Comparative Processing Practices of the World's Major Oilseed Crops[1]

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*The major oilseed crops were domesticated primarily as sources of edible oil. However, in all cases, yields of by-products are greater than the oil fraction, and, in reality, all oilseed crops serve dual purposes as sources of oil and of protein for human food, animal feed, and industrial products. Each crop has special requirements for extraction and for processing of oil and meal, and each has limitations as to location and timing of production and as to processibility in oil mills originally designed for other crops. Further, each oilseed has unique cultural, economic and utilization characteristics; for example, rapeseed (*Brassica*) can be grown in cool climates with short growing seasons. Cottonseed (*Gossypium*) is a by-product of the more valuable fiber crop, and its availability is dictated by the profitability of growing cotton for the world market. Although peanuts (*Arachis hypogaea*) are used primarily as peanut butter and nuts in the United States, they are almost exclusively pressed for oil in other countries. In this paper, cultural practices and processing requirements of soybean (*Glycine max*), cottonseed, sunflower (*Helianthus annuus*), rapeseed, peanut, and sesame (*Sesamum indicum*) oils and by-products are compared, as well as compositions of major oilmilling fractions, oils and proteins.*

In the early 1960s 2 major United States oilseed production areas were compelled to seek alternative crops because of decreasing markets. In the Red River Valley of North and South Dakota and Minnesota (Tri-State area), flaxseed (*Linum usitatissimum*) growers and processors were concerned about diminishing needs for linseed oil because of the development of latex paints. In the Cotton Belt, cottonseed crushers were concerned that continued replacement of cotton by synthetic fibers might result in no cottonseed for their oil mills. Both groups desired an oilseed crop that would fit into the existing agricultural processing infrastructure with minimum change.

The new crop selected for development by state, federal, and trade association-sponsored research was sunflower. The types of sunflower products that could be produced initially were dictated by the characteristics of current linseed or cottonseed oil mill equipment. Recent history tells us that a 4.5–5 mill-acre crop industry was successfully established in the Tri-State area. Also, varieties of sunflower that grow well in the drier areas of the Southwest were developed. However, world demand for natural fibers increased, and the growing of United States cotton was relocated to Texas, Arizona and California. Thus, sunflower growing opportunities were not exploited in the Southwest because of the greater profitability of growing cotton. The objective of this paper is to compare similarities and

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differences of oilseeds, relative to adaptability to existing production and processing infrastructures. Although emphasis is on soybean, cottonseed, sunflower, rapeseed, peanut and sesame, the principles are generally applicable to other row-crop oilseeds, such as safflower (*Carthamus tinctorius*) and lupine (*Lupinus albus*), and to mill fractions of cereal crops, such as corn (*Zea mays*), wheat (*Triticum*) germ and rice (*Oryza sativa*) bran. These fractions resemble the oilseeds in composition and in processibility in current oil extraction equipment.

The world's most prevalent seeds for edible oil production are, in descending order, soybeans, palm, sunflower, rapeseed, and cottonseed (USDA, 1982). In the processing of most crops, more meal is produced than oil. When estimated on the basis of 44% protein content (which is the standard content for soybean meal), the most abundant meals are soybean (60.2 mill MT), cottonseed (8.1), sunflower (4.6), rapeseed (4.6), flaxseed (0.9), copra (0.8), and sesame (0.7). In actuality, most of these meals are traded at lower protein contents than soybean meal. Oilseed meals are important protein sources for animal feeds and even for direct human food uses, but not all meal produced is currently useable. For example, much of the world's peanut meal is contaminated with aflatoxin, some rapeseed meal still contains toxic glucosinolates, and sesame meal is seldom fed to animals. Also, meals of some industrial crops, like that of castor seed (*Ricinus communis*), are too toxic for feed use at any level under today's generally available technologies. Thus, the major protein meals actually available for feed and food use are soybean, cottonseed, sunflower, and rapeseed.

The rank order of countries that produce the 5 major oilseeds is summarized in Table 1. The United States is first in soybean, second in cottonseed and sunflower, and third in peanut production.

CROP ADAPTATION

Each oilseed has its unique story of domestication by man. Soybeans originated in Ancient China, and were first planted in the United States in 1765 (Hymowitz and Harlan, 1983). However, the crop was grown primarily for hay until oil processing was started just prior to World War I (Smith and Circle, 1978). About 5,000 yr ago, natives of India and Peru were growing, spinning and weaving cotton by almost identical techniques, although no proof exists of communications between these 2 civilizations (Cooper, 1948). Peanut and sunflower seed are New World crops, but each was first exported to the Eastern Hemisphere before reintroduction to new growing sites in North America (Lusas, 1979; Putt, 1978). Rapeseed appears to have been a weed, which became so prevalent in northern European wheat fields that the farmers eventually started harvesting it by economic necessity (Appelqvist, 1972). Sesame probably is the oldest oilseed of commerce; and the plant is still regarded as a culinary herb by some people (Johnson et al., 1979).

Plant oils were initially used for medicinal and cosmetic purposes, and for soap making and illumination. The search for new edible oilseed crops often has been motivated by pressures of expanding populations that no longer can be fed by traditional means. Economic necessity also has been a key motivator in many instances. For example, the boll weevil's ravages of the Southeast cotton crop encouraged local evaluation of peanut, soybean, and sunflower. As another ex-

TABLE 1. RANK ORDER OF COUNTRIES PRODUCING THE WORLD'S MAJOR OILSEEDS.[a]

Soybean	Cottonseed	Peanut (in shell)	Sunflower	Rapeseed
U.S. (55.3)	China, Mainland (5.9)	India (6.0)	U.S.S.R. (4.6)	China, Mainland (4.1)
Brazil (12.8)	U.S. (5.8)	China, Mainland (3.8)	U.S. (2.1)	India (2.5)
China, Mainland (9.2)	U.S.S.R. (5.0)	U.S. (1.8)	Argentina (1.8)	Canada (1.8)
Argentina (4.3)	India (2.8)	Senegal (0.9)	Romania (0.8)	France (1.0)
Paraguay (0.6)	Pakistan (1.5)	Sudan (0.8)	Bulgaria (0.5)	Poland (0.5)

[a] USDA, 1982. Figures in parentheses indicate millions of metric tons.

TABLE 2. ADAPTABILITY OF MAJOR OILSEEDS TO VARIOUS CLIMATES.

Crop	Frost-free days	Approximate annual rainfall dm	Temperature	Photoperiodic requirement
Soybean	120[a]	5.1–7.6[a]	Mean summer 21°C+[a]	Extremely sensitive[a]
Cottonseed	180–200[a]	5.1–15.2[a]	Mean 16°C+[a]	Day neutral[a]
Peanut	200[a]	10.2 (4.8 during growing period)[a]	Mean annual 7°C+ Mean July 24°C+[a]	12 h or less[c]
Sunflower	120[a]	5.1[a]	21–30°C 28°C optimum[d]	Day neutral[a]
Rapeseed	90–120[a]	3.8–4.6[a]	Survives 10°C Heads at over 26°C[b]	12+ h[a] Quick-maturing varieties are day neutral[c]
Sesame	150[e]	3.8–4.6[b]	23–38°C 28°C optimum[b]	12 h or less[b]

[a] Chapman and Carter, 1976.
[b] Smith, 1982.
[c] Wynne, 1982.
[d] Adams, 1982.
[e] Martin et al., 1976.

ample, marketplace concerns about potential effects of erucic acid and glucosinolates on health motivated the Canadian government to invest heavily in the development of rapeseed varieties with low contents of these components.

Although man has modified crops throughout the ages by selection of seeds for replanting, the changes have often gone undocumented. An exception is sunflower, a crop originally native to the Mississippi-Missouri Rivers Basin, which underwent nearly 450 yr of improvement in Europe and Russia before high-oil type varieties were returned to the United States. Dorrell (1976) found that defatted meals of wild American sunflowers contained 1.6–2.7% chlorogenic acid, while meals of Russian oil-types contained approximately 3.5%. Morrison et al. (1981) have reported that the thinner seed hulls of oil-type sunflower contain appreciably more wax than do the thicker hulls of confectionery varieties. They have suggested that breeders of oil-type sunflower seed unknowingly may have selected for higher hull-wax content varieties because of the seed's better ability to withstand drying out. In the thicker-hulled confectionery varieties, this protection is believed to be imparted by the pithy layer of the hull. Both hull wax and chlorogenic acid are considered undesirable from the processor's viewpoint, and breeding programs are now in progress to reduce these components in oil-type sunflower seed.

General climatic requirements of various oilseeds are summarized in Table 2. In Canada and the United States, the general growing zones of these crops, from north to south, are rapeseed, sunflower, soybean, peanut, sesame and cottonseed. Many variables enter into the adaptability of a species or variety to a specific location. For example, short-season crops often can be grown as either early or late second crops in the South. However, if growth of the plant is accelerated during a temporary January thaw, freeze loss of fall-seeded rapeseed can occur. Although soybeans can be adapted to grow in latitudes from 0° to more than 50°, the plant is very daylight-sensitive, and the United States has been mapped into 9 generalized areas, based on day length required for growing of varieties of different maturity times. On the other hand, seed of a daylight-neutral species (like sunflower) harvested in Canada can be successfully grown in Texas. Even though the growing season may be long, local conditions sometimes favor specialized crops—for example, short-season cotton that can be harvested in the Texas Coastal Bend area before insects become a serious problem.

The conditions under which an oilseed is grown sometimes affect its composition. For example, by planting the same sunflower seed lot in several locations from Canada to Mexico, Robertson et al. (1979) showed that oils of seed maturing in cooler temperatures were higher in linoleic acid content than those maturing in warmer temperatures. A regression formula, i.e., % linoleic acid = 89.094 − 1.951 × (av. min. temp. in °C), with a correlation coefficient of $R^2 = 0.69$, was developed on the basis of 2 yr data, including 64 observations. Similar tendencies of sunflower oils produced in cooler climates to have higher linoleic-oleic acid ratios were demonstrated by Filipescu and Stoenescu (1978), in plantings spread from Sweden to Israel. The fact that seed maturation temperature, rather than latitude, is the determining factor in linoleic-oleic acid ratio was further demonstrated by Robertson and Green (1981). In 5 plantings throughout the year in Florida, they found linoleic acid variations of 32.7–71.0% (and 58.4–17.6% oleic acid), with linoleic acid content being the highest in seed from mid-August plantings, and lowest from early April plantings. Howell and Collins (1957) also observed decreased contents of linoleic acid in oils of soybeans maturing at higher mean daily temperatures. However, no relationship has been found between location or latitude of growing and protein content of sunflower seed (Kurnik, 1979).

Aside from differences in polyunsaturation of oil, the relationships between climatic conditions, soil fertility, and oilseed composition are not well known, with researchers often reporting more variation in the same variety grown at different locations than among varieties. However, Noor-Mohammadi and Ehdaie (1979) reported that percent protein content of oil-type sunflower was positively correlated (and oil content negatively correlated) with the amount of fertilizer applied during growth.

INFRASTRUCTURE OF OILSEEDS

Each of the major oilseeds has a unique infrastructure and role in the United States agribusiness and economy.

Soybeans

Approximately 4 lb of meal are produced per lb of oil, and the value of the feed meal in a bushel of soybeans has exceeded the oil value since the early 1950s. Thus, soybeans actually are a feed-protein crop, rather than an oil crop. However, presence of antinutritional factors, such as trypsin inhibitors, requires centralized processing or installation of on-farm roasting equipment before soybeans can be fed to livestock. Therefore, it is more profitable for farmers to sell soybeans to processors, then buy back the meal, than to use the seed directly as feed. Approximately 52% of the domestic soybean crop is exported—36% as whole beans, and 16% as oil and meal.

Cottonseed

In contrast, cottonseed is a by-product of cotton growing. Although fiberless cottonseed has been studied in Australia, no one has seriously attempted to develop fiberless varieties for oil and protein production. Approximately two-thirds of the weight of a dry cotton boll is seed, and, for each 480-lb bale of cotton produced, 875 lb of fuzzy ("grey") seed is also harvested. Since returns to the farmer from the fiber are approximately 6–10 times greater than from the seed, availability of cottonseed is primarily determined by the profitability of growing cotton. As long as the cotton fiber market holds strong, gins will produce cottonseed as a by-product. As a result, the economics of cottonseed processing are more recession-proof than those of other oilseeds planted specifically as oil crops. Also, the ability to feed unprocessed cottonseed directly to dairy and beef cattle guarantees a minimum price for cottonseed at least equal to its feed value.

Cottonseed was the first crop to use modern processing equipment, and it was the pioneer of today's oilseeds industries. It was the first major source of plant oil to compete with lard, tallow and butter in United States markets, and also the first exported oil to compete with olive and sesame oils in the Old World. Cottonseed oil milling provides one of the first examples of pollution control legislation in the United States. After invention of the cotton gin, cottonseed disposal became a serious problem. It was common practice to move the gin (as was done with saw mills), thus leaving piles of cottonseed behind. The rotting seed often polluted streams, and it was believed to be the source of sickness for inhabitants of the area. As a result, in 1857 the Mississippi legislature passed a law that any gin within a half mile of a city had to remove or destroy all cottonseed in order not to "prejudice the health of the inhabitants." The same law prohibited dumping cottonseed into rivers, creeks or streams that might be used for drinking or fishing (Cooper, 1948).

Cottonseed also has the problem of gossypol, a green-brown pigment, which is toxic to monogastric animals. However, the meal has limited use in feeding of ruminants. Attempts to deactivate or remove gossypol by mechanical or extraction means generally have been unsuccessful. It is only in recent years that genetically gossypol-free varieties of "glandless" cottonseed have become available for potential use as food proteins and as feeds for swine and poultry.

Because of the complexity of processing cottonseed, including delintering, hulling, separating, conditioning and flaking, most cottonseed oil mills are well equipped to process alternative oilseeds.

Peanuts

Approximately 60% of the peanuts harvested outside the United States are crushed for oil, while about 70% of the United States crop is used as peanut butter, nuts, and other foods (Lusas, 1979). Thus, Americans often are not aware of the major role of peanuts in the world's diet. Unfortunately, much of the world's peanut meal is contaminated with aflatoxins, which are formed by growth of the mold *Aspergillus flavus*. These compounds are carcinogenic at low levels and toxic at high levels. Because of aflatoxins, a considerable amount of peanut protein is not available for feed or food use; and technological breakthroughs to prevent growth of *Aspergillus flavus* in the maturing peanut, or to remove or "destroy" aflatoxins during processing, are needed.

Sunflower

There are 2 types of sunflower seed—the thick-hulled, often grey-striped "confectionery" type, and the black, smaller "oil" type. Only about 8.6% of the United States sunflower production (about 180,000 MT) is of the confectionery type. Of this, approximately 35% is sold as in-shell "snack-food" seed, 40% is dehulled for nut-like uses, and 25% (primarily the smaller seed) is sold in birdfeed mixtures.

The majority of oil-type seed grown in the United States is shipped whole to Europe for processing; however, by the end of 1982 approximately 1.5 mill tons of sunflower-crushing capacity will have been built in the Tri-State area. The main problems of processing oil-type sunflower seed result from the thinner hull, which is more flexible and therefore harder to remove than confectionery hulls. As a result, much of the sunflower meal produced in the United States contains appreciable amounts of hulls and is sold at 28–36% protein content. The high fiber content of this sunflower meal limits its uses to feeding of cattle. Development of more completely dehulled meals, containing 42% or more protein, is needed in order for sunflower meal to compete more effectively with soybean meal in swine and poultry feeds. Most cottonseed mills also are able to process sunflower seed.

Rapeseed

Like sunflower, rapeseed is grown primarily as an oil crop. Most of the North American rapeseed is grown in Canada for export. Modern rapeseed is an outstanding example of what scientific teamwork by industry and government can do to preserve and expand an export market. The earlier rapeseed oils were high in erucic acid, which had limited digestibility characteristics and was reported in the 1960s to cause heart damage and other health problems. Also, the meal contained appreciable amounts of glucosinolates, which were shown to be goitrogenic and limited its uses in animal feeds to 10% or less. Through an accelerated development program, the first low-erucic-acid (LEAR) variety rapeseed was released in 1969, and the first "double-low" variety of rapeseed (containing less than 5% erucic acid, and not more than 3 mg of glucosinolate per g of dry meal) was released in 1974. This type of seed was renamed "Canola" (implying "Canadian low-acid" seed) in 1980 (Appelqvist, 1972; Ohlson and Anjou, 1979; Anonymous, 1981). The United States Food and Drug Administration does not allow the sale of rapeseed oil for general cooking uses.

Sesame

Sesame once was grown in the United States, but, because of high costs of hand harvesting, it now is primarily imported from Mexico, Asia and Africa. Asia and Africa produce nearly 90% of the world supply (India, 21%, China, 20%, Sudan, 14%). Less than 5% of the world's production enters the export trade.

A major problem of the crop is that the plant blooms over a long period, and the lower seed pods open ("shatter" or dehisce) upon ripening and spill the seed, while flowers are still being formed at the growing tip of the stalk. The traditional method of handling sesame has been to hand-cut, bundle, and field-dry the stalks before threshing. Two major approaches currently are being followed to mechanize

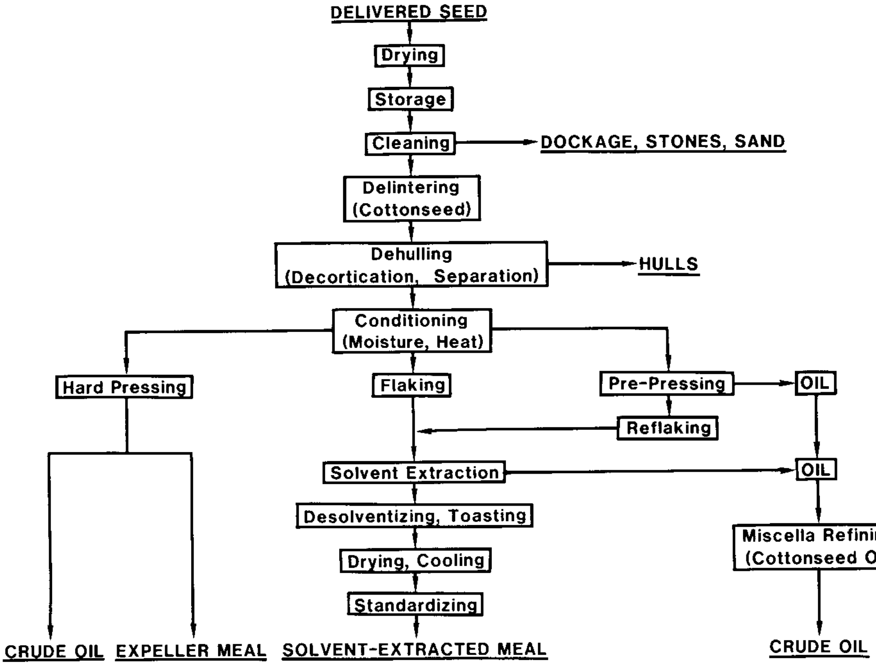

Fig. 1. Schematic diagram for manufacture of edible vegetable oil products.

sesame harvesting: mechanical cutting, binding, and field-threshing of dried current dehiscent varieties; and development of indehiscent varieties, whose pods will not open until they are harvested and threshed by field combine.

PROCESSING OF OILSEEDS

A generalized process for production of oils and meals is shown in Fig. 1. Each oilseed has its own requirements as to specific conditions and even as to the order of operations. Typically, seed is analyzed for moisture content, then segregated for early processing or dried to 10–12% moisture content before storage. Lower moisture and storage temperatures retard development of free fatty acids and are sought whenever possible. Most bins, storage houses, and outside piles are equipped with thermocouples to monitor seed temperature and with aeration systems for further drying and cooling of seed.

Seed taken from storage is cleaned to remove dockage (sticks and other large plant materials), stones, and sand. At this point, moisture may be added to the seed to facilitate later operations. In processing of cottonseed, the adhering fibers are removed in 2 or 3 stages with linters saws. First-cut linters are used as cushioning material in mattresses, quilts, and upholstered furniture. The shorter-fiber second- and third-cut linters usually are combined and sold to the cellulose chemicals industry.

Dehulling typically consists of 2 operations: decortication (or cracking of the hulls); and separation of the kernels (often called "meats") from the hulls by

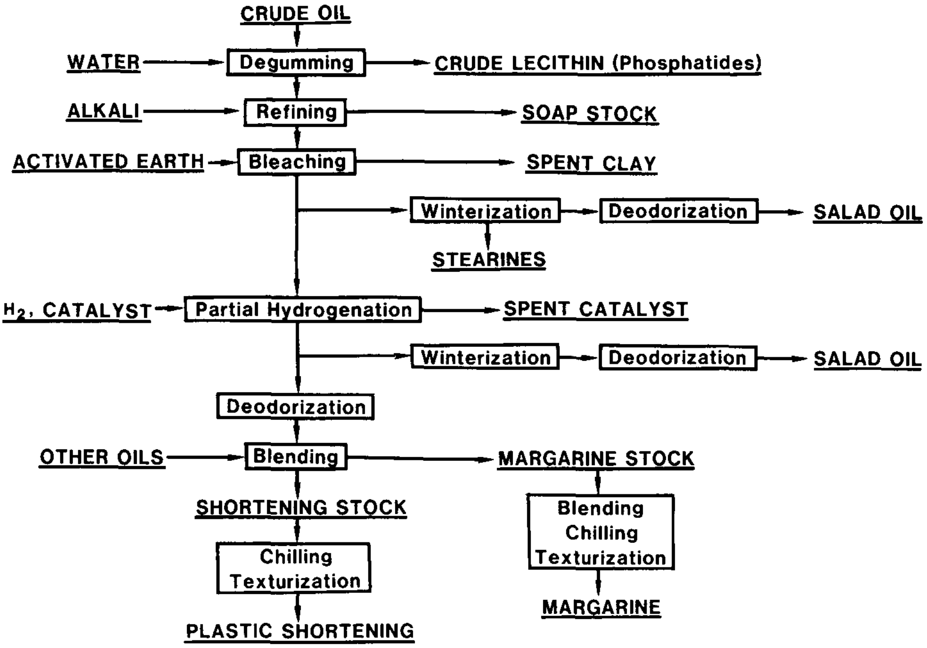

Fig. 2. Generalized process for refining and processing of oil.

sieving, aspiration, gravity tables or other techniques. For some seeds, such as cottonseed, dehulling can be very complex, but for smaller seeds like flaxseed, it may be by-passed entirely. Since their presence enhances screwpressing and solvent percolation during extraction, complete removal of hulls is usually not desired, unless food-grade protein flours or low-fiber animal feed meals are to be produced. The efficient oil mill operator initially attempts to remove the exact amount of hulls required to achieve the protein content desired in the final meal; however, the option still exists to standardize meal by adding back hulls after extraction.

The objective of the next few steps is to maximize rupturing of seed cells by thermal and mechanical stress and to free the oil for recovery by later pressing and/or solvent extraction. Often, steam is added at this point in order to raise moisture content of the seed to 11–14%, then the seed is heated by contact heat to 180°F or more.

Three processes for oil extraction are available—hard press, direct solvent extraction, and prepress-solvent extraction.

- The oldest procedure is hard pressing, for which the seed is usually well-cooked to a lower moisture content, then continuously screw-pressed for maximum oil recovery. Except for high-fiber meals, residual oil content of hard-pressed meals usually is about 6–8%, although some operations produce meals with 3–4% residual oil. Hard pressing usually inflicts considerable heat damage to the protein, but, under some conditions, it may be the most practical process. Hard press operations often are used in processing copra and in older cottonseed and peanut oil mills.

- In direct solvent extraction, the seed is flaked by rolls to about 0.010 inch in thickness, then extracted, usually with hexane, in a continuous extractor. Solvent extractors, operating in counter-current fashion, lose from 0.5–1.5 gal of solvent per ton of seed processed. Residual oil contents of 0.5–1.0% are sought in the meals, and recovery of the additional oil usually pays for the added equipment and operating expenses. However, because of the increased complexity of the process, and the potential explosive hazard of hexane, it is critical that the staff be well-trained in safe operation of the extractor. Direct solvent extraction typically is used for low to medium oil content oilseeds, including soybean and cottonseed.
- Prepress-solvent extraction is used for processing high oil content seeds, especially sunflower, peanut, rapeseed, flaxseed, and, occasionally, cottonseed. In processing high oil seeds, it is difficult to make flakes that will not disintegrate during solvent extraction and bind the percolation bed. In prepress-solvent extraction processes, conditioned seed is first pressed to an oil content of 15–18%, then the intermediate meal is reflaked and extracted with solvent. Occasionally, prepressing equipment is installed in cottonseed oil mills to increase the capacity of the solvent extractor.

The mixture of oil and solvent that exits the extractor is called the "miscella" and is separated by distillation to recover the solvent for reuse. In extraction of cottonseed, a very dark oil is obtained which, if not refined within several weeks, results in a "fixed" color that cannot be bleached by traditional methods. To prevent this, a unique "miscella refining" technique has been developed, especially for cottonseed oil, in which alkali solution is added to the hexane-crude oil miscella to convert the free fatty acids to soaps. These soaps are recovered, along with the gums and color pigments, by centrifugation, and the hexane-partially refined oil mixture then proceeds to the solvent recovery system.

The drained mixture of meal and solvent leaving the extractor is called the "marc." This usually is passed to a desolventizer-toaster (DT) unit, in which the residual solvent is driven off by heat, and the meal is then "dry-toasted" to the desired level of protein solubility. Usually, steam is added to the DT to help drive off the residual solvent as a hexane-water azeotrope vapor. After leaving the toaster, the hot meal is cooled.

The question, "Given an oil mill designed for a specific oilseed, what else can be processed through it?," sometimes arises. Soybean oil mills are primarily of the direct solvent extraction type, and they do not have the dehulling or prepressing equipment needed for optimum processing of other oilseeds. They usually can only make full-hull meals from other oilseeds. These meals may be limited in marketability because of high fiber content. Also, since hulls absorb oil, solvent-extracted, full-hull meals of other species may contain several percent oil, compared to the well under 1% level common in solvent-extracted soybean meal. Cottonseed oil mills typically have dehulling equipment suitable for all but the smallest of seed, such as flaxseed and rapeseed. The hard press mills will leave higher residual oil contents in meals of all varieties. The direct solvent extraction mills may have problems handling the high oil content seeds, like peanut and sunflowerseed, which typically require prepressing. For these seeds, thicker flakes normally would be run in order to prevent disintegration during extraction; as a result, residual oil in the meal may be as high as 2–3%. Peanut and sunflower oil mills would not have the optimum equipment for dehulling cottonseed, but, if the prepress-solvent type, would be able to handle most other oilseeds. Rapeseed and linseed oil mills would not have the decortication and separation equipment required for removal of hulls from cottonseed, peanut, or sunflower, and thus they would be forced to make full-hull (high-fiber content) meals.

UTILIZATION

A generalized process for refining and processing of oils is presented in Fig. 2. When recovery of saleable lecithin is desired, as in the processing of soybean oil, the phosphatides are first hydrated with water and other agents, then removed by centrifugation. If the gums are not removed separately, the oil is treated directly with phosphoric acid to chelate polyvalent cations, and alkali solution is then added to convert the free fatty acids to soap. After removal of soap by water wash and centrifugation, the oil next is bleached with clay-like materials to remove color bodies. If the product is to be sold for salad oil, at this point it may be "winterized" (chilled to precipitate the high melting point triglycerides that would cause cloudiness at cool or refrigerated temperatures). The resulting "stearine" solids are removed by decanting or centrifugation, and the oil is then deodorized by heat and vacuum treatment before bottling. The less stable oils, such as soybean oil, may be lightly "touched" (hydrogenated) to enhance their stability before winterization, deodorization, and sale as salad oils (Dutton, 1981); or, hydrogenation can be continued to produce triglycerides of varying degrees of "saturation" (or hardness). These partially hydrogenated oils then can be blended to obtain distinctive plasticity profiles at different temperatures. With further chilling and texturization, the oil mixtures can be converted into plastic shortenings, or, after blending with flavor and color ingredients, they can be texturized to produce margarines (Brekke, 1980; Sleeter, 1981).

At the current state of the art, the vast majority of oilseed meals are used as animal feeds. However, in some locations, peanut and cottonseed meals need to be checked for aflatoxin content before use. Unless specially treated to remove the gossypol, cottonseed meals are used primarily for feeding of ruminants. The Canola-type, "double-low" rapeseed meals seem acceptable for animal feed use. The high fiber content of undehulled meals, such as the 28–36% protein sunflower meals, may limit their use in high-energy rations. Also, for applications such as feeding poultry, some meals may require supplementation with lysine and other essential amino acids.

The major consumption of oilseed proteins occurs directly as whole or processed seed forms (including peanuts, peanut butter, sunflower seeds, toasted sesame seeds, tahini, and halvah), and as Asiatic foods prepared from soybeans (including tofu, tempeh, miso and soya sauces). A limited amount of glandless cottonseed kernels also is produced for food uses in the United States. The oilseeds provide a major, untapped source of vegetable food proteins for the world's rapidly growing population. Generally, the defatted meals of dehulled oilseeds contain 50% or more protein and can be made into flours by grinding to pass an 80-mesh screen. Vegetable protein concentrates, which contain 70% or more protein, can be made by washing the natural sugars from flours with alcohol or acidic water, then redrying. "Isolates," of even greater purity (over 90% protein), can be made by

TABLE 3. APPROXIMATE COMPOSITIONS OF WHOLE OILSEEDS AND KERNELS, MOISTURE-FREE BASIS.

Fraction or component	Soybean[a]	Cottonseed	Peanut[b]	Sunflower (oilseed type)	Rapeseed[c]	Sesame[d]
Whole seed						
Oil	20.3	22.2	40.9	43.5	41.0	53.3
Protein	40.4	23.1	24.4	23.4	44.5	25.0
Fiber	5.0	24.7	—	17.8	11.8	4.8
Ash	4.9	5.2	—	4.0	7.5	5.4
% Hulls (and linters)	7.5–8.5	40–45	20–26	20–25	16.5–18.7	15–20
Kernels (without hulls or testa)						
Oil	22.0	39.7	50.3	52.7	46.1	57.5
Protein	43.4	39.4	30.0	27.2	53.5	29.9
Fiber	4.9	4.8	2.9	10.6	5.0	3.4
Ash	5.0	4.5	3.0	4.2	3.3	3.5

[a] Smith and Circle, 1978.
[b] Lusas, 1979.
[c] Appelqvist, 1972.
[d] Johnson et al., 1979.

solubilizing protein from flours with alkali, separating the insoluble impurities, precipitating the proteins with acid, and drying. For over 25 yr, soybean protein flours, concentrates, and isolates have been marketed in the United States as bakery, confectionery and meat-processing ingredients. Texturized meat extenders and imitation milks also have been developed. Processes to make food protein flours, concentrates and isolates from almost any oilseed are well documented in the literature.

PRODUCT COMPOSITION

Hundreds of feed, food and industrial products are manufactured from various oilseed species, and a listing of their compositions would be impractical in this

TABLE 4. RANGES FOR FATTY ACID DISTRIBUTIONS FOR OILS (IN WEIGHT PERCENT).[a]

Fatty acid	Soybean	Cottonseed	Peanut	Sunflower	Rapeseed high erucic	Rapeseed low erucic (Canadian)	Sesame
<14	<0.1	<0.1	<0.1	<0.1	—	—	<0.1
14:0 Myristic	<0.5	0.5–2.0	<0.1	<0.5	tr.–1.2	0.9–1.2	<0.5
16:0 Palmitic	7–12	17–29	6.0–15.5	3–10	3.0–4.9	4.5–6.0	7.0–12
16:1 Palmitoleic	<0.5	0.5–1.5	<1.0	<1.0	—	—	<0.5
18:0 Stearic	2.0–5.5	1.0–4.0	1.3–6.5	1–10	1.1–2.0	1.5–2.1	3.5–6.0
18:1 Oleic	19–30	13–44	36–72	14–65	14–35	48–61	35–50
18:2 Linoleic	48–58	33–58	13–45	20–75	11–14	19–22	35–50
18:3 Linolenic	3–8	0.1–2.1	<1.0	<0.7	5–23	9–11	<1.0
20:0 Arachidic	<1.0	<0.5	1.0–2.5	<1.0	0.5–0.7	0.6–0.8	<1.0
20:1 Gadoleic	<1.0	<0.5	0.5–2.1	<0.5	0.8–14.0	0.4–4.3	<0.5
22:0 Behenic	<0.5	<0.5	1.5–4.8	<1.0	—	0.1–0.2	<0.5
22:1 Erucic	—	<0.5	<0.1	<0.5	20–54	0.1–5.1	—
24:0 Lignoceric	—	<0.5	1.0–2.5	<0.5	0.1–1.4	0.2	—

[a] Sonntag, 1979; also represents ranges tentatively adopted by FAO/WHO Codex Alimentarius on Fats and Oils.

TABLE 5. AVERAGE NUTRIENT VALUES OF SELECTED FEED INGREDIENTS.[a]

Ingredient	% Dry matter	% Crude protein	% Crude fat	% Crude fiber	% Ash
Soybeans, full fat	90	37.0	18.0	5.5	5.0
Soybean meal (expeller)	90	42.0	3.5	6.5	6.0
Soybean meal (solvent)	90	44.0	0.5	6.5	6.0
Soybean meal, dehulled (solvent)	90	48.5	0.5	3.2	6.0
Cottonseed meal (41%)	94	41.0	4.0	12.5	6.0
Cottonseed meal (41%, solvent)	94	41.0	1.0	13.0	6.5
Cottonseed meal (36%)	92	36.0	4.5	14.5	6.0
Peanut meal and hulls (expeller)	92	44.0	6.0	13.0	5.8
Peanut meal and hulls (solvent)	90	46.0	1.0	12.0	5.0
Sunflower meal (dehulled, mechanically extracted)[b]	96	37.0	9.1	15.8	6.5
Sunflower meal (with hulls, solvent extracted)[b]	91	30.8	3.6	24.8	6.0
Sunflower meal (28%)	90	28.0	0.5	30.0	—
Sunflower meal (34%)	90	34.0	0.5	21.9	—
Rapeseed meal	90	35.0	8.0	12.0	8.0
Sesame meal	93	43.0	5.0	6.5	12.0

[a] All values from Feed Industry Red Book (1979) except for "b".
[b] Lusas, 1982.

review. Approximate compositions of the major whole oilseeds and their dehulled kernels are shown in Table 3. The objective of oil milling is to recover as much saleable oil and meal as possible. Some hulls may also be sold separately as animal feed roughages or, in the case of sunflower hulls, as fuel. The ranges of fatty acid distribution of the various oils produced are summarized in Table 4. Because of wide variations in composition, it is difficult to generalize relative rankings of oilseed species by degree of polyunsaturation, instead, it is more reliable to operate on the basis of actual assays. A selected nutrients listing of feed meals is shown

TABLE 6. PERCENT ESSENTIAL AMINO ACID CONTENTS OF OILSEED PROTEIN MEALS (G/16 G N).

Amino acid	Soybean meal[a]	Cottonseed meal[a]	Peanut meal[a]	Sunflower meal[a]	Rapeseed concentrate[b]	FAO/WHO scoring pattern[c]
Isoleucine	4.0	3.3	3.4	4.3	4.2	4.0
Leucine	7.8	5.9	6.4	6.4	7.3	7.0
Lysine	6.4	4.4	3.5	3.6	5.8	5.5
Methionine + cystine	2.6	2.8	2.4	3.4	4.9	3.5
Phenylalanine + tyrosine	8.1	8.1	8.9	6.3	7.2	6.0
Threonine	3.9	3.3	2.6	3.7	4.5	4.0
Valine	4.8	4.6	4.2	5.1	5.2	5.0
Tryptophan	1.3	1.2	1.0	1.4	1.4	1.0
Histidine	2.5	2.7	2.4	2.3	2.7	1.4[d]
Arginine	7.2	11.2	11.2	8.0	6.6	—

[a] FAO, 1970.
[b] Ohlson and Anjou, 1979.
[c] FAO/WHO, 1973.
[d] Essential for infants.

in Table 5. Finally, amino acid contents of proteins of the various oilseeds, in comparison to the FAO/WHO Scoring Pattern for protein quality (FAO/WHO, 1973), are presented in Table 6. Once the oilseeds have been converted into oil and into food and feed protein ingredients, the challenge of using them for maximum nutritional and functional benefits begins.

LITERATURE CITED

Adams, J. 1982. Pers. comm. Natl. Sunflower Assoc., Bismarck, ND.

Anonymous. 1981. Canola—a new oilseed from Canada. J. Amer. Oil Chem. Soc. 58: 723A–729A.

Appelqvist, L. A. 1972. Historical background. *In* Rapeseed: Cultivation, Composition, Processing and Utilization, A. Appelqvist and R. Ohlson ed, Elsevier, New York.

Brekke, O. L. 1980. Edible oil processing. *In* Handbook of Soy Oil Processing and Utilization, D. R. Erickson, E. H. Pryde, O. L. Brekke, T. L. Mounts, and R. L. Falb, ed, Amer. Soybean Assoc., St. Louis, MO. and Amer. Oil Chem. Soc., Champaign, IL.

Chapman, S. R., and L. P. Carter. 1976. Crop Production Principles and Practices. Freeman, San Francisco, CA.

Cooper, M. R. 1948. History of cotton and the United States cottonseed industry. *In* Cottonseed and Cottonseed Products, A. E. Bailey, ed, Interscience, New York.

Dorrell, D. G. 1976. Chlorogenic acid content of meal from cultivated and wild sunflowers. Crop Sci. 16: 422–424.

Dutton, J. J. 1981. History of the development of soy oil for edible uses. J. Amer. Oil Chem. Soc. 58: 234–236.

FAO. 1970. Amino Acid Content of Food. Nutrition Studies, No. 24. Food and Agric. Organ. of United Nations, Rome.

FAO/WHO. 1973. Energy and Protein Requirements. FAO Nutritional Meetings Report Series 52. Food and Agric. Organ. of United Nations, Rome, Italy.

Feed Industry Red Book. 1979. Communications Marketing, Inc., Edina, MN.

Filipescu, H., and M. Stoenescu. 1978. Variability of linoleic acid content in sunflower oil, depending on genotype and environment. Helia (Res. Inst. Cereals and Industrial Crops, Fundulea, Romania) 1: 42–46.

Howell, R. W., and F. I. Collins. 1957. Factors affecting linolenic and linoleic acid content of soybean oil. Agron. J. 49: 593–597.

Hymowitz, T., and J. R. Harlan. 1983. Introduction of soybean to North America by Samuel Bowen in 1765. Econ. Bot. 37: 371–379.

Johnson, L. A., T. M. Suleiman, and E. W. Lusas. 1979. Sesame protein: a review and prospectus. J. Amer. Oil Chem. Soc. 56: 463–468.

Kurnik, E. 1979. Protein content of sunflower hybrids and varieties tested in international trials (1977). Helia (Res. Inst. Cereals and Industrial Crops, Fundulea, Romania) 2: 21–23.

Lusas, E. W. 1979. Food uses of peanut protein. J. Amer. Oil Chem. Soc. 56: 425–430.

———. 1982. Sunflower meals and food products. *In* Sunflower. National Sunflower Association, Bismarck, ND.

Martin, J. H., W. H. Leonard, and D. L. Starup. 1976. Principles of Field Crop Production. Macmillan, New York.

Morrison, W. H., III, D. E. Akin, and J. A. Robertson. 1981. Open pollinated and hybrid sunflower seed structures that may affect processing for oil. J. Amer. Oil Chem. Soc. 58: 969–972.

Noor-Mohammadi, G., and B. Ehdaie. 1979. Effect of nitrogen and phosphorous fertilizer on sunflowerseed yield and other agronomic characters. Sunflower Newslett. 3: 21–24.

Ohlson, R., and K. Anjou. 1979. Rapeseed protein products. J. Amer. Oil Chem. Soc. 56: 431–437.

Putt, E. D. 1978. History and present world status. *In* Sunflower Science and Technology. No. 19 Agronomy, J. F. Carter, ed, Amer. Soc. Agron., Madison, WI.

Robertson, J. A., and V. E. Green. 1981. Effect of planting date on sunflower seed oil content, fatty acid composition and yield in Florida. J. Amer. Oil Chem. Soc. 58: 698–701.

———, W. H. Morrison III, and R. L. Wilson. 1979. Effects of Planting Location and Temperature on the Oil Content and Fatty Acid Composition of Sunflower Seeds. USDA, SEA-ARS-S-3, New Orleans, LA.

Sleeter, R. T. 1981. Effects of processing on quality of soybean oil. J. Amer. Oil Chem. Soc. 58: 239–247.

Smith, A. K., and S. J. Circle, ed. 1978. Soybeans: Chemistry and Technology. Vol. I. Proteins. AVI, Westport, CT.

Smith, O. 1982. Pers. comm. Texas A&M Univ.

Sonntag, N. O. V. 1979. Composition and characteristics of individual fats and oils. *In* Bailey's Industrial Oil and Fat Products, D. Swern, ed, Vol. 1. Wiley, New York.

USDA. 1982. World Oilseed Situation and U.S. Export Opportunities. Foreign Agricultural Circular FOP 6-82, May.

Wynne, R. 1982. Pers. comm. Natl. Weather Serv., College Station, TX.

Book Review

Bryophyte Ecology. Edited by A. J. E. Smith. 511 pp. illus. Chapman and Hall, New York, 1982. $75.00.

Bryophyte Ecology is a delight to browse through. Especially interesting are the chapters on tropical forest bryophytes (T. Pocs), desert bryophytes (G. A. M. Scott), and bryophytes and invertebrates (U. Gerson). The other chapters cover: quantitative approaches; life-forms; bryophyte vegetation in polar regions; alpine communities; epiphytes and epiliths; ecology of *Sphagnum*; physiological ecology; mineral nutrition; responses of bryophytes to air pollution; and Quaternary bryophyte paleo-ecology. All chapters seem to be well done and balanced, with adequate coverage of historical and modern literature. Most are reviews, but some include previously unpublished information. Scott's chapter on desert bryophytes, based mainly on his studies in Australia, has intriguing challenges for future investigations on adaptive physiology-morphology of arid-land bryophytes. It is fascinating to learn that colonies of *Tortula princeps* can move offending tree leaves that fall on the moss colony and drop the leaves "off the edge" of the colony, with "travel" of 55 cm noted for one leaf transported in this fashion. (The *Tortula* plants do this by the twisting and untwisting of their leaves in response to changing moisture content.) The tenacious hold on life of some desert bryophytes is demonstrated by the fact that *Barbula torquata* achieved net photosynthesis in 16.5 hours after 72 weeks without water in a greenhouse. Among other things, Uri Gerson discusses bryophytes as a factor in invertebrate evolution, and vice versa, pointing out that bryophytes are relatively free from arthropod predation, which suggests that they have evolved good chemical and other defenses against arthropod attack. In general the book is quite well edited and adequately illustrated. I did note that in Figure 9.1 the numbers 1 and 2 are reversed, and in Table 5.2 the definitions for "Short turf" and "Tall turf" are identical. Ecologists in general and bryologists in particular will want to have access to *Bryophyte Ecology*, although the price is a deterrent.

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