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### Oils

#### VEGETABLE OILS, FATS, AND WAXES

Vegetable oils, fats, and waxes, are derivable from a great many sources; economics—the price of the oil in its market—usually governs which crops will dominate the vegetable-oil industry. In recent years, soybean oil has been a leading product—both for edible and industrial purposes—to the extent that more than 10 million metric tons of it is produced each year in the United States alone. Ponderous production, rather than glamour, characterizes the vegetable-oil business, with only moderate exploration and search for new sources and no wars fought to command the trade. Alternate supplies of standard types of oil are too readily available. Indeed, today's vegetable-oil chemist is so adept at changing oils (as by hydrogenation) and substituting one for another that price differentials often overshadow inherent qualities. And not only can one vegetable oil be made to substitute for another, but petroleum or mineral derivatives often take over markets from botanicals, and vice versa. An example is provided by the paint industry, in which synthetic resins and latices have appreciably substituted for the once dominant drying oils, linseed and tung.

About a dozen crop plants make up the main vegetable oil-seed market. Most are traditional sources, for which an established industry has been built, which gives these plants considerable commercial advantage. It takes a while to work out details with new crop introductions and to create grower and market acceptance; but government agencies such as the USDA are on the lookout for newer specialty oils, and *Crambe* (Cruciferae), safflower (*Carthamus*, Compositae), jojoba (*Simmondsia*, Buxaceae), and others have spawned small but promising industries based upon the unique chemical qualities of the oils they produce. Since oils are relatively abundant in almost any seed, it is no wonder that researchers have looked at such an assortment as ironweed (*Vernonia*), *Cuphea*, wild carrot (*Daucus*), *Limnanthes*, and *Comandra*, and even spruce (*Picea*), *Tribulus*, and grape seed (*Vitis*). A table 50 pages long lists the oil content and other characteristics of seeds and surrounding tissues for 1253 species investigated by the USDA (Barclay and Earle, *Economic Botany* 28(2), 1974).

Vegetable oils, fats, and waxes serve many uses. About two-thirds are used for foods and one-third for industrial purposes. Several, such as corn, cottonseed, peanut, olive, and soybean oil, are used for cooking oils, margarine, and salad dressings; some are incorporated into many food products and animal feeds. But equally important are the industrial uses of these and other oils, including coconut and palm oils, but especially linseed oil, castor oil, tung oil, grape seed oil, and tall oil (a by-product of papermaking). The major industrial uses are for paints, coatings, plasticizers (especially for vinyl), polyamide resins for plastics, and surface-active agents (including soaps and detergents), and as components in linoleums and oilcloths. Other industrial uses are for lubricants, additives, hot-dip tinning of metal products, hydraulic fluids, glycerol, synthetic fibers, lecithin, food coatings, cosmetics, medicinals, printing inks, plastic foams, and fatty acid raw materials.

Of course, many plant parts contain oils, fats, or waxes, which are chemically quite similar. Oils occur in small droplets within the plant cells, and are typically most abundant in seeds. The globules are removed from the oil-bearing tissue by crushing (expression) or a combination of crushing and solvent extraction. Vegetable fats differ only slightly from oils, having acidic constituents that are more or less solid at ordinary temperatures rather than liquid. They, too, are usually most remuneratively garnered from seeds. Waxes are the fatty acid esters of monohydroxy

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alcohols; oils, by contrast, are fatty acid esters of trihydroxy glycerol. Waxes are found mostly as protective coatings on the leaves and stems of plants, where they function to retard water loss. Waxes are a less voluminous (and typically more expensive) commodity than the vegetable oils and fats.

The oil seeds utilized commercially generally have an oil content of 40% or more, some as high as 70%. With more than 75 million metric tons of soybeans, 27 million metric tons of cottonseed, and 18 million metric tons of peanuts produced annually, most of which is subjected to oil extraction, it is apparent that we are talking about sizable quantities of vegetable oils. In addition, about 12 million metric tons of sunflower seed, 8 million metric tons of rapeseed, 5 million metric tons of copra (dried coconut meat, used for oil extraction), about 4 million metric tons of palm-husk oil, 1.5 million metric tons of palm-kernel oil, 3 million metric tons of linseed, 2 million metric tons of sesame seed, and 1.6 million tons of olive oil are produced annually.

The production of vegetable oil is not concentrated in any single part of the world; rather, production of vegetable oil is important to less advanced agricultural economies as well as to countries that are agriculturally mechanized and industrialized.

Vegetable oils are fundamental to the functioning of the modern industrialized world. Thus they will be in continuing, steady demand, and their importance can be expected to increase as nonrenewable mineral resources become exhausted and petrochemicals become more costly. In this respect the crop plants we are reviewing here are equally as basic as are food plants.

There would seem to be little cause to dwell on the uses of vegetable oils as foods. Their main use, as has been noted, is for making cooking fats and margarines. There has been a great deal of commotion in recent years about substituting unsaturated oils (Table 1) for saturated fats in the diet, because of the concern about cholesterol in the blood. Thus a moderately unsaturated oil, such as corn oil (rich in oleic and linoleic components), carries something of a premium for the manufacture of margarine. But almost any edible oil can be converted to a cooking fat or margarine by chemical manipulation, such as changing fluid oils into fats by elevating them to a higher degree of saturation through hydrogenation.

This is accomplished by introducing hydrogen under pressure into the heated oil in the presence of catalysts, such as pulverized nickel compounds. Margarine is formulated through such techniques, with the addition of small percentages of milk products, vitamins, and other ingredients, to make a spread that is nutritionally the equal of butter and scarcely different in taste. As a matter of fact, margarines are generally advertised as being less fattening than butter, particularly when formulated from unsaturated vegetable oils.

Industrially, many things can be made from vegetable oils (Fig. 1). The oils, being fatty acid esters of glycerol, can readily be broken down to fatty acids and glycerol. In fact, most fats and oils are naturally unstable: when kept for considerable lengths of time, they become rancid due to breakdown of the glycerides into various lesser products. When oils are largely glycerides of saturated acids, such as the oleics characteristic

**Table 1.** Percentages of polyunsaturates in major edible oils.

Oil	% Polyunsaturates
Safflower	75.5
Sunflower	72.5
Soybean	60.0
Corn	55.5
Cotton	51.5
Peanut	26.0
Coconut	1.5
Lard	11.0
Olive	9.5
Butter	5.0
Linseed	70.5

Source: After C. Moses, 1977, Proceedings of Twenty-third Annual Farm Seed Conference. Washington, D.C.: American Seed Trade Association.

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of palm, peanut, olive, and grape oils, they are said to be **nondrying** oils. They remain in a liquid state when exposed to air. If the oil is high in glycerides of the unsaturated type, particularly linoleic and linolenic with little oleic and lauric, the oil is said to be a **drying** oil (capable of forming an elastic film upon absorption of oxygen from the air). Linseed, safflower, soybean, and tung are oils of this type. Drying oils are more important commercially, and they are used in such products as paint and varnish. The nondrying oils (and an intermediate group termed “**semidrying**,” such as cottonseed, corn, and sunflower oils) are used in the manufacture of soaps and detergents and as raw materials for other industrial purposes. The classification as to drying type is not as meaningful as once it was, what with many specialty oils prized for particular chemical characteristics rather than degree of acid-chain saturation.

**Saponification** is the process whereby soap is made. Vegetable oils treated with alkalis, such as potassium or sodium hydroxide, split into three molecules of the metal salt of the particular fatty acid and one molecule of glycerin. Early civilizations mostly utilized animal fats boiled with wood ashes from the fire to make soap. (Wood ashes are rich in potassium carbonate.) Gradually vegetable oils, such as olive oil, were substituted for animal fat, and sodium hydroxide (which makes a harder soap than does its potassium equivalent) was substituted for wood ashes. The byproduct, glycerin, has found many industrial uses, including the making of explosives (trinitroglycerin and TNT).

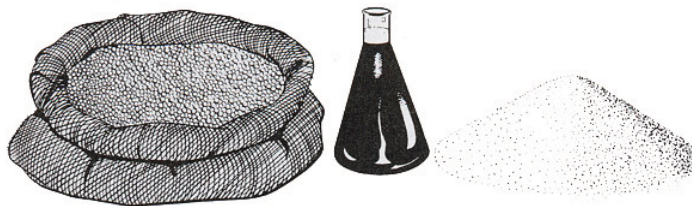
Linoleum was invented about a century ago, when it was discovered that boiled drying oil made an excellent binder for pulverized cork (or other particles). Today many plastic materials substitute for the original linoleum (the name derived from *linum* for flax, and *oleum* for oil). Likewise, drying oils made an excellent vehicle for pigments of various sorts, which hardened into a resinous protective coating, or paint. Varnishes and enamels are basically similar to paint.

Compared to oils, vegetable waxes are of relatively minor importance. The waxes are used chiefly for polishes and carbon paper, and to a minor extent for such diverse products as candles and chewing gum.

## NONDRYING OILS

### Oil from palm fruits (Palmae)

Because oils from palm fruits of many species are remarkably similar, they are often interchangeable and mixed in commerce. Palmitic, lauric, and oleic fatty acids tend to predominate. M.J. Balick listed 23 palm species in 13 genera in Amazonia alone as sources of “oil palms of promise” (*Economic Botany* 33(1), 1979). Most are still not cultivated and are therefore only of incidental commercial importance. As commercial successes, two palms stand out, the coconut (*Cocos nucifera*) and the African oil palm (*Elaeis guineensis*). But throughout the tropics the palm family is as ubiquitous as the grass family is in temperate climates—there are 1250 species indigenous to the Western



**Fig. 1.** One of the major sources of vegetable oil is the soybean. Represented here are the proportions of drying oil and protein meal resulting from milling. A bushel of soybeans produces about 11 pounds of oil and 48 pounds of meal. The price of beans depends largely on the value of oil and meal in the marketplace.

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Hemisphere—and it is no wonder many other species of palm contribute oil-bearing fruits of greater or lesser importance.

In the lower Amazon Valley, there is considerable traffic in murumuru palmtree (*Astrocaryum murumuru*). In northern Brazil (especially Maranhão), hundreds of thousands of tons of fruits of the babassú (*Orbignya speciosa*) are gathered from extensive wild stands for use in the soap industry. The ouricuri (*Syagrus coronata*) of eastern Brazil yields not only an oil from the fruit, but a wax that is scraped from the leaves, much like the wax of the carnauba palm. Extensive stands of the mbocayá or gru-gru (*Acrocomia totai*) grow in Paraguay, supplying many materials for rural living. One palm abundant in Venezuela, the bataua (*Jessenia bataua*), contains as much as 24% oil in the pulp (rather than the nut); the oil is chemically very similar to olive oil (about 7% palmitic, 9% stearic, 73% oleic, and 5% linoleic acids). Usually, the transportation, marketing, and processing facilities are primitive or lacking in such tropical locales, which prevents much greater production from wild sources.

In contrast are the oil palm and coconut (copra). Nearly 4 million metric tons of palm-husk oil reach commerce annually, chiefly from west-central Africa, but significantly also from Indonesia and Malaysia and from scattered parts of the New World where *Elaeis guineensis* has been introduced or naturalized. World production of copra is about 5 million metric tons, chiefly from the South Pacific region. More than 30 billion coconut fruits are harvested annually, again mostly from the tropical Far East but also from Mexico and Brazil.

The African oil palm (Fig. 2) is one of the world's most useful oil-yielding species. The “palm oil” of commerce comes from the outer husk or pericarp of the fruit; a less prized kernel oil is obtained from the nut or seed. The “pulp oil” from the husk is used for making soap, in metal plating (to protect the metal surface from oxidation before plating), and in foods (margarine). The kernel oil is used mostly in the making of soap and as a source of glycerin. Under favorable circumstances, fantastic annual yields that exceed 4.5 metric tons of oil per hectare (about 2 tons per acre) can be achieved.

The African oil palm is a heliophile, growing naturally in a coastal belt about 150 miles deep from Angola to Senegal, where it is often adventive on disturbed land. A similar species, *Elaeis oleifera*, is found in the New World, and is even better



**Fig. 2.** Three-month-old oil palms in a government-sponsored nursery, Ivory Coast. They will be planted in plantations when about 8 months old. [Photograph by Hilda Bijur, courtesy World Bank.]

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adapted to wet habitats. The two species can be cross-bred. The palm fruit is still much harvested from wild stands, but some extensive plantations have been developed, particularly in Nigeria and the Congo Basin, where attempts at mechanization have been made. In Nigeria, palm oil is both an important source of food and a leading export source of foreign exchange. Several groups of cultivars have been selected there. In 1910 the African oil palm was introduced into Sumatra and Malaya, where it has been widely interplanted with rubber trees. A great many cultivars were selected, and Dutch agriculturists sent expeditions to Africa in search of potentially more valuable breeding stock. As a result, in the Far East, and to a limited extent in the New World, there has been considerable plantation growing of the African oil palm.

Under primitive circumstances, the palm fruit is boiled, the free oil is skimmed off the cauldron, and residual oil is squeezed from the pulp. The nuts are marketed or processed separately. On managed plantations, the fruit is subjected to a preliminary digestion, after which the pulp oil is centrifuged or pressed free and purified; the nuts are cleaned, dried, and cracked, and the freed kernels are further dried.

The exact home of the coconut is uncertain, for it has been widely scattered throughout the tropical coastal environments of the world. These picturesque, graceful trees of the sea coasts are often sources of food, thatch, and income for island people. Coconut fruits are among the largest in the plant kingdom, and as many as 400 may be produced annually from a single tree under favorable circumstances. Production is chiefly from the Philippines, Kampuchea, and Indonesia. The husk of the coconut is usually removed and discarded (although there is a limited market for it as a fiber, coir). Copra oil, from the coconut, is of course a kernel oil, being derived from the endosperm of the coconut seed. In making copra, the inner shell is cracked and the "meat" is removed to be smoked or sun-dried before being sent to the extraction plants. Most of the harvesting and splitting is done by hand. The copra is gathered to a central location (or even imported into industrialized countries without processing), where it is usually expressed while heated to yield coconut oil. The press cake is sold as stock feed.

Attempts to cross coconut lines to yield "hybrid" planting stock were made as early as 1926 in Fiji, but the enterprise proved to be too cumbersome and expensive to be practical. A system of bringing select pollen to an isolated field of high-yielding mother palms (emasculated) is now producing  $F_1$  hybrid coconut planting stock in Ivory Coast and Jamaica. But much of the world's production still comes from unselected, chance trees.

### Other important nondrying oils

The **castor bean**, *Ricinus communis* of the family Euphorbiaceae (Fig. 3), is potentially an important industrial oil, but is of uncertain supply and poses difficulties in adapting it to mechanization. The chief fatty acid component is ricinoleic (which is amenable to dehydrogenation). Presumably native to northeastern Africa, castor bean is grown today throughout the world tropics, and it frequently "goes wild." It was introduced into India and China before recorded history. It is adaptable as a summer annual in temperate climates, although it can be a short-lived perennial in the tropics. Efforts have been made to breed cultivars that will not shatter seeds so readily, making them more suitable for mechanical harvesting. Yet, world production is only about 700,000 metric tons annually, mainly from Brazil and India. The seeds, borne in spiny capsules, have an oil content of as much as 50%. The oil is removed mainly by expression; whatever remains in the press cake is extracted with solvents. Because the castor bean contains an extremely toxic alkaloid, ricin, the press cake is unsuitable for stock feed. The oil is used mostly as a medicinal (purgative) and

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high-grade lubricant, and to some extent in soaps, linoleum, plastics, inks, and various finishes. Through chemical alteration castor bean oil is often made to serve other purposes, such as substituting for drying oils and in the plastics industry.

The **olive** was discussed at some length as a fruit in the previous chapter. More than 8 million metric tons of olives are produced annually, and perhaps 90% of the crop is crushed to produce oil. Annual production of olive oil amounts to about 1.6 million metric tons, most of it from Spain, Italy, and Greece. Many of the cultivars have been selected with oil production in mind rather than edible fruit. Olives grown for oil may contain as much as 40% oil. The fruit, usually gathered by hand on small, private holdings, is crushed to yield the oil. Several expressions are made, the first giving the more valuable “virgin” oil suitable for use without further refining. The press cake is generally treated with solvents to get the final measure of oil, and the press cake may then serve as cattle feed or as a fertilizer for the orchards. Olive oil finds its greatest use as a salad and Cooking oil.

Also discussed at some length in Chapter 20 was the **peanut**, grown for its edible seed as well as its oil. Much of the African and Indian production is imported into Europe, where the oil is extracted. The nuts contain as much as 45% oil, with oleic and linoleic constituents predominating. It may be recovered by expression or extraction with solvents. The oil is used mostly in edible products, and the press cake, rich in protein, is a valuable livestock feed.

### SEMIDRYING OILS

#### Major semidrying oils

The major semidrying oils of commerce originate as by-products from crops grown primarily for other purposes. Especially important are **corn** (mainly a feed cereal, yielding corn oil) and **cotton** (mainly grown for the fiber, but yielding cottonseed oil). Cottonseed production generally exceeds 27 million metric tons annually, chiefly from the United States, the USSR, China and India. Most cottonseed contains 30 to 40% oil, rich in linoleic glycerides, and the remaining press cake contains approximately 10% nitrogen.

Corn-oil production is the “other half” of wet-milling the grain for starch (see the discussion of corn in Chapter 20). The oil-rich “germ,” or embryo, constitutes 6 to 13% of the grain. In wet milling this is freed by “cracking,” which follows the initial steeping



**Fig. 3.** An Indian farmer examines a new castor bean bred for quick maturation, near Hyderabad, India. [Courtesy Agency for International Development.]

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(which yields “corn-steep liquor,” used in industrial fermentations). The germ is removed by flotation, and is then subjected to expression or solvent extraction. Refined corn oil, which is used principally as a cooking oil and in margarine, is rich in linoleic fatty acids.

Huge quantities of cottonseed are left after the ginning of cotton fiber. In oil production, the hulls are first removed from the seed, and they may be incorporated into cattle feeds as roughage. The kernels are then crushed between rollers, heated (to expel moisture, to make the oil fluid, and to coagulate albumenoids), and subjected to hydraulic expression or solvent extraction. After refining, the oil may be hydrogenated for margarine or used to some extent as a liquid cooking oil and in the manufacture of soap.

### Other semidrying oils

**Rapeseed**, from *Brassica napus* and other members of the cabbage group, enters commerce to the tune of more than 8 million metric tons annually. Canada, India, and China are the chief producing nations. Rapeseed is used chiefly to produce an edible oil. The seeds contain as much as 40% oil, largely of erucic, oleic, and linoleic types, and about 24% protein. Rape was grown in India and Japan at least 4000 years ago.

**Sesame** or benniseed (*Sesamum indicum*, of the family Pedaliaceae) yields about 2 million metric tons of commercial seed annually, mostly from India, China, and Sudan. It is one of the most ancient of oil seeds, originating in the Near East at least 4000 years ago. The seed, which is often used as a garnish on bakery products, contains as much as 55% oil, largely of the oleic and linoleic types. The oil, which is extracted by expression, is used to a great extent as a salad or cooking oil. The crop is adapted to semiarid conditions, and most production comes from areas that are not agriculturally mechanized. Harvesting is often done by hand, by flailing the pods with a stick. It is said that, under mechanized agriculture, this oil seed can yield more per acre than any other annual oil crop; efforts have been made to develop nonshattering cultivars suitable for mechanized growing in the United States. Sesame oil is said to keep for several years without turning rancid, and the press cake is an excellent livestock feed.

The **sunflower** (*Helianthus annuus*, of the family Compositae) is native to North America, but the oil-crop cultivars are highly modified from the wild plants of the plains. It produces an oily seed that may be toasted for direct consumption, but chiefly the oil is expressed to make margarine and other foods, or to be used for industrial purposes. More than 12 million metric tons of sunflower seeds are produced annually, chiefly in the USSR, the United States, Argentina, and southeastern Europe. The oil, which contains large amounts of linoleic acid, is resistant to rancidity, and it has attracted attention as an extender for more expensive oils. The press cake contains more than 50% protein. Plant breeding in the USSR is chiefly responsible for transforming this “cinderella” species (25% oil, 50% hulls) to a modern oil crop (50% oil, 25% hulls). The oil is advocated for low cholesterol diets.

## DRYING OILS

### Major drying oils

**Linseed** or flax (*Linum usitatissimum*, of the family Linaceae) is a source both of fiber and of a valuable oil (Fig. 4). However, cultivars selected for the stem fiber generally differ from those used for production of oil seed (from which flax fiber is the “by-product”). Total world production of linseed is approximately 3 million metric tons annually, chiefly from Argentina, Canada, India, and the United States. Linseed oil has long been the chief ingredient in oil paints, but its

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importance there has been declining as various latex paints and plasticlike substitutes have been developed. Linseed contains as much as 43% oil, which is extracted by expression. When refined, linseed oil is said to keep almost indefinitely in sealed containers. Typical of drying oils, however, when it is exposed to air (oxygen) it turns into the tough, impervious coating that makes it so valuable for paints, oilcloths, and linoleum.

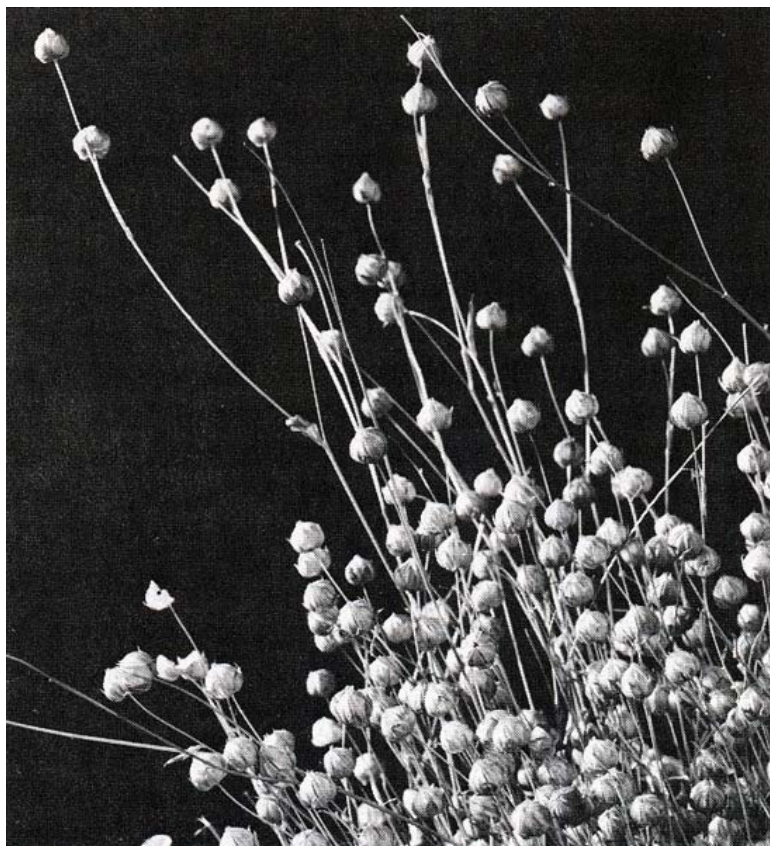
**Tung** (*Aleurites fordii*, of the family Euphorbiaceae) once showed great promise as the source of one of the world's best drying oils. *A. fordii* is native to central and western China. *A. montana* of southern China and Malaya yields an oil of equally high quality. Tung is a small monoecious tree, with fruits that contain 2 to 5 heavy-shelled seeds with white kernels that are about 65% oil, chiefly of the eleostearic type. The oil is not edible because of its laxative effect, and it is used mainly in the manufacture of paints, linoleum, water-proofing, and printers ink. World production comes to about 100,000 metric tons annually, two-thirds of it from China, but Paraguay also produces a significant amount. In the 1940s a significant tung oil industry developed along the Gulf Coast of the United States, but rising costs have now made tung growing uneconomical there.

*A. fordii* is highly susceptible to frost kill once it buds out; but it can stand mild winter frosts, and indeed some cold is needed to initiate full flowering and fruit production. The species does best on well-drained, fertile soils in climates with ample rainfall. The tree starts bearing at about three years of age, and it has a productive life of about 30 years. It tends to bear more heavily in alternate years. Tung responds well to fertilization, especially with nitrogen fertilizer. Since the press cake that remains after oil expression is toxic as a feed, it is usually returned to the fields for fertilizer, often accompanied by applications of ammonium sulfate.

The tung fruit is collected after it has fallen to the ground. The seed should be collected immediately and dried to prevent any hydrolysis of the oils. Often the fruits are hulled in the field; transporting the husks is eliminated by the use of portable hulling machines. Nut shells are removed mechanically at centralized locations, after which the kernels are heated, ground, and expressed, usually in a screw expeller. Solvent extraction is also feasible. Except for filtering, no refining is necessary. Tung oil dries rapidly into a hard, waterproof coating, resistant both to acids and to alkalis. In this respect, it is said to be superior to linseed oil.

### Other drying oils

Scores of other species yield oils that are either minor items of com-



**Fig. 4.** Flax plants with maturing seed pods ready for harvest and extraction of linseed oil. [Courtesy J.C. Allen & Son.]



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merce or are potentially useful as drying oils. By and large, only safflower, among the new entries, and soybean, among the established agricultural crops, have been of much significance. **Safflower** (*Carthamus tinctorius*, of the family Compositae) yields an oil that is rich in oleic and linoleic constituents. Production, chiefly from Mexico and India, amounts to about 1 million metric tons each year. Originally the species was grown for the yellow dye that the flowers yield, a substitute for saffron. Safflower is apparently indigenous to the Near East, and it may have arisen from *C. oxycanthus* or *C. lanatus*.

Safflower is a slow-growing thistlelike plant that produces a rosette of leaves close to the ground and orange-yellow flowers on stems that may be nearly 1 meter tall. It is tolerant of heat and drought. Safflower is planted and grown in about the same way as some of the small grains. Combines like those used for barley have also been used to harvest safflower seed in the United States. Higher-yielding lines have been developed from Sudanese and Egyptian germplasm, some producing seed with an oil content as high as 38%. The oil is either extracted with solvents or expressed in a screw expeller.

Safflower oil has long been used for cooking and illumination in India and as an edible oil in Europe. In the United States, safflower oil has been used for margarine, but also to make synthetic resins. The press cake is quite suitable as a livestock feed, but is not very palatable when used alone.

The **soybean** (*Glycine max*, of the family Leguminosae) has been discussed in Chapter 20. It is noted here because one of its chief products is the oil extracted from the seeds. The oil, which is high in linoleic acid, is expressed either by expeller or by hydraulic press, or it is extracted with solvents. In the United States, the most common method is continuous expelling, in which the beans are crushed or ground, steam heated to about 66°C (150°F), then fed into the expeller. The oil is chiefly used for shortening, margarine, and salad oil, but it is also used to some extent for making soap, paint, ink, linoleum, and oilcloth. The protein cake remaining after oil expulsion is especially valuable.

**Nigerseed** (*Guizotia abyssinica*, of the family Compositae) has long been cultivated in Africa and India for its seed, which yields an oil that is about 70% linoleic acid. Only recently has it gained much attention in the United States, primarily as thistle birdseed, which is especially esteemed by goldfinches. Imports are chiefly from Ethiopia, where production is about 200,000 metric tons annually. India produces less than 100,000 metric tons.

**Buffalo gourd** (*Cucurbita foetidissima*, of the family Cucurbitaceae), and other members of its genus, yield a seed oil that can run as high as 65% linoleic acid. Because buffalo gourd is native to the arid southwestern United States and northern Mexico, it has been suggested as a possible crop plant for this region, where few productive species are adapted. Other cucurbit seeds have an even greater content of unsaturated oil (the oil from *Lagenaria* seeds, for example, contains as much as 78% linoleic acid), and would seem to offer promising opportunities for the production of highly digestible drying oils as well as useful protein cake.

### SPECIALTY VEGETABLE OILS

A number of species have been proposed as prospective oil sources because their oils contain particularly useful chemical compounds. Seeds of *Euphorbia lagascae*, of the family Euphorbiaceae, are rich in epoxy acids, which are valuable for making plastics and protective coatings. Also rich in epoxy acids are the seed oils of *Cephalaria setosa* (Dipsacaceae) and *Vernonia anthelmintica* (Compositae). *Crepis alpina* (Compositae) yields crepenninic (acetylenic) acids, which

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are useful for resins and coatings. Various members of the family Cruciferae, such as species of *Crambe* and *Eruca*, can be good agronomic sources of erucic acid, which is useful as a lubricant in continuous casting of steel, as a rubber additive, and as a raw material in the production of various chemicals. Many other potentially valuable oil species are listed by White et al. [*Economic Botany* 25(1), 1971].

### WAXES

Vegetable waxes differ from the oils in being esters of a long-chain alcohol and a fatty acid, rather than triglycerides of three fatty acid molecules. Most are solid rather than liquid at room temperature.

**Carnauba** palm (*Copernicia prunifera*, of the family Palmae) is the world's premier wax plant. Both wild and planted carnauba palms grow in arid northeastern Brazil, the chief area for the production of carnauba wax. Several other palms of the tropics yield waxy substances as well as oil seeds. For example, the ouricuri palm (*Syagrus coronata*) of eastern Brazil and the caranday palm (*Copernicia australis*) of Paraguay yield leaf wax that approaches carnauba wax in quality. Wax from various desert shrubs or even from sugarcane stems may substitute for carnauba wax when prices are high or the supply is short.

*C. prunifera* is a slow-growing fan palm that develops thick secretions of wax on the leaves in response to the seasonal drought and scorching winds of its native habitat. But the tree prefers to root in moist soil, and it is commonly found in low areas that, in certain seasons, have a high water table or even standing water. Harvest of the leaves is regulated, to prevent overcutting and exhaustion of the plants. The leaves of young trees that have been planted are cut by machete; those from wild trees, which are older and taller, are cut with the aid of long pole-saws and ladders. The leaves are taken to a drying shed where they are fed into shredding machines. The shredded leaves are left to dry for several days, during which they wither and the waxy coat becomes loose, falling to the floor as a whitish powder. Laborers further flail the shredded leaf parts to remove adhering wax. The loose wax is swept up and put into containers for further processing. Spent leaf is then returned to the field as a mulch.

The dustlike wax is melted, strained, and poured into molds, where it hardens for shipping to market. Most crude wax goes to the United States, where it is the most prized natural wax for polishes and floor coatings; but it is also much used for plastics, cosmetics, films, and other products that require a very hard, high-melting wax.

**Candelilla** (*Euphorbia antisyphilitica*, of the family Euphorbiaceae) is a native desert plant of the southwestern United States and Mexico. The leafless candelilla secretes an epidermal wax in adaptation to the arid environment. For years candelilla has been gathered in rural Mexico, in some places to the point of extermination. Plants are pulled by hand and transported on burros to an extraction camp, where they are boiled in water in sunken tanks. About 8 kilograms of sulfuric acid is added for each 100 kilograms of candelilla in the brew. The wax floats to the surface as a light-colored foam, which is skimmed into other containers for further refining. It eventually solidifies as a cake, which can be cut to convenient size for shipping to market. This crude wax, containing much debris, must be further refined before being put to commercial use.

In Mexico, candelilla wax is often mixed with paraffin to make candles. Although of limited and erratic industrial supply in the United States, it often substitutes for more expensive waxes, such as beeswax and carnauba wax. Candelilla finds occasional use in coatings and adhesives, automobile polishes, printing inks, chewing gum, cosmetics, explosives, and various dressings or

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polishes, Since only wild plants are harvested, candelilla production is destined to be a declining industry.

**Jojoba** (*Simmondsia chinensis*, of the family Buxaceae) is native to the southwestern United States and Mexico, in spite of the name *chinensis*. It bears a seed that contains about 50% liquid wax, which is prized as a lubricant. Jojoba substitutes for sperm whale oil, and its adoption as an agronomic crop has received much impetus from various restrictions on whaling, including the ban on sperm whale imports into the United States under endangered species legislation. By hydrogenation, the liquid wax of jojoba can be transformed into a substitute for carnauba wax and the other hard waxes of commerce. It seems the equal of hard waxes for furniture polishes and as an extender for other waxes in a variety of uses.

Wild jojoba is found from southern California and Arizona south into northwestern Mexico, usually at elevations between 600 and 1200 meters (roughly 2000 to 4000 feet). The plants are dioecious. As much as 4.5 kilograms (about 10 pounds) of seeds, which contain about 50% wax, can be harvested from a single, well-nurtured crop plant. Although mainly gathered from the wild by American Indian families, some plantings have been made in Israel, Africa, and Australia, as well as in the species' native range in the southwestern United States and Mexico. Jojoba has been experimentally planted directly to the field, but it is usually transplanted from nurseries. In cultivation, it responds to proper spacing, pruning, arid irrigation, but mechanical harvest of the seed has proven difficult.