brown sarson, yellow sarson and toria, restricted to distinct ecogeographical regions – collectively they are known in India as rape. In Western Europe, *B. campestris* is also grown as an oilseed crop but the varieties are different from those cultivated in South-East Asia.

Considerable confusion exists as to the identification and nomenclature of the rape and mustard seeds that are grown in India. However, the nomenclature as given by Singh (1958) and Sikka and Rajan (1964) have been followed (Table 6.2).

In India, *Brassica alba* and *B. nigra* are not much used for oil extraction, but they are used in Europe and Canada. In Indian trade, three varieties of *Brassica* are collectively known as rape, while the *rai* is known as mustard.

Mustard has long been used as a condiment. Rape and mustard crops are adapted to temperate climates, preferring cool moist conditions and rich loamy soils. They are also grown both in subtropical and tropical countries as winter crops. There are three types of mustard; black mustard (*B. nigra*), brown, Indian or oriental mustard (*B. juncea*) and white or yellow mustard (*B. hirta*, earlier known as *Sinapis alba*). Brown mustard is also grown commercially as an oilseed crop in the Indian subcontinent, Canada, the Great Britain, Denmark, China, the US and South Ukraine. Yellow or white mustard comprises about 90 per cent of the Europe, especially in England and the Netherlands. It is usually

Oleic and linoleic acids, on average, represent about 47 per cent, the former varying from 20 to 3[illegible] per cent. The other saturated acids such as palmitic, stearic and lignoceric are present in very small quantities.

White mustard

Sinalbin ($C_{30}H_{42}O_{15}N_2S_2$) + H_2O $\xrightarrow{\text{myrosin}}$ Acrinyl isothiocyanate (sinalbin mustard oil) + dextrose + sinapin hydrogen sulphate.

Black mustard

Sinigrin ($C_{10}H_{16}O_9NS_2K$) + H_2O $\xrightarrow{\text{myrosin}}$ Allyl isothiocyanate (volatile oil of mustard) + dextrose + potassium hydrogen sulphate.

Mustard seeds, particularly *rai* are used as a condiment in the preparation of pickles and for flavouring curries and vegetables. The oil extracted from rape and mustard is used almost entirely for edible purposes such as salad and cooking oils and in margarine. General purpose greases, lubricants, soft soaps and synthetic rubber are important industrial products for which the oil is used. Inferior grades of oil are used as an illuminant and also as a cutting oil. The erucic acid fraction of the oil is used for lubricating jet engines and in the manufacture of plastics. Mustard oil is employed to impart a soft and pliable texture to skins and hides during the tanning process. It is also used for greasing loaves of bread, before cooking. In India, the oil obtained from mustard seeds is often used for anointing the body. The oilcake is mostly used as livestock feed in India, especially in Uttar Pradesh and Punjab, but an equally large amount is used as a fertiliser in Japan, India and Europe owing to its high-content of nitrogen. The presence of isothiocyanate in the rapeseed meal greatly limits its utilisation as a protein supplement for all classes of livestock feed, but processes have been developed which destroy the enzyme (myrosinase) during milling. Efforts are also being made to breed strains with little or no thioglycoside. On the contrary, the value of mustard seed as a table condiment lies in the production of isothiocyanate.

The leaves of young plants are used as a green or leafy vegetable. Mustard is also raised as a green fodder crop and occasionally as a green manure.

Medicinally, the essential oil of mustard is an extremely powerful irritant, causing severe blisters on the skin and, therefore, is used as a counter- irritant in highly dilute concentrations.

Coconut

***Cocos nucifera* L. (n = 16)**
Family: Arecaceae

The coconut palm is one of the nature's greatest gifts to mankind. Practically all parts of the plant are useful in one way or the other but it is the dried kernel (copra) which is of prime importance. The true geographic area of its origin is a much-debated subject. At one time, it was believed to be a native of the Pacific coast of tropical America, carried westward by oceanic currents to Polynesia and Asia. However, available evidence now indicates that the place of origin of coconut is somewhere in the Indo-Pacific region from where it has been scattered throughout the coastal regions of the world

Coconuts are propagated by the seeds. Germination is slow, and it takes about four months for the shoot to emerge. The cotyledon of the embryo begins to swell and elongate and extend backwards into the cavity of the endosperm where it enlarges into a haustorial organ, known as the 'apple'. Initially, it absorbs nutrients from the coconut water and then from the solid endosperm. The young shoot and root then grow through the eye of the nut. Nutrients are also absorbed by the root from the fibrous mesocarp. Thus, for the first nine months or more of its life, the young plant is nourished by the food reserves laid down in various parts of the fruit.

For successful cultivation, the palm requires plenty of sunlight, an average temperature between 27-32 °C, and a well-distributed rainfall of 1270-2550 mm per annum. It can be grown on a wide variety of soils, including coastal sands and alluvial, volcanic, lateritic or clay soils provided they have good drainage and adequate soil aeration. Thus, a porous soil behind beaches is best suited for the growth of coconut.

For copra production, fully ripe fruits should be harvested as copra and the oil content is high at this stage. On the other hand, 'nuts' for coir production are picked when ten months old. Drinking nuts are harvested earlier, usually at about seven months.

The fruits are dehusked with the help of an upright steel bayonet fixed on a wooden post. An experienced worker can husk about 2000 fruits per day. The husked nuts are split across the middle, usually with a sharp blow from a cutlass. The endosperm is removed and dried either in the sun or the kiln. Good quality copra contains as little as three to five per cent moisture and has an oil content of 60 to 65 per cent, sometimes going as high as to 75 per cent. The oil content of copra is also affected by the method of extraction, varying from 55 to 65 per cent.

The main fatty acid constituents of coconut oil are: lauric, 44-51 per cent; myristic, 13.1-18.5 per cent; palmitic, 7.5-10.5 per cent; caproic, 0.2-0.5 per cent; caprylic, 5.4-9.5 per cent; capric, 4.5 -9.7 per cent; stearic, 1.0-3.2 per cent, arachidic, 0-1.5 per cent; oleic, 5.0-8.2 per cent and linoleic acid, 1.0-2.6 per cent. The latter two unsaturated acids constitute only 9.0 per cent of the total fatty acid content. Coconut oil is a white to yellowish solid fat at temperature below 24 °C. At higher temperatures, however, it melts to give a colourless or pale brownish-yellow oil.

Owing to its many and varied uses, coconut palm has attained a unique position among the tropical plants, providing all the necessities of life. On account of these useful features, coconut has been called 'The tree of heaven' –*Kalpavriksha*,

The fresh kernels are eaten raw or in the preparation of puddings, sweets, curries and chutneys. Coconut milk from the tender nuts is a very refreshing and delicious drink and is highly prized as a source of food. The coconut water is known to have laxative and diuretic properties. Coconut milk contains plant growth substances and is, therefore, used in the experimental culture of plant tissues. An exudation, 'toddy', is obtained by tapping the unopened spadices of coconut. It may be drunk fresh or may be boiled down to produce palm sugar or 'jaggery'. Toddy, if left, ferments rapidly due to the action of naturally occurring yeasts and the fermented toddy makes a highly intoxicating beverage containing about six per cent alcohol. After 24 hours of fermentation, the toddy is unpalatable as a beverage and can be used for the production of vinegar. The coconut apple or haustorium of the germinating nut is eaten in some regions. The freshly cut tender terminal bud, known as 'palm cabbage', is regarded a delicacy and may be eaten cooked or raw. Desiccated coconut, owing to the low-content of unsaturated acids, is widely used in confectionery and bakery products.

Coconut oil is classed as an edible-industrial oil. Due to its higher content of lauric and myristic acids, the oil has a very high saponification value, and the soap obtained from coconut oil lathers freely in hard and salt water. The oil is still being employed in the manufacture of margarine. It also finds wider application in the manufacture of lubricants, detergents, cosmetics such as face creams, shampoos, rubber, synthetic resins and hydraulic brake fluids for aeroplanes. The oil is also employed for anointing the body and for illumination. The coco-stearin fraction from coconut oil is used in the manufacture of candles.

Ripe or fully mature coconut (ball copra or cup copra) is used as religious or sacrificial offerings, occupying a very important place in Hindu rituals.

The fibrous mesocarp provides the coir of commerce, which has been discussed in Chapter 2 on fibres and fibre yielding plants. Whole shells are used for domestic utensils such as drinking vessels. They take a high polish and can be carved and decorated. They are employed for making buttons, combs, bangles and musical instruments. The shells are also used for fuel, particularly in copra kilns. Finely powdered shells are used as a filler in plastics. On distillation, shells yield wood tar and furfural. The tree trunk is used as a timber for house construction, and the leaves can be plaited and used for thatching, mats, screens, baskets and other articles used in daily life. The press cake, known as 'poonac' in the East, is an excellent feed for cattle and poultry.

Oil Palm, African Oil Palm

Elaeis guineensis **Jacq. (n = 16)**
Family: Arecaceae

The African oil palm gives the highest yield of oil per acre than any other oilseed crop and also produces two distinct vegetable oils; palm oil derived from the fleshy mesocarp of the fruit and palm-kernel oil from the seeds (kernels). The oil palm is native to West Africa where it grows wild in the coastal areas. The palm oil is extracted in the country of origin but expression of the seed is seldom carried out in the producing country. Palm kernels are generally shipped whole.

For centuries, wild oil palms have been used in West Africa but now extensive plantations have grown up in Africa, South-East Asia, the American tropics and the West Indies. During the year 2011–12, around 49.9 million tonnes of palm oil was produced with about 87 per cent coming from Indonesia and Malaysia. At present, Indonesia is by far the largest producer with 25.4 million tonnes (with a share of little over 50 per cent). Malaysia comes next at 18 MT (with a share of about 36 per cent), followed by Thailand, the distant third with 1.54 MT (about 3 per cent share) and Colombia and Nigeria at 0.8 MT each (with 2 per cent share). In Africa, the major palm oil producers are Nigeria, Democratic Republic of Congo, Ghana, Cameroon, Côte d'Ivoire, Benin and Liberia. Colombia has now become the largest palm oil producer in the Americas, followed by Ecuador, Guatemala, Brazil, Costa Rica, Mexico, Peru and Venezuela. The other producing countries include Papua New Guinea and Solomon Islands. Malaysia and Indonesia are the two largest exporting countries of palm oil, accounting for more than 80 per cent of the world's export. The other notable exporters are Benin and Papua New Guinea. India is the largest buyers of palm oil, followed by China, Pakistan, the US and the EU-27 nations. India and China primarily use palm oil for edible purposes while the EU nations import palm oil for biofuel production.

Tung may be raised from seeds but selected clones are now budded on seedling rootstocks. *A. fordii* grows well on poor, rocky wastelands which are unfit for other crops but grows best at elevations from 610-1070 m, preferring well-drained, deep, fertile and slightly acidic soils. The trees can withstand mild winter frost. Indeed, it needs a temperature of about 7 °C for nearly three weeks to initiate flowering and fruiting. An annual rainfall of 100-125 cm is essential. It begins to bear fruits after three years and has a productive cycle of nearly 30 years. The fruits are harvested either before maturity, or allowed to fall to the ground. Often, the fruits are hulled in the field with the help of portable hullers. The husk may also be removed either by heating the fruits in a large iron pan over a fire or by fermentation. The seeds should be dried immediately to prevent any hydrolysis of the oil. In China, the oil is recovered by primitive means; the oil is expressed from the separated, crushed and pre-heated kernels. The kernels have an oil content of 50-60 per cent.

Tung oil is largely composed of elaeostearic acid, about 80.0 per cent in *fordii* oil. Its iodine number is 163. The other fatty acids are: oleic, 15.0 per cent; palmitic, 4.0 per cent and stearic, 1.5 per cent. When heated, the oil sets into a gel. The chemical characteristics of '*montana* oil' (also known as mu oil) are virtually the same as that from *A. fordii* but it contains about 70-75 per cent elaeostearic acid. *Fordii* and *montana* oils are the only two commercial vegetable oil known to contain elaeostearic acid.

The press cake is unsuitable for livestock as it contains a toxic substance similar to toxalbumin, hence is usually used as a manure. Hulls are returned to the fields to be used as a mulch for tung or other crops such as coffee.

Soya Bean

***Glycine max* (L.) Merr. (n = 20)**
Syn. *G. soja* (L.)Sieb. and Zucc.; *G. hispida* (Moench) Maxim.; *Soja max* (L.) Piper
Family: Fabaceae

Soya bean has been cultivated in China from prehistoric times, as is evident from Chinese writings dating back to 2800 BC, in which it is mentioned as one of the five principal and sacred crops. It was an important food plant in the Orient (China, Manchuria, Korea and Japan) since the earliest times and was carried to Europe by French missionaries in 1740 and to the Royal Botanic Gardens, Kew, in 1790. Soya beans were first brought to the United States in 1804 but failed to receive any recognition. It is only relatively recently that its potential has been recognised and has, therefore, now become widespread. At present, it ranks high among the leguminous crops in its nutritional value owing to a high protein content (as high as 43 per cent). In addition, it has about 20 per cent oil. Soya bean is an excellent protein supplement for enriching our cereal diet. It has earned a special place in the nutrition programme. So numerous are the modern uses of the soya bean that it is known as the 'wonder bean'.

In spite of the fact that commercial production of soya bean began only in the 1930s in the US, it is now a leading producer together with Brazil and Argentina. At present, soya bean is the largest oilseed crop in the world accounting for more than 50 per cent of the world oilseed production. Its cultivation is concentrated mainly in the three countries, namely the US, Brazil and Argentina, producing nearly 80 per cent of the global output of 276.3 million tonnes (2013), with their individual share of 89.4 MT (32.4 per cent of the total), 81.6 MT (29.6 per cent) and 49.3 MT (17.8 per cent), respectively. China is distant fourth with 12.5 MT, followed closely by India at the fifth position with a production of 11.9 MT annually. South America as a continent contributes more soya bean than North America, that is, the US and Canada combined. Several other small soya bean producers include Paraguay, Canada, Uruguay, the Ukraine, Bolivia, Russia, South Africa, Uganda, Romania and Vietnam. In the US, soya beans are grown mostly in the Midwest, in the states of Iowa, Illinois, Minnesota, Indiana and Nebraska. The US is the major exporter of soya beans in the world, followed by Brazil, Argentina and Paraguay. The other soya bean exporting nations are Canada, Uruguay, the Ukraine, Bolivia and the Russian Federation. China is the major buyer of soya beans from overseas, followed next by the EU-27 nations, Japan, Mexico, Indonesia and Thailand. Genetically modified soya beans were introduced into the market in 1996 and now its commercial production has risen very sharply in the US, Argentina and Brazil accounting 87 per cent, 98 per cent and 41 per cent of the crop, respectively. In India, the chief soya bean growing states are Madhya Pradesh, Maharashtra and Rajasthan, accounting for 95 per cent of its production.

It is believed to be derived from *G. soja* Sieb. and Zucc. (syn. *G. ussuriensis* Regel and Maack), a slender, prostrate, twining legume which is found wild throughout eastern Asia, possibly in hybridisation with *G. tomentella* Hayata (syn. *G. tomentosa* sensu Benth., non-L.), which grows wild in southern China. Its long history of cultivation, and more recently because of an intensive breeding programme, many great cultivars exist, differing in their growth habits, maturation period, oil content and composition.

Soya bean is an erect, much-branched, pubescent annual, 0.6-1.8 m high, depending on the cultivar, although in some varieties it tends to be creeping or twining. The leaves are large, alternate, stipulate and generally have a long petiole. They are trifoliate (rarely with five leaflets); leaflets are ovate to lanceolate, each being subtended by a short pointed stipel (Figure 6.17 A). The flowers are small, varying in colour from nearly white to deep purple and are borne on short axillary racemes, each bearing three to 15 flowers. Self-fertilisation is normal. The seeds are small, globose with a small hilum, ranging in colour from creamy white through various shades of grey and brown to nearly black, and are enclosed in short, narrow hairy legume or pod (Figure 6.17 B). The pods are slightly constricted between the seeds, each having two or three seeds (occasionally four). *G. max* is essentially a subtropical plant but its cultivation extends to tropical and temperate regions up to latitude 52 °N. The general climatic requirements are almost identical to those of maize. Soya bean cultivation is concentrated mainly in the regions with hot, damp summer weather. An evenly distributed rainfall during the growing period and more or less dry weather during the period of ripening are necessary. Excessively high temperatures or extreme winters are harmful to the crop. Soya bean will succeed on nearly all types of soil, but grows best on deep, fertile soils with a high calcium content. It is essentially a short-day plant.

The crop is raised from seeds. Early varieties of soya bean mature in 75-110 days, while the late ones take 100-200 days. The crop is harvested by hand in Asia and many tropical countries when the leaves begin to turn yellow and drop. In the US, combines are used for harvesting, shelling and bagging.

Black-seeded varieties are richest in protein and have a low percentage of oil. Yellow-seeded forms, on the other hand, have a higher oil content but are low in proteins. The fatty acid constituents of soya bean oil are: oleic acid, 23-34 per cent; linoleic acid, 52-60 per cent; palmitic acid, 7-14 per cent; stearic acid, 2-6 per cent; linolenic acid, 3.0 per cent and higher saturated acids up to 2.0 per cent. Soya bean contains the glycosides genistin and diadzin (daidzin) and four saponins. It has a higher percentage of proteins than many other foodstuffs, the proteins being of a higher biological value. The chief form of proteins is a globulin (glycinine), accounting for nearly 80-90 per cent of the total seed protein. In addition, another globulin (phaseolin) and an albumen (legumelin) are also present. The seeds are also a rich source of calcium, iron and vitamins, especially of the B-complex type.

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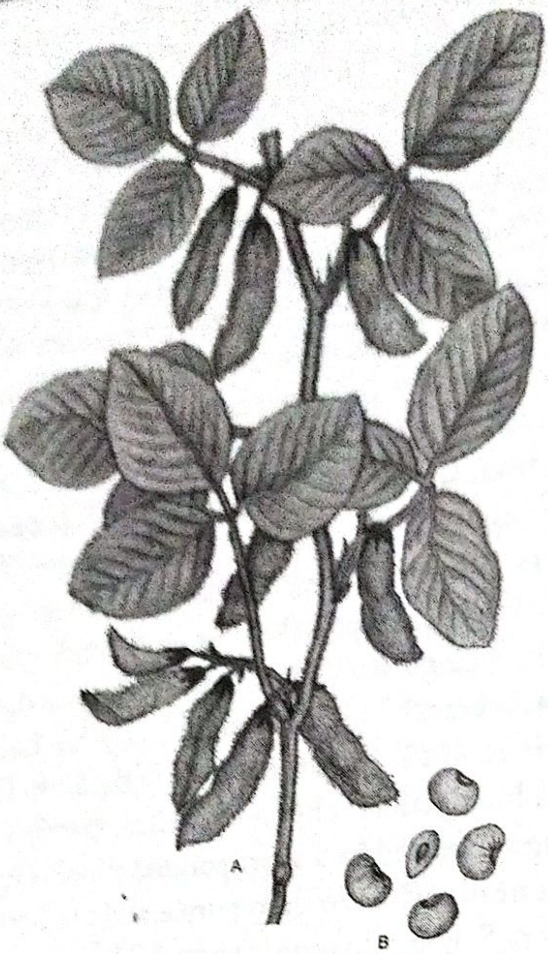

Figure 6.17 (A) Shoot of a soya bean plant, (B) seeds with hilum.

Soya beans are grown mainly as a food crop in China, Japan and other East Asian countries. The seeds are consumed green, dry or sprouted. The unripe seeds are consumed as a vegetable. Roasted and salted seeds are used in cakes and candies. Soya bean milk, obtained by grinding boiled seeds with water, is extensively used for infant feeding throughout China. It is as nutritious as cow's milk. Five to six kilogrammes of milk can be obtained from one kilogramme of beans. Soya milk is made into curd, butter milk, cheese and other milk products. Soy sauce – a brown sauce is made by subjecting soya bean and rice flour to a long fermentation by *Aspergillus oryzae* (Ahlb.) Cohn. The fermented beans are then immersed in brine for many months in the sun to extract the flavour. The brown liquid is used with meat and fish and also to flavour rice. In Indonesia, boiled seeds are fermented by mould and then made into cakes (tempe).

Soya bean flour is becoming increasingly important as an ingredient of foodstuffs and bakery products such as bread, biscuits and cakes. Because of its low starch content, the flour forms an ideal ingredient of food for diabetic patients all over the world. Since the raw seeds contain a trypsin-inhibiting substance, soya bean flour must be specially treated to destroy the inhibitor before it can be used in substantial amounts.

A large proportion of the soya bean oil is used for edible purposes in the US, particularly as a salad oil and for the manufacture of margarine and shortening. It is also employed for packing sardines, tuna and other kinds of fish. Soya bean oil finds wider application in the manufacture of soaps, glycerine, printing inks, greases, lubricants, waterproofing material, oilcloth, linoleum, putty, resins, insecticides, disinfectant and leather dressings. The oil is now being used extensively with other drying oils in the paint, varnish and enamel industries. Soy lecithin, an important by-product of the oil industry, is used in the food industry as an emulsifier and in the cosmetics, pharmaceuticals, paints and plastic industries, and in soaps and detergents. Soya meal, the residue left after the extraction of oil, is a very rich protein feed (40-48 per cent) for cattle, pigs and poultry. The meal is also used in the manufacture of adhesives, sizings, water proofings, plastics, synthetic textile fibres, foaming solutions and as a fertiliser.

It is often grown as a pasture, forage or fodder crop and used either as hay or as silage and also as a green manure. Nowadays, soya beans are widely employed for the industrial production of antibiotics.*

Linseed

***Linum usitatissimum* L. (n = 15)**
Family: Linaceae

Linseed is one of the earliest plants to have been domesticated for the extraction of fibres in the Mediterranean region and southern Asia. However, it has now attained prominence as a dual-purpose crop, that is, as a source of both oil and fibres. It is grown widely in many parts of the world, both in tropical and temperate zones. Generally speaking, the crop is grown in hot dry regions mainly for oil production and for high-grade fibre in temperate regions. The varieties grown for fibre are usually different from those for oilseed production. Of the estimated global flaxseed production of 2 238 938 tonnes during 2013, the bulk came from Canada with 712 000 tonnes, representing about 32 per cent of the world's total. China comes next with 330 000 tonnes (14.7 per cent), followed closely by Russia and Kazakhstan, contributing a share of 14.5 and 13.2 per cent, respectively. All the four countries together accounted for about three-fourth of the global output. The other major producers were India, Ethiopia, the US, the UK, the Ukraine and Sweden. The US, Great Britain, Canada, Russia and the Ukraine are the major suppliers of linseed and its products to the many EU countries, China, Afghanistan and Chile.

The botany and cultural requirements of the flax plant have been discussed in Chapter 2 on fibres and fibre yielding plants. The fruit is a small, indehiscent, globular, multi-chambered capsule with a persistent calyx, developing from a pentacarpellary ovary (Figure 2.4 in Chapter 2). It contains up to ten seeds, one each in the ten locules of the fruit. The seeds are oval or lenticular in outline, 4-6 mm long by 2 to 3 mm wide, and have a distinct obliquely pointed end where the hilum and micropyle are located in a slight depression. The seeds are characteristically smooth and flattened with a shining yellow to reddish brown testa and possess a distinct raphe line along one edge. The testa produces a large amount of mucilage when wetted. The endosperm is scanty and surrounds the thick cotyledons.

Varieties grown for seeds are shorter, more branched and spaced farther apart to encourage added branching and increased seed production. The linseed crop matures in about six to seven months. After harvesting, the crop is allowed to dry in the field for a few days and then threshed. The seeds are separated from the chaff by winnowing.

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* Today, most steroids (widely used to treat arthritis, achieve contraception, etc.) are made from natural compounds called sitosterol and stigmasterol, by-products of soya bean processing. Recent research studies indicate that women, who eat soya bean-rich diets are up to eight times less likely to develop breast cancer than other women, probably because of the presence of anti-estrogen compounds such as phytoestrogens.

Flaxseeds (also called linseeds) contain high levels of omega-3 fatty acids, especially alpha-linolenic acid (or ALA), dietary fibres, mucilage gums as well as a group of phytoestrogens called lignans. They are rich in many important B-complex group of vitamins (such as riboflavin, niacin, thiamine, pantothenic acid and folates), magnesium, potassium and manganese. Flaxseeds are excellent source of vitamin E (gamma-tocopherol). The high-fibre content, both soluble and insoluble, helps to lower the triglycerides as well as total cholesterol and LDL or 'bad' cholesterol in the blood by a significant amount. It also increases the HDL or 'good' cholesterol level which may help to reduce the risk of heart diseases. The strong fibre content helps to delay gastric emptying and thus can improve intestinal absorption of nutrients, which further helps to keep the bowels regular, preventing constipation. Flaxseeds are one of the most concentrated plant sources of omega-3 fatty acids (which must be consumed because our bodies don't make them) – a key factor that can help prevent the blood vessels from inflammatory damage, and it is known to further improve brain health, prevent memory loss and depression.

Flaxseeds contain lignans which are esterogen like chemicals that also possess antioxidant properties, that is, they remove free radicals from the body, thus helping to protect against prostate, colon and breast cancer.

The ground roasted flaxseed can be sprinkled on fruits, veggies, hot and cold breakfast cereals or can be used in shakes, and as a topping for yoghurt and desserts (for details see Box 6.1). Ground flaxseeds can be baked into cookies, muffins and breads. Flaxseeds contain very small amount of cyanide compounds, but these are broken down on roasting. The roasted ground meal or 'chutney' should be consumed within a week or else stored in air-tight, steel containers in a cool place or a refrigerator. However, the ground seeds when exposed to air become quickly rancid, and lose their nutritional properties.

The oil is present in the cells of the two large cotyledons in the form of yellowish globules intermixed with aleurone grains. Both cold and hot expression methods are used for the extraction of oil. In general, before crushing, the seed is rolled into a meal and cooked in a steam jacketed trough. The oil content of the seed is between 33 and 43 per cent. If protected from air and light, the oil has a good keeping quality. However, on exposure to air it is converted into an elastic solid known as linoxyn. Linseed oil is a yellowish-brown liquid, characterised by the presence of a high percentage of linolenic acid (30-60 per cent). Other fatty acids are: stearic and palmitic, 6-16 per cent; oleic, 13-36 per cent; linoleic, 10-25 per cent and traces of myristic and arachidic acids.

Linseed oil, being a drying oil, is principally used in the paint and varnish industry and also in the manufacture of linoleum, oilcloth, printing and lithographic inks and soft soaps. The oil is also employed in the preparation of lubricants, greases and polishes.

Raw linseed oil is used in pharmaceuticals as an emollient, demulcent, expectorant and diuretic. Because of the hydrophilic property of the mucilaginous substance present in the seed coat (spermoderm), the whole seed is used as a laxative as it draws fluid from body tissues with which it is in contact. The extracted mucilage is often used in the cosmetics and pharmaceutical industries as a demulcent. It is also used for the preparation of water paints.

The poisonous effect of the seed is due to the presence of a cyanogenetic glycoside, 'phaseolunatin' (linamarin). Cattle poisoning is caused by the hydrocyanic acid or prussic acid which is released by the activity of the enzyme linase on linamarin. Hot pressed linseed cake is harmless as the linamarin fraction is not hydrolysed to HCN owing to the denaturation of the enzyme linase during cooking. Oilcake is a palatable, protein-rich (30 per cent) livestock feed. It has a slightly laxative action. Linseed straw (leaves, stem and chaff) also makes a low-grade feed for cattle. Woody material and short fibres, left after fibre extraction, are converted into a useful pulp for paper production.

Quite often the raw linseed oil is heated to 90–150 °C in the presence of driers such as the salts of certain metals (lead, manganese, cobalt and zinc). Boiled oils dry at a faster rate and form a smooth and lustrous film. They are preferred for most industrial uses, for example, in the paint, lacquer and varnish industries, and are also used in the manufacture of waterproofing materials, patent leather and for imparting special finishes to cotton and silk fabric.

Oilcake, either alone or with other inorganic manures, can be used for increasing soil fertility.

Canola

The use of rapeseed oil (currently sold under the trademark canola) dates back to antiquity, and its cooking and medicinal values have been recorded in the ancient writings from Greece, Rome, India and China, dating as far as back to 1500 to 2000 BC. Rape has been cultivated as an oilseed crop in Asia and Europe for hundreds of years. The rapeseed oil produced in the nineteenth century has been much used in oil lamps and also as a source of a lubricant for steam engines. However, its use as a lubricant was much increased in the war ships in the Word War II. Natural rapeseed oil has a much higher erucic acid content (about 50 per cent) which makes it less useful for human consumption, and the rapeseed press cake or meal is not particularly palatable for livestock because of high levels of sharp-tasting compounds called glucosinolates (or mustard oil glycosides).

The name rapeseed is now commonly used for two *Brassica* species, namely *B. napus* L. and *B. rapa* L. of the family Brassicaceae, which includes many vegetables like cauliflower, cabbage, broccoli, Chinese cabbage, brussels sprout and turnips. *B. napus* is an allopolyploid (2n=38) with a genomic assignment AACC, and it is thought to have originated from a cross between *B. rapa* (AA genome, 2n=20) and *B. oleracea* L. (CC genome, 2n=18). The rapeseed was cultivated by the ancient civilisations of Asia and the Mediterranean. Traditionally, in the Western countries, it was considered unsuitable for humans and animals because of the presence of toxic compounds in the seeds (Figures 6.18 and 6.19).

Figure 6.18 Canola in flowering. Canola is a crop with plants from 3 to 6 ft. tall that produce pods. The flowers have a typical cruciferous plan, and are small, yellow in colour, beautifying the landscape. The plant needs a dry and cool place to grow.

Essential oils are known to occur in every organ of the plant, for example, flower (rose, jasmine, cananga, tuberose), fruits (orange), leaves (mint, sage, rosemary), bark (cinnamon), rhizome (ginger), wood (cedar, sandalwood), seeds (nutmeg, coriander, fennel, dill), roots (vetiver) or many resinous exudations as well, for example balsams and pines which flow from injured trees.

The oils may occur throughout the plant or may be restricted to specific organs. They frequently occur as droplets in cells lining the glandular hairs, or secretory cavities or ducts (vittae) which permeate the tissue, or between the cell wall and cuticle of epidermal hairs where a slight break in or damage to the cuticle permits volatilisation, resulting in characteristic fragrance. Glands often occur as translucent dots in leaves or tissues (termed pellucid-punctate) when viewed against light. The amount of essential oil varies from an infinitely small quantity to as much as 1-2 per cent (up to 18 per cent in cloves). They are frequently associated with substances such as gums and resins. Different parts of the same plant may yield oils with different composition, for example, sour orange, *Citrus aurantium* L., yields orange blossom oil or neroli oil (flowers), petitgrain oil (leaves and twigs) and bitter orange oil (from fruits). Ceylon cinnamon tree, for instance, possesses three distinct oils, each with a different principal component, root oil (camphor), leaf oil (eugenol) and bark oil (cinnamaldehyde).

The chemical composition and quality of an essential oil strongly depend upon the varietal form, prevailing climatic condition, time of harvesting and the extraction procedure. In several flowers, rhythms of opening and scent production are important, since the secretions reach a peak during the night or at a particular time of the day.

CLASSIFICATION OF ESSENTIAL OILS

It is difficult to classify the essential oils based on the economic uses to which they are put, since the uses often overlap and in numerous cases, the same oil is used for making perfumes, flavouring and medicines. One way of empirical grouping is to divide oils as grass oils, wood oils, leaf oils, root oils, flower oils and essential oils of less importance. However, for the sake of convenience in this chapter, we will classify the essential oils mainly into perfume oils, flavouring oils and wood oils (as discussed, some of the oils may come under more than one of these categories).

Extraction Methods

There are six methods of extracting essential oils from the plants, distillation, enfleurage, maceration, solvent extraction, mechanical expression and adsorption, depending upon the nature of plant material, the quantity of oil present and the relative stability of various components.

DISTILLATION

It is the simplest, most ancient, and still by far the most common method of essential oil extraction. Three types of distillation are used (a). water or hydrodistillation, (b). water and steam or 'wet steam' distillation and (c). direct steam or 'dry steam'. In water distillation, the plant material (which is usually comminuted) or crude turpentine oleoresin is completely immersed in water in a closed still, and boiled by either direct heat (open fire) or with the help of perforated steam coil or steam jacket. In water and steam distillation, the plant material is packed and supported above the water level in the still with the help of a perforated grid. In this case, the steam is generated elsewhere and piped into the water of the still. The resulting 'wet' steam passes through the aromatic material, thus operating at low pressure. In direct steam distillation, live steam is introduced into the bottom of the still that passes above through aromatic plant materials supported on grids set at intervals. Since, the third method is relatively fast, charging and emptying the still is much faster, and therefore, energy consumption is lower. Distillation at a pressure higher than the atmospheric pressure or using superheated steam is also practised in certain specific cases. In orris roots (*Iris florentina* L.), the distillation is carried out in a partial vacuum as its major constituent irone or ionone, which is also the basis of the best violet perfumes, is easily damaged at high temperature. The partial vacuum helps to keep the temperature in the still as low as possible. The distillate collected in the receiver separates out into the upper immiscible oily layer or essence (from where the term 'essential oil' is derived) and the lower aqueous phase; the former layer is then removed and filtered. However, the oil of clove is heavier than water, thus forming a lower layer. Fractionation or rectification of the distillate is carried out in those cases (such as rose) where water and essential oils are soluble in each other. In such cases, the temperature is increased gradually during distillation, through which the most volatile constituent of the mixture distils first and the less volatile components separate later. In industrial units, the same result is readily achieved by using a fractionating column operating in conjunction with a constant-pressure or constant-temperature maintained retorts. However, because of the prolonged exposure to high temperatures, the components of the oil may undergo hydrolysis, isomerisation or polymerisation, thus altering the oil's natural fragrance.

ENFLEURAGE OR COLD-FAT EXTRACTION

The process is used (a). to extract delicate floral scents from flowers that continue producing essential oils even after being picked (for example, jasmine, tuberose and violets), (b). in case the oil is destroyed by heat through hydrolysis, polymerisation or resinification and (c). if delicate oils are lost in large volumes of water.

The usual practice is to spread a thin layer of purified fat on both sides of a glass plate mounted one above the other to form an airtight compartment within a frame called a 'chassis', assembled in a cool dark room or cellar. The fresh blossoms are then placed over the fat (either tallow or high-grade lard). Every few days, the spent flowers are removed (defleurage) and replaced by a fresh batch until in about four weeks the fat becomes saturated with the perfume. Earlier the flowers were picked off by hand, but now it is done mechanically or by using a vacuum cleaner. The resulting scented grease is called a 'pomade' – the most common being 'pomade 36', which is made by charging the glass plates with fresh blossom 36 times. This semisolid mass of fat with the floral essence is called 'concrete'. A floral 'absolute' is prepared from the concrete by dissolving out the essential oil fraction with alcohol. The alcoholic extract (also called 'lavage' in France) is chilled to about -10 °C and filtered, as far as possible, at the same temperature. This step eliminates waxes and resinous matter, which is commonly used to make scented soaps. The alcoholic solution is distilled off under vacuum to remove alcohol, leaving behind the 'floral absolute', which is a highly concentrated form of perfume oil.

Even though, enfleurage is a time-consuming and expensive process, it produces extremely natural fragrances and is able to capture very delicate scents that elude other techniques.

MACERATION

It is a quicker method where successive batches of chopped plant material are digested with hot oil at a temperature ranging from 45-80 °C for several hours. The filtrate is heated with successive batches of fresh flowers for up to 20 times. The saturated oil is later subjected to alcoholic extraction to retrieve the essential oil. In the 'pneumatic process', a current of warm air is passed through the flowers and the air laden with essential oils is then passed through a spray of molten fat that absorbs the essence.

SOLVENT EXTRACTION

Whenever an oil with a more natural odour is required (as in the perfume industry), direct extraction with solvents, such as petroleum ether or benzene is practised.. The solvent is allowed to run slowly through the plant material, washing out the essential oils and waxes. The 'solvent' is then evaporated under vacuum, leaving behind a semisolid residue of essential oils and waxes in the retort. The mass is treated with alcohol to dissolve out the essential oil, the waxes being removed by filtration or precipitated out by freezing. Later, the alcohol can be evaporated to isolate the 'floral absolute'.

EXPRESSION

Much of the oil is produced as a by-product of the concentrated citrus juice industry. The fruits are compressed or squeezed in claw-shaped bowls where the juice is sucked out of the fruit through a cannula inserted in the pulp, while the oil, released from the oil cells, is rinsed with water and then the two are separated by centrifugation or the fruits are placed in a revolving vessel fitted with spikes that are just long enough to break up the oil cells to release 'the oil' (the eculle method). The oil is washed with a water jet and the resulting mixture of oil and water then separated by centrifugation or the oil is extracted by pressing the fruit peel between two sponges and the oil so collected is squeezed out later.

ADSORPTION METHOD

The method involves the passage of hot air or an inert gas over the aromatic material, which is then led through the activated carbon from where the essential oil is recovered by solvents.

STORAGE AND UTILISATION OF ESSENTIAL OILS

Most essential oils tend to polymerise rather readily on exposure to air and light, becoming less intense, growing darker, more viscous and eventually turning into a brown odourless resin. To prevent this darkening, the essential oils should be stored in cool dry cellars in a hermetically sealed amber glass container, preferably full. Some oils such as vetiver and patchouli gradually improve and acquire a fuller aroma in storage.

Essential oils have many industrial applications. They are mainly used in the manufacture of perfumes, creams, aftershave lotions, soaps, detergents, *agarbathis* (joss sticks), incense, shampoos, bath oils, hair oils, talcum powder and other toiletries. They are used to flavour all types of food products, such as candies, beverages, tobacco, soups, chewing gum, sauces, desserts, cake mixes and virtually everything one finds on a supermarket shelf. Many oils are known for therapeutic*, antiseptic, bactericidal or germicidal properties and are used in making balms, toothpastes, mouthwashes,

* From the Roman times to the Middle Ages and on to the eighteenth and nineteenth centuries, the use of fragrant compounds and essential oils as therapeutic agents is well-documented. Perhaps the most ancient way to treat patients in the sense of aromatherapy was fumigation, which was practised by all cultures, especially in China, India, Egypt and Babylonia.

antiperspirants, deodorants, insecticides and aerosols. Many are used to protect furs, wool, silk clothing, and for making shoe polish, library paste and printer's ink. Some oils are used as clearing agents in histological preparations and also as solvents in the paint and varnish industry. Among the recent uses of essential oils are the manufacture of paper, plastics, leather, textiles, paints, as well as synthetic odour and flavours. These are often used as flavouring materials to make some drugs more palatable.

PERFUME OILS

The word perfume is derived from the Latin words *per* (through) and *fumum* (to smoke), meaning to perfuse with smoke. It refers to the age-old tradition of burning scented woods at religious ceremonies. The use of essential oils as perfumes and scents dates back to ancient times. History is replete with an endless array of the fascinating role of perfumes in our daily rituals, customs, as also love and war. In early days when people were less conscious of personal hygiene, essential oils not only masked offensive odours but also may have acted as antiseptics. Egyptians used essential oils for their personal adornment, religious ceremonies and for mummification or perfuming the dead by providing phials of their favourite perfume. Perfumes have been important in the lives of Romans and Greeks, reaching a high degree of specialisation in Greece, where a special perfume was used for each part of the body. In Greece, men and women wore laurel and floral wreaths on their head. Customarily, Romans were heavily perfumed and even the rugged legionaries reeked of the fragrances of the East. It was during the Roman Empire that perfumery reached its zenith. Perfumes were added to baths and used for anointing the body. Incense was commonly used in temples and homes. In the Greek and Roman cultures, perfumery, once largely devoted to religious purposes, became a treasure peculiar to the rich.

Babylonians, Jews, Persians and Indians also propitiated their gods with offerings of fragrant incense. The Hindus still considers camphor, sandalwood and rose water essential for their rituals. Also in the East began the history of essential oils that gave birth to the science of perfumery and cosmetics. Indeed, aromatic plants have been cultivated in the East as early as 3000 BC. The Hanging Gardens of Babylon, built by King Nebuchadnezzar for his wife Amytes, were heavily scented. The ancient Chinese used incense in temples and private homes. They used scents in ceremonies, flavoured their food with essence and even developed an incense clock indicating the hour it burned. The Japanese modified the incense clock by introducing sticks of different odours (joss sticks) that provided scents appropriate for the different parts of the day.

However in Europe, the use of perfumes declined during the Middle Ages (from about AD 476 to 1095) until the crusaders, in the eleventh and twelfth centuries, brought back information from the Holy Land to France about unusual perfumes and secrets of perfumery. Shortly thereafter, the popularity of perfumes soared. In the twelfth century, Royal Charter developed the perfume industry in France and to this day France is the leader of the same (although recently, American firms have severely challenged the leadership of France). By the late Middle Ages, the use of essential oils had become common in Europe. The need for perfumes and spices thus led to the exploration and colonisation of the parts of the Far East and the New World.

During this period, perfumery was an important craft in the Near East and Asia, and India had a leading position in the world of perfumery. Emperor Babar was very fond of roses and *Ain-i-Akbari* refers to his deep interest in the preparation of perfumes and scented oil. In addition, Empress Nur Jahan too loved the fragrance of roses, and used to take a bath in water scented with the same. For many years, Indian perfumes were the rage in foreign lands, and Queen Elizabeth I (1533–1603) and Mary Queen of Scots (1542–87) extravagantly used the Indian perfumes. Napoleon Bonaparte believed that the scenting of his gloves with violets and roses enhanced his superiority on the battlefield and personal well-being. At the French Court of Versailles, the King himself supervised the blending of essences for the royal bath, for which there was a different formula for every day of the year. In the banquet halls of those days, perfumed doves fluttered about and spread the aroma all around the room, and slave girls comforted the guests with scented fans. Even today during marriage festivals in some parts of India, water mixed with essential oils is sprinkled on guests. In the eighteenth century, the exports of Indian perfumes to England shot up to such an extent that the British Parliament passed an Act in 1774 that prohibited all women from using perfume of any kind, as they were considered deceitful,* imparting a seductive appearance, failing which they would be imprisoned. Fortunately, such law does not exist today else, it would have been very monotonous to live in a world without scents. In fact for this reason, the Russian space programme paid the perfume industry perhaps its greatest compliment by sending their astronauts into space with phials of essential oils to remind them of earth and overcome their emotional deprivation of a scentless space.

Although, the production of some essential oils has decreased owing to the advent of synthetic fragrances, the worldwide production of essential oils has increased in recent years because of the spectacular successes in plant breeding. However, essential oils of natural origin still remain the basis of a multimillion dollar business. Today, the perfume industry is centred around the town of Grasse in the south of France where there is an extensive cultivation of species such as mimosa, jasmine, narcissus, violets, tuberose and damask rose. Perfume production is a flourishing trade in the United States, England, India and Turkey. The most important essential oils produced in India are sandalwood oil, lemon grass oil, palmarosa oil, eucalyptus oil, khus oil, linaloe oil and turpentine oil (Table 17.1).

Table 17.1 Important aromatic plants grown in India for natural flavour and fragrance ingredients.

Plant material	*Botanical name*	*Essential oil produced*
Bergamot	*Citrus aurantium* subsp. *bergamia* (Risso & Poit.) Wight & Arn.	Bergamot
Cananga	*Cananga odorata* (Lamb.) Hook f. *et* Thoms.	Cananga and ylang-ylang
Capsicum	*Capsicum frutescens* L.	Capsicum oleoresin
Cedarwood	*Cedrus deodara* (Roxb.) Loud.	Himalayan cedar wood
Cinnamon	*Cinnamomum verum* J.S. Presl (Syn. *Cinnamomum zeylanicum* Garc. ex Blume)	Cinnamon leaf/bark
Citronella	*Cymbopogon winterianus* Jowitt	Java-type citronella
Clove	*Eugenia caryophyllus* (Spreng.) Bullock & Harrison	Clove leaf/clove bud
Eucalypts	*Eucalyptus globulus* Labill., *E. citriodora* W.I. Hooker	Eucalyptus
Geranium	*Pelargonium graveolens* L., Hérit	Geranium
Ginger	*Zingiber officinale* Rosc.	Ginger
Jasmine	*Jasminum officinale* L. var. *grandiflorum* Bailey	Jasmine concrete

Contd.

* Very likely that a few of its member might have discovered to their chagrin that the beautiful damsels whom they had married were not so pretty as they looked, shedding a good part of their beauty with every passing day!

Contd.

Plant material	*Botanical name*	*Essential oil produced*
Lavender	*Lavandula officinalis* Chaix *et* Kitt.	Lavender
Lemon	*Citrus limon* (L.) Burm.f.	Lemon
Lemon grass	*Cymbopogon flexuosus* (Nees ex Steud.) Wats.	Lemon grass
Lime	*Citrus aurantifolia* (Christm.) Swingle	Lime
Mint	*Mentha arvensis* L.	Corn mint
Orange (sweet)	*Citrus sinensis* (L.) Osbeck	Orange
Patchouli	*Pogostemon cablin* (Blanco) Benth.	Patchouli
Peppermint	*Mentha piperita* L.	Peppermint
Pepper (black)	*Piper nigrum* L.	Black pepper oleoresin
Petitgrain	*Citrus aurantium* L.	Petitgrain
Rose	*Rosa damascena* Mill.	Rose concrete
Sage clary	*Salvia sclarea* L.	Clary sage
Sandalwood	*Santalum album* L.	Sandalwood
Sassafras	*Sassafras albidum* (Nutt.) Nees	Sassafras
Spearmint	*Mentha spicata* (L.) Huds.	Spearmint
Star anise	*Illicium verum* Hook. f.	Star anise
Pine	*Pinus roxburghii* Sarg.	Turpentine
Vanilla	*Vanilla planifolia* Andrews.	Vanilla extract
Vetiver	*Vetiveria zizanioides* (L.) Nash.	Vetiver

The art of perfumery is an extremely complex and a very creative activity, where talent and experience count for everything. It requires a careful blending of many fragrances into unique creations whose recipes are kept a secret. Today, perfume houses not only employ chemists and engineers who utilise the most sophisticated analytical instruments and techniques, but also at least one master perfumer who has an intimate knowledge of perhaps 1,000 aromatic substances. Through his understanding, memory and experience, he is able to blend several oils to create a masterpiece (in a manner similar to a musical composer who combines the musical 'notes' of various instruments into a perfect whole). The various odorants can be classified, like musical notes, into top, medium and base notes. Nowadays, the perfumer can work more efficiently by entering the tremendous variety of details in a computer and retrieving it quickly as and when required for a new formulation.

Design and advertising are vital for the success of a perfume, so often linked to the major fashion houses. Salvador Dale designed highly prized bottles for Schiaparelli saying, "Smell is unquestionably the sense which best expresses 'immortality'". The bottle for *Femme* by Rochas was shaped like the hips of voluptuous actress Mae West. In modern perfumery, pure essential oils are seldom used but extended with oils of high volatility and less tenacity (top note), and with low volatility and high tenacity (base notes also called fixatives). Since the beginning of this century, synthetic compounds have been added just to impart a certain creativeness, imagination and novelty to the blends. Because of environmental pressure, there is now a trend to create a worldwide new market segment for non-alcoholic fragrance.

Fixatives are added to delay volatilisation of the essence and to equalise volatilisation of numerous components in the perfume so that none of them predominates. The fixatives may be predominantly of animal origin, such as *musk* (the dried secretions from the preputial follicles of the male musk deer of Asia), *civet* (glandular secretions of both male and female civet cat of India, Malaya, Indochina and Indonesia), *castor* or *castoreum* (secretions of certain glands of the beaver, found in Canada, Alaska and Siberia) and most importantly *ambergris* (pathological product formed in the stomach of the sperm whale in response to irritation caused by the indigestible break of the cuttle fish or squid on which it feeds). Balsams and oleoresins (such as benzoin, styrax), oak moss (lichen), essential oils with low rate of evaporation (such as orris, patchouli, sandalwood) and various synthetic materials may also be used to produce more enduring fragrances. Myrrh (derived from *Commiphora molmol* Engl., and *C. abyssinica* Engl.) and frankincense (*Boswellia carteri* Birdw.), both of the family Burseraceae, have been valuable oleogum resins since the Biblical times. They have been used in perfumes and incense for religious observances because of their excellent fixative qualities.

Amongst the most famous perfumes are *Frangipani* and *Eau de Cologne*, the former contains sandalwood, sage, neroli, orris root and musk, while the formulation for *Eau de Cologne*, dating from 1709, is neroli, rosemary, lemon and bergamot dissolved in alcohol and then aged. The original formula is known to have been developed by an Italian hairdresser and merchant, Gian Paolo Feminis, who brought his fragrance to Cologne and sold it under the name of *Eau Admirable* (*Aqua Admirabilis*). The formula eventually passed on to his nephew, Giovanni Maria Farina (1685–1766) who had also settled in Cologne and renamed the fragrance *Eau de Cologne.*

Table 17.2 lists a few well-known essential oil-yielding plants used in perfumery, together with their Latin and common names, family and useful part.

Table 17.2 A few well-known essential oil-yielding plants used in perfumery.

Common name	*Botanical name*	*Family*	*Plant part used*
Attar (otto) of Rose	*Rosa damascena* Mill. *R. centifolia* L. *R. moschata* Mill.	Rosaceae	flowers petals
Bay oil (or oil of bay)	*Pimenta oleracea* (Mill.) J.W. Moore	Myrtaceae	leaves
Bergamot oil	*Citrus aurantium* ssp. *bargamia* (Risso and Poit.) Wight and Arn.	Rutaceae	rind or peel of fruit
Calamus, sweet flag	*Acorus calamus* L.	Araceae	rhizome
Cassie flower or Acacia	*Acacia farnesiana* (L.) Willd.	Fabaceae	flowers
Champaca	*Michelia champaca* L.	Magnoliaceae	flowers
Citronella	*Cymbopogon nardus* Rendle	Poaceae	leaves
Jasmine	*Jasminum officinale* L. var. *grandiflorum* Bailey *J. sambac* (L.) Aitch	Oleaceae	flowers

Contd.

Contd.

Common name	Botanical name	Family	Plant part used
Gardenia or Cape Jasmine	*Gardenia jasminoides* Ellis (Syn. *Gardenia florida* Hook.) *G. citriodora* Hook.	Rubiaceae	flowers
Geranium	*Pelargonium graveolens* L. Hérit.	Geraniaceae	fresh leaves
Lavender	*Lavandula officinalis* Chaix	Lamiaceae	flowers
Lemon grass	*Cymbopogon citratus* (DC.) Stapf.	Poaceae	leaves
Neroli oil	*Citrus aurantium* L.	Rutaceae	flowers
Orris	*Iris pallida* L. *I. florentina* L.	Iridaceae	rhizome
Patchouli	*Pogostemon cablin* (Blanco) Benth.	Lamiaceae	leaves and young buds
Sandalwood	*Santalum album* L.	Santalaceae	heartwood
Scented boronia	*Boronia megastigma* Nees ex Bartling	Rutaceae	flowers
Tuberose	*Polianthes tuberosa* L.	Amaryllidaceae	flowers
Vetiver	*Vetiveria zizanioides* (L.) Nash.	Poaceae	roots and rhizomes
Violet	*Viola odorata* L.	Violaceae	flowers
Ylang-Ylang	*Cananga odorata* (Lam.) Hook. f. and E. Thoms.	Annonaceae	blossoms