2004

Low-Cost Oil-Processing Techniques

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Abstract

Advances in edible oil refining have been discussed in previous chapters of this book. These recent developments in physical-, chemical-, and adsorption-based refining techniques and related equipment designs will allow higher quantities of natural and bioactive compounds to be retained in the oil during refining compared with the use of conventional refining processes. This chapter summarizes recent research on mechanical extraction, minimum refining, and frying applications of soybean oil. The soybean is the dominant oilseed crop produced in the world due to its favorable agronomic characteristics, high-quality protein, and versatile edible oil. Soybeans constitute over one-half of all oilseeds produced worldwide (Fig. 13.1). Soybean oil accounted for 80–90% of total edible oil consumption in the United States in 1998 because of its availability and its desirable compositional and functional properties.

Disciplines

Food Chemistry | Food Processing | Food Science | Human and Clinical Nutrition | Plant Sciences

Comments

This book chapter is published as Wang, T., L.A. Johnson, and W. Wijeratne. Low Cost Oil Processing Techniques. In *Nutritionally Enhanced Edible Oil Processing* (ed. N.T. Dunford and H.B. Dunford) *AOCS Press*, 2004, pp 219-238. Posted with permission.

Low-Cost Oil-Processing Techniques

Chapter · April 2004

DOI: 10.1201/9781439822272.ch13

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AOCS Press, Urbana, IL 61802

Chapter 13

Low-Cost Oil-Processing Techniques

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Advances in edible oil refining have been discussed in previous chapters of this book. These recent developments in physical-, chemical-, and adsorption-based refining techniques and related equipment designs will allow higher quantities of natural and bioactive compounds to be retained in the oil during refining compared with the use of conventional refining processes. This chapter summarizes recent research on mechanical extraction, minimum refining, and frying applications of soybean oil.

The soybean is the dominant oilseed crop produced in the world due to its favorable agronomic characteristics, high-quality protein, and versatile edible oil. Soybeans constitute over one-half of all oilseeds produced worldwide (Fig. 13.1). Soybean oil accounted for 80–90% of total edible oil consumption in the United States in 1998 because of its availability and its desirable compositional and functional properties.

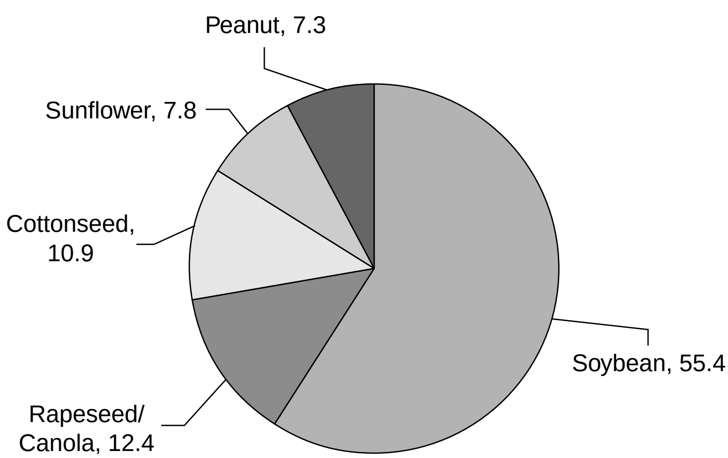

Figure 13.1. Percentages of the five major oilseeds produced in the world during 2000–2001.

Recently there has been a trend toward increased use of mechanical processing of soybeans and minimal or physical refining of soybean oil in order to provide consumers with specialty oils having unique characteristics (natural, non–genetically modified, organic, with modified fatty acid composition for better nutritional or physicochemical properties, with maximal retention of phyto-micronutrients, etc.) that some consumers want and for which they are willing to pay premium prices.

Oil Extraction: Solvent versus Mechanical Means

Two common processes for soybean oil extraction are solvent extraction and mechanical extraction, involving screw pressing. In the United States today, however, less than 1% of soybeans are processed by mechanical means. Solvent extraction with a petroleum distillate known as hexane, but actually a mixture of hexane isomers (45–70% *n*-hexane), is the standard practice in modern oilseed-processing facilities (1). This process has recently been reviewed by Woerfel (2) and is shown in Fig. 13.2.

There are three major steps in traditional solvent extraction: seed preparation (drying, cleaning, cracking, optional dehulling or decortication, conditioning, flaking, and often expanding), oil extraction (typically via hexane percolation as opposed to immersion), and meal and oil desolventizing and meal toasting. Mechanical processing involves seed preparation (cleaning and heat treatment), mechanical pressing with a screw press, and foots (sediment) removal from the oil (Fig. 13.3).

Seeds can be prepared in different ways for screw pressing, but usually they are either heated to 93–149°C using a rotary tube dryer or a stacked-tray cooker, or they are extruded (sometimes referred to as expanded). The objectives of the heat treatments are to denature protein, rupture the cell walls, and reduce oil viscosity, all of which cause minute oil droplets to coalesce into large drops so that the oil can be released readily by the application of mechanical force. After the pressing operation, the high-protein cake is normally broken or ground and cooled for storage. The pressed oil usually contains a large amount of meal fines, which are removed in a sedimentation tank followed by filtering through a pressure leaf or plate-and-frame filter. The quality of such oil is generally considered better than that from solvent extraction (3,4) because of a lesser amount of oil-soluble impurities, which increase refining costs. In fact, oil from some pressing operations, such as olive or evening primrose, is suitable for direct consumption without any refining.

A growing number of mini–crushing mills that employ extruding-expelling (E-E) technology developed by Nelson *et al.* (5) and now marketed by Insta-Pro International (Triple "F", Inc., Des Moines, Iowa) have been built as farmer-owned cooperatives or as on-farm operations to process locally produced soybeans or other oilseeds (5–120 metric tons [MT] per day processing capacity). A flow diagram is shown in Fig. 13.4, and system setups are shown in Figs. 13.5 and 13.6.

E-E uses a dry autogenous extruder in which heat is generated by friction prior to screw pressing, replacing more capital-intensive use of steam-heated dryers

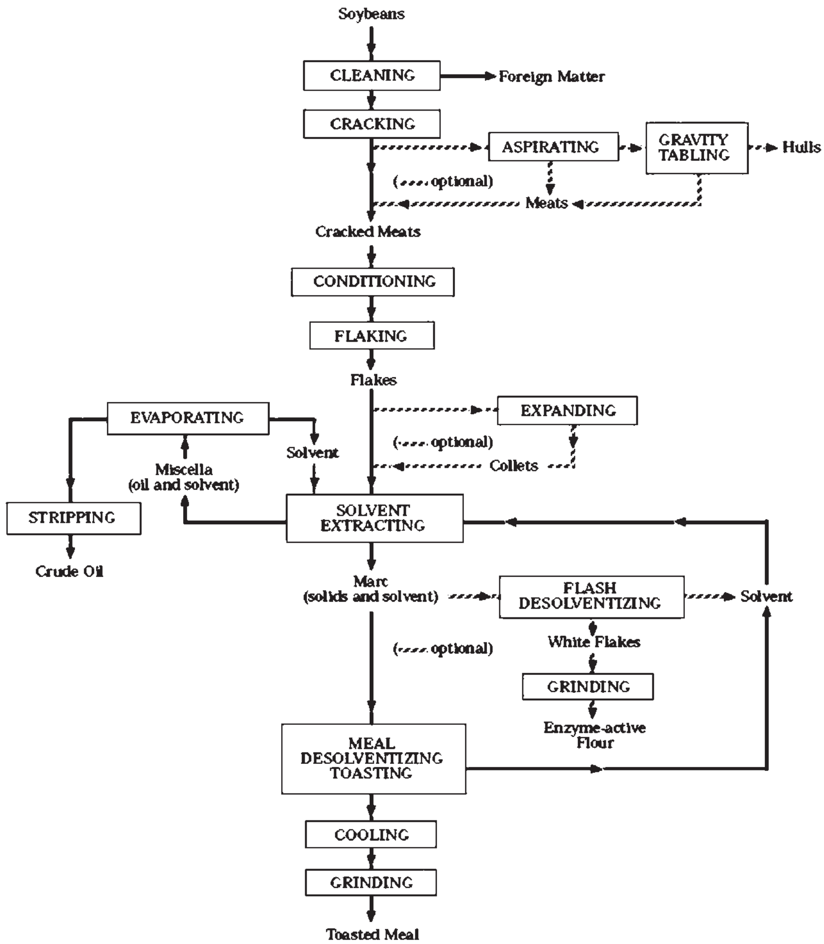

Figure 13.2. Flow diagram for solvent extraction of soybean oil. (Courtesy of Center for Crops Utilization Research, Iowa State University.)

and cookers and associated steam generation equipment. Economic analysis of such an operation has been discussed by Said (6). It is convenient and economical to market E-E soybean meal to local livestock feeders. The partially defatted meal, typically with 6–7% residual oil content, is used in livestock rations in which the residual fat contributes metabolizable energy (often as specialty feeds for dairy cattle, where rumen bypass characteristics and high metabolizable energy increase the value of the meal). It has also been shown that the meal can be texturized to prepare excellent ground beef extenders (7–9), and the functional properties of the flour have been characterized for other food applications (10,11). Also, there is growing interest in natural, organic, identity-preserved,

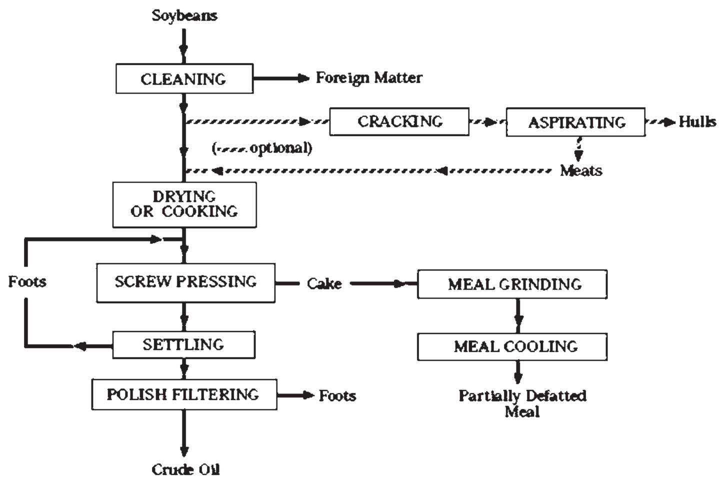

Figure 13.3. Flow diagram for traditional screw pressing of soybeans. (Courtesy of Center for Crops Utilization Research, Iowa State University.)

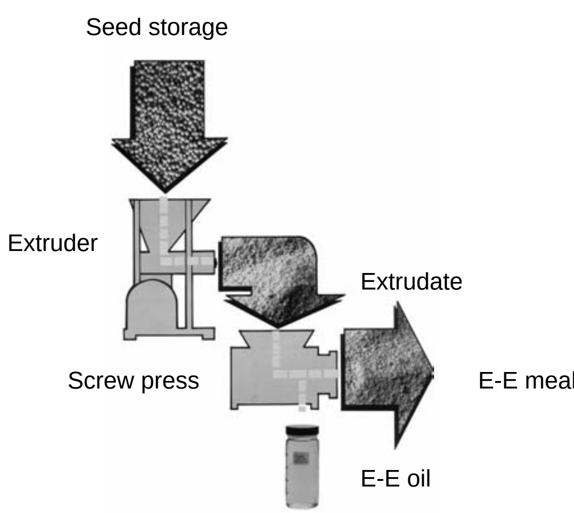

Figure 13.4. Flow diagram for extruding-expelling (E-E) processing of soybeans. (Courtesy of Insta-Pro International, Des Moines, Iowa.)

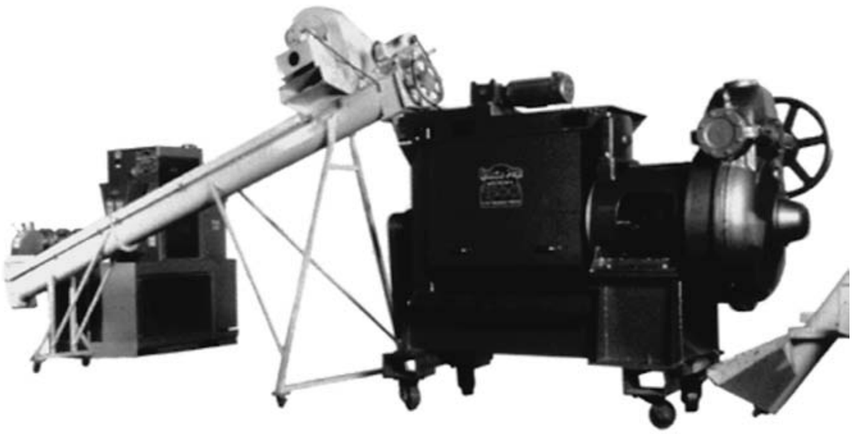

Figure 13.5. An extruding-expelling (E-E) system. (Courtesy of Insta-Pro International, Des Moines, Iowa.)

Figure 13.6. An operating E-E plant for soybean processing. (Courtesy of Center for Crops Utilization Research, Iowa State University.)

non-GM (non-genetically modified by transgenic means) or genetically enhanced (GE, modified by traditional breeding) soybean products. Various types of GM and GE soybeans are being developed to improve nutritional and functional properties of soy oil, such as seeds containing higher percentages of oleate, lower percentages of linolenate or saturates compared with commodity soybean oil, or seeds containing no lipoxygenases, which are believed responsible for the beany flavor of oil and protein meal. Oils from these seeds may command higher prices than commodity oils. These market opportunities cannot be easily served by today's large solvent extraction plants (typically greater than 3,000 MT/d operation scale), but the small E-E plants are eager to adopt such strategies to capture greater returns provided low capital investment is required and the processing technology employed is relatively simple.

Solvent-extracted and conventionally refined oils are considered to be chemically treated because of the exposure to the organic solvent hexanes during extraction and the subsequent extensive refining with chemicals under harsh conditions, including conditioning for degumming, neutralization with alkali, and high-temperature deodorization (which can cause double-bond isomerization). E-E oil, on the other hand, is completely mechanically extracted, and the settled crude oil contains low levels of phospholipids and free fatty acids (12). This oil can be further refined or processed by natural or physical means to produce an array of value-added soybean oil products.

Qualities of Soybean Oils Extracted by Different Methods

Soybean oil produced by E-E processing has unique characteristics compared with oil produced by solvent extraction. Wang and Johnson (12) compared quality characteristics of oils produced by different soybean processing methods (Table 13.1). Soybean oil and meal samples were collected three different times over a one-year period from 13 E-E mills, eight solvent-extraction plants, and one continuous screw press plant. Screw pressing was found to be slightly more efficient in recovering oil than E-E processing, leaving 6.3% oil compared with a mean of 7.2% for E-E meals. These values are considerably higher than those for solvent-extracted meals (1.2%).

Peroxide value (PV), a measure of primary lipid oxidation products, of the crude E-E oil (1.73 meq/kg) was significantly higher than that of crude solvent-extracted oil (0.96 meq/kg); this was attributed to the high temperature used in the E-E process, the long time period allowed for oil cooling, and the poor oil storage conditions and longer storage times at the E-E mills. Free fatty acid (FFA) content, a measure of hydrolytic degradation during seed storage and oil extraction, of E-E oil (0.21%) was significantly lower than that of solvent-exracted oil (0.31%), which may be due to the rapid inactivation of lipases during extrusion. Screw-pressed oil contained 0.33% FFA, which was similar to the content of solvent-extracted oil. The amount of phospholipids (PLs), polar lipids that are also referred to as gum, of the oil after natural settling was much lower in E-E oil (75 ppm phosphorus) than in solvent-extracted oil

TABLE 13.1
Quality Characteristics of Soybean Oils Produced from Extruding-Expelling (E-E), Solvent Extraction (SE), and Continuous Screw Press (SP) Operations[a]

	E-E		SE		SP	
PV, meq/kg	1.73	a	0.96	b	1.76	a
FFA, %	0.21	b	0.31	ab	0.33	a
Phosphorus, ppm	75	c	277	b	463	a
AOM stability,[b] h	23.9	b	39.8	a	36.2	a
Moisture, %	0.08	a	0.08	a	0.05	b
Tocopherols, ppm	1257	b	1365	a	1217	b
Color, red	10.2	b	11.1	b	17.5	a

[a]The means with different letters in the same row are significantly different at 5%.
[b]AOM = active oxygen method.

(277 ppm phosphorus). Screw-pressed oil had much higher PL content (463 ppm phosphorus) than did solvent-extracted oil. The PLs in E-E oil seem readily hydratable and easy to settle, which is attributed to the rapid heat inactivation of the phospholipases.

Tocopherols, a group of natural antioxidants, of crude E-E oil were present in slightly, but statistically significantly, lower concentration than in crude solvent-extracted oil (1,257 vs. 1,365 ppm). Oxidative stability, as measured by the active oxygen method (AOM), of the E-E oil (23.9 h) was significantly lower than that of solvent-extracted oil (39.8 h), probably due to the higher PV value and lower contents of PLs and tocopherols in crude E-E oil. The colors of E-E (10.2 red) and solvent-extracted (11.2 red) oils were not statistically different, although solvent-extracted oil tended to be slightly darker than E-E oil. Screw-pressed oil (17.4 red) was much darker in color than were the other two types of oils, probably due to the more severe heat treatment before pressing.

Soybean Oil Refining

The minor components of crude soybean oil include PLs, FFAs, chlorophyll pigments, oxidation products, and other unsaponifiable matters (tocopherols, sterols, hydrocarbons, etc.). Some of these minor components negatively affect oil quality whereas others may play positive roles in nutrition and food quality. The goal of oil refining is to remove the undesirable components while maximizing retention of the beneficial ones.

Conventional Oil Refining

An overview of conventional soybean oil refining is presented in Fig. 13.7.

Degumming is the process of removing PLs from crude soybean oil to improve its physical stability, prevent adverse color changes, and facilitate further refining. The

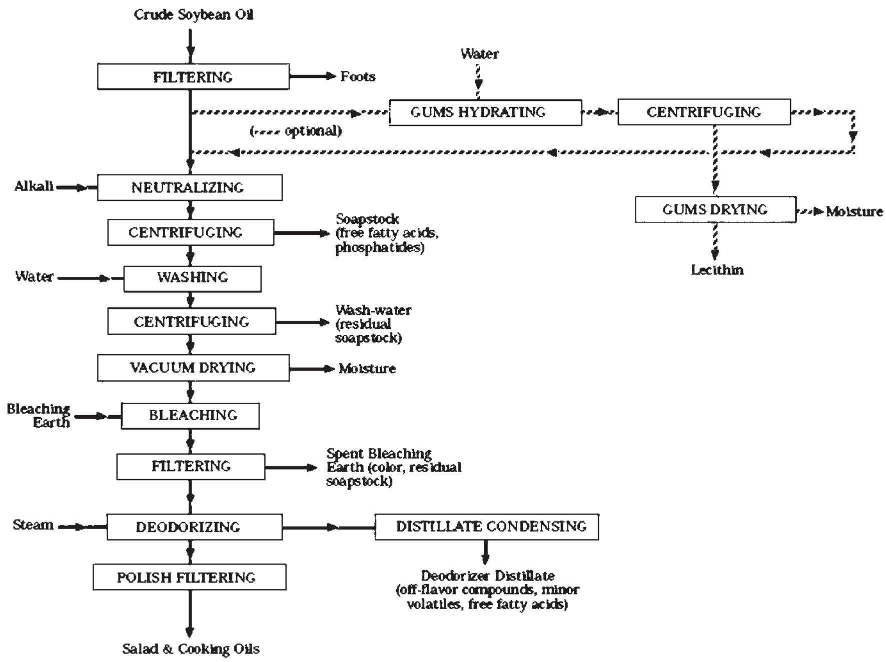

Figure 13.7. Diagram of conventional soybean oil refining. (Courtesy of Center for Crops Utilization Research, Iowa State University.)

water degumming procedure is simple but its efficacy is influenced by the quality of the crude oil. Often chemical agents such as citric or phosphoric acid are added to the oil as conditioning agents to enhance the hydratability of PLs. Gums can be removed by centrifuging, as is the usual case, or occasionally by settling. Neutralization is a process of removing FFAs, an oil decomposition product. The process is also described as deacidification or caustic refining. It is achieved by treating the soybean oil with aqueous alkaline solution (generally sodium hydroxide) to neutralize the FFAs. The soap formed in the reaction flocculates and adsorbs some natural pigments, the unhydrated gum, and mucilaginous substances contained in the oil. The soapstock is normally removed by centrifuging but can also be removed by settling. Bleaching is designed not only to remove red and green pigments (especially chlorophyll) but, more important, to break down hydroperoxides (the primary oxidation products) into lower-molecular-weight carbonyl compounds, which can subsequently be removed by deodorization. Deodorization is usually the last step in oil refining. It is a steam stripping process in which good-quality steam is injected into soybean oil under high temperature (252–266°C) and high vacuum (<6 mm Hg). Under these conditions hydroperoxides are decomposed, and the FFAs and odorous compounds are vaporized. During this step certain undesirable reactions, such as lipid hydrolysis, polymerization, and isomerization, can take place. Therefore, deodorization conditions must be carefully controlled to achieve finished soybean oils of maximum quality. Changes in oil quality and composition of minor components during conventional refining of soybean oil are given in Tables 13.2 and 13.3. It is worth noting that the nutritionally desirable tocopherols and phytosterols are reduced by more than 30% in the fully refined, bleached, and deodorized (RBD) oil. Other micronutrients are also reportedly lost during harsh oil refining treatments (13).

Minimal Refining of Mechanically Extracted Soybean Oils

Natural and low-capital-investment methods are needed to refine E-E or other mechanically extracted oils with normal and modified fatty acid compositions and to retain maximal quantities of micronutrient in the oil. The high capital cost and energy requirements of continuous centrifuges, steam and vacuum generation equipment, and deodorizers are limiting factors in setting up refineries to process relatively small quantities of E-E or other specialty oils. Alternatively, FFAs and residual PLs can be simply removed by adsorption and filtration. It is also possible to modify or eliminate the energy-intensive, expensive, and nutrient-stripping deodorization step. A diagram of minimal soybean oil refining is shown in Fig. 13.8.

In the study of Wang and Johnson (16), four E-E processed, GM or GE soybean oils (high oleic acid [HO], low saturated fatty acid [LS], low linolenic acid [LLL], and lipoxygenase free [LOX]) and a commodity soybean oil (CS) were used to study quality changes during minimal refining. The crude oil was water degummed without the use of chemical conditioners; the FFAs, residual PLs, and other impurities were removed by adsorption onto a particulate adsorbent (Magnesol, Dallas Group of America, Jeffersonville, Indiana) and silica; and the adsorbent was removed by filtering. "Soft" deodorization (200°C) using temperatures lower than those typically used in conventional deodorization was applied. These oils were also refined using conventional methods, and quality changes during the two refining processes are presented in Fig. 13.9.

PLs present in crude E-E oils hydrate and settle readily due to the rapid denaturation of the phospholipases during crushing, which minimizes formation of unhydratable PLs. On average, phosphorus contents of E-E oils were reduced from a mean of 400 ppm to less than 55 ppm, except for high–oleic acid oil, which was reduced to 100 ppm residual phosphorus. The higher level of the unhydratable phospholipid in high–oleic acid oil may be related to its poorer initial seed quality, as indicated by the high FFA content (0.6% FFAs in HO crude oil vs. 0.2–0.3% FFAs in the other E-E oils).

By using 3% Magnesol adsorbent, FFA content was reduced to less than 0.05%. If a stepwise countercurrent system is used for such adsorption treatment, the process should be more efficient and less adsorbent may be needed. One unique property of Magnesol is that it also effectively removed (adsorbed and/or decomposed) hydroperoxides. Although Magnesol and silica considerably reduce peroxide value (PV) and anisidine value (AV) of E-E oils, the oil still has a slight off flavor that may be objectionable to some consumers. Mild or soft deodorization successfully removed

TABLE 13.2
Effects of Processing Steps on Quality of Soybean Oil

Processing step	Phosphorus (ppm)	Iron (ppm)	Free fatty acids (%)	Peroxide value (meq/kg)	Tocopherols (ppm)
Crude	510	2.9	0.30	2.4	1,670
Degummed	120	0.8	Not determined	10.5	1,579
Neutralized	5	0.6	0.23	8.8	1,546
Bleached	1	0.3	0.08	16.5	1,467
Deodorized	1	0.3	0.00	0.0	1,138

Source: Jung *et al.* (14).

these off flavors. New and more effective adsorption products are appearing on the market, and they should be tested for various applications, especially for deodorization.

Bleaching is almost always used in conventional refining to break down hydroperoxides present in the oil so that the secondary oxidation products (as indicated by AV) can be easily removed during deodorization. If deodorization is not used in minimal refining, the generation of these secondary products must be minimized. Therefore, conventional bleaching becomes an undesirable step. However, there is a need to further evaluate how effectively chlorophyll can be removed by various adsorption treatments. It is also a challenge to remove hydroperoxides without any breaking down for a low-cost, minimal refining process.

Oils with different fatty acid compositions and contents of minor nutrients, such as tocopherols, are oxidized to different degrees during refining. Low–saturated fatty acid and low–linolenate oils were found to be much more susceptible to oxidation than other genetically modified oils, and high–oleic acid oil was the most stable oil as indicated by peroxide and anisidine values. Therefore, special precautions should be taken when refining highly unsaturated soybean oils. Overall, conventional refining generated much more hydroperoxides and secondary oxidation products than did minimal refining. Total tocopherol content was not significantly changed during

TABLE 13.3
Effects of Processing on Tocopherol, Sterol, and Squalene Contents in Soybean Oil

	Tocopherols		Sterols		Squalene	
Processing step	ppm	% loss	ppm	% loss	ppm	% loss
Crude	1,132	—	3,870	—	143	—
Degummed	1,116	1.4	3,730	3.6	142	0.7
Neutralized	997	11.9	3,010	22.2	140	2.1
Bleached	863	23.8	3,050	21.2	137	4.2
Deodorized	726	35.9	2,620	32.3	89	37.8

Source: Ramamurthi *et al.* (15).

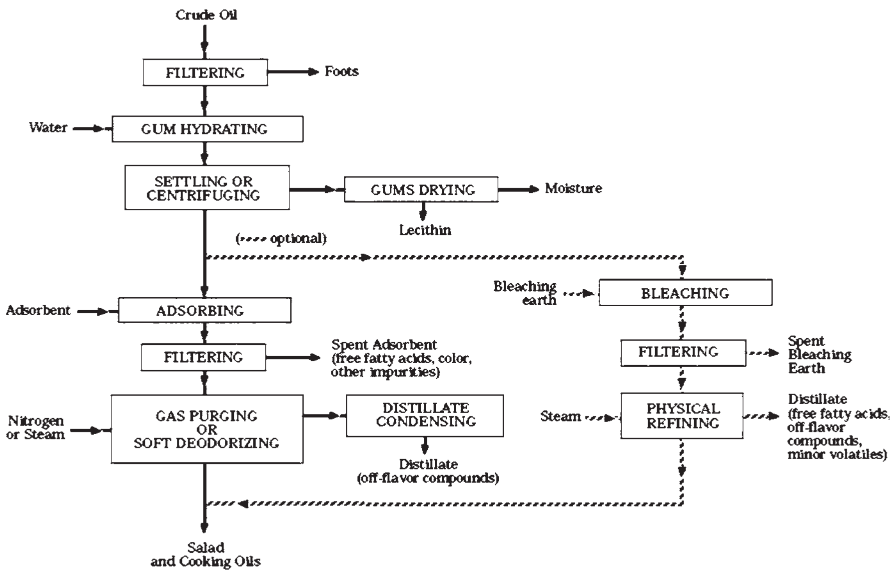

Figure 13.8. Diagram of minimal soybean oil refining. (Courtesy of Center for Crops Utilization Research, Iowa State University.)

minimal refining, whereas the neutralization step of conventional refining appreciably reduced total tocopherol content. Commercial deodorization operations also significantly reduce tocopherol and phytosterol contents in the refined oil (Table 13.3).

Gas Purging Deodorization

Simpler deodorization methods are still needed to achieve good-quality minimally refined oils. Nitrogen (N_2) has been used as a stripping gas to deodorize olive, sunflower, and soybean oils (17–19). There are certain advantages to using N_2 gas versus steam, such as no steam generation requirement and potential recovery of high-quality deodorizer distillates. Wang *et al.* (20) compared compositional and sensory qualities of soybean oils deodorized by different methods.

Degummed commodity oil and high–oleic acid oil were deodorized by direct gas purging (N_2, CO_2, and steam, at 150°C for 1 h under partial vacuum) and by conventional deodorization. These oils were also treated with adsorbents to remove FFAs and then deodorized by purging with various gases. The refined oils were evaluated for their oxidative qualities and sensory properties (Tables 13.4 and 13.5). Sensory evaluation provides information most closely associated with the quality of food lipids. This method is sensitive in that flavor or odor defects may be detected by panelists at lower concentrations that can be recognized by chemical or instrumental methods.

All four deodorization treatments significantly decreased toasty/nutty flavors (Table 13.5). Among the four deodorization treatments, conventional deodorization and

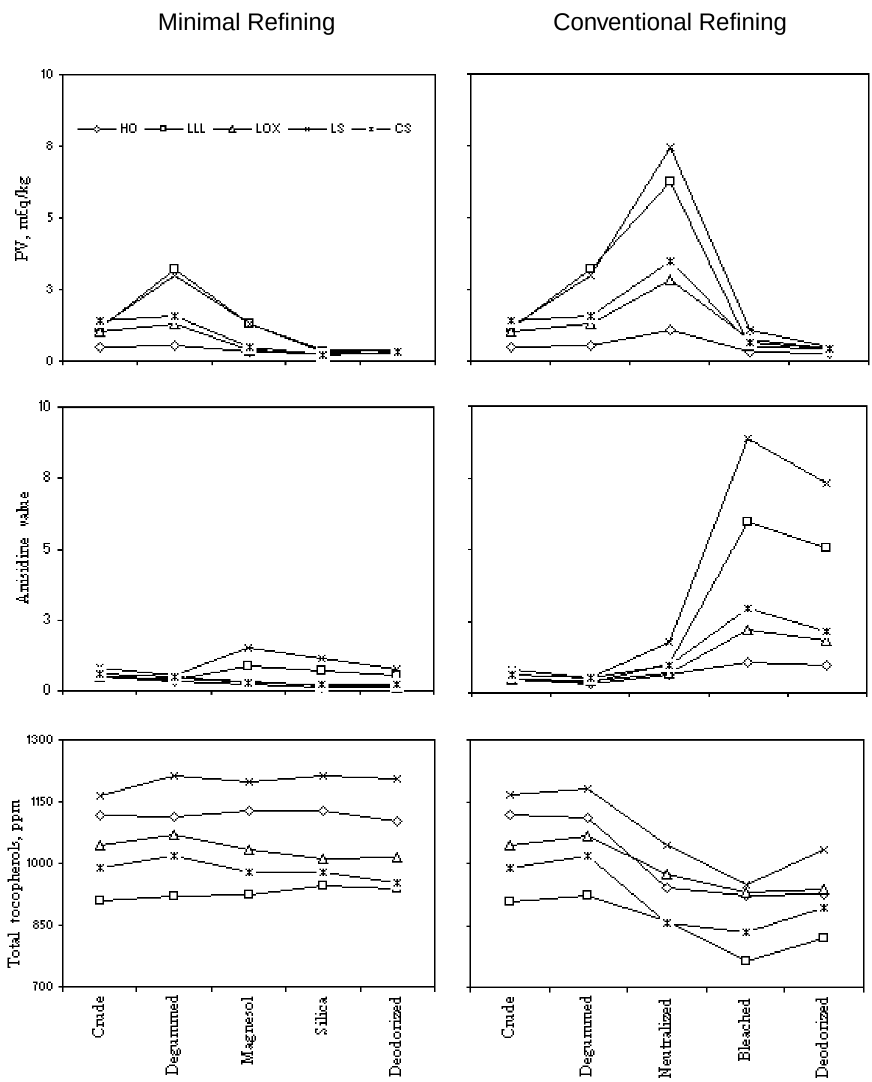

Figure 13.9. Oxidation and tocopherol retention during minimal and conventional refining of various types of soybean oils. CS denotes commodity soybean oil; LOX, lipoxygenase-free soybean oil; HO, high–oleic acid soybean oil; LS, low–saturated fatty acid soybean oil; and LLL, low–linolenic acid soybean oil (16).

gas purging with N_2 and CO_2 were much more effective in removing toasty/nutty flavors than was the use of steam. Compared with N_2, CO_2 seemed to be more effective in removing toasty/nutty flavor. For the two oils at different processing steps, the deodorized degummed oils always had stronger flavor than did the deodorized Magnesol-treated oil. Magnesol adsorption apparently significantly removed off-flavor compounds.

TABLE 13.4
Oxidative Qualities of Soybean Oils after Various Deodorization Treatments

Oil type[a]	Extent of processing	No deodorization	N_2	CO_2	Steam	Conventional deodorization
(a) PV (mEq/kg), $LSD^b_{0.05}$ = 0.13						
CO	Degummed	0.86	0.86	0.71	0.82	0.39
	Deacidified	0.22	0.37	0.49	0.39	0.36
HO	Degummed	0.44	0.52	0.44	0.71	0.30
	Deacidified	0.39	0.32	0.38	0.74	0.16
(b) p-AV, $LSD_{0.05}$ = 0.08						
CO	Degummed	0.14	0.23	0.38	0.25	0.22
	Deacidified	0.14	0.25	0.18	0.25	0.25
HO	Degummed	0.16	0.16	0.14	0.50	0.17
	Deacidified	0.21	0.25	0.17	0.53	0.18
(c) OSI[c] (h, at 100°C), $LSD_{0.05}$ = 1.19						
CO	Degummed	14.0	13.5	12.8	9.9	11.4
	Deacidified	13.2	13.0	11.9	10.0	11.1
HO	Degummed	>70.0	>70.0	>70.0	>70.0	>70.0
	Deacidified	>70.0	>70.0	>70.0	>70.0	>70.0

[a]CO denotes commodity oil and HO denotes high–oleic acid oil.
[b]LSD denotes least significant difference.
[c]OSI denotes oxidative stability index.

Buttery flavor tended to increase after gas-purging deodorization. This change is opposite that for toasty/nutty flavor, possibly because the strong toasty/nutty flavor masked the buttery flavor of the untreated samples. Conventional deodorization and gas purging significantly decreased beany flavor, except for the steam treatment, and the beany flavors of the deodorized oils were not statistically different, indicating that simple gas purging at lower temperature produced good-quality oil. However, degummed and deodorized high–oleic acid oils had much stronger beany flavor than did the commodity oil. The flavor difference between the high–oleic acid and commodity oils may have been due to the differences in their fatty acid compositions. The unique composition of high–oleic acid oil may have made it a good precursor for certain volatiles that were responsible for the flavor observed.

The overall flavor intensity was significantly reduced by conventional deodorization and gas purging. The desirabilities of the oils were also significantly increased. Magnesol-treated oil had better desirability scores (lower values) than did the corresponding degummed oil after deodorization, although Magnesol-treated oil always had a strong unpleasant flavor before deodorization. Magnesol treatment not only removed free fatty acids, but also improved the flavors of the deodorized oils. Gas purging was as effective as conventional deodorization in achieving overall oil quality.

TABLE 13.5
Sensory Evaluations of Soybean Oils after Various Deodorization Treatments[a]

Oil type[b]	Extent of processing	No deodorization	N_2	CO_2	Steam	Conventional deodorization
(a) Toasty/nutty flavor, $LSD^c_{0.05}$ = 2.0						
CO	Degummed	9.5	4.4	2.7	7.8	1.7
	Deacidified	N/A[d]	1.5	1.0	3.4	1.5
HO	Degummed	4.3	2.8	1.8	4.9	2.7
	Deacidified	N/A	1.8	1.7	2.5	1.5
(b) Buttery flavor, $LSD_{0.05}$ = 1.6						
CO	Degummed	1.9	2.7	3.3	1.6	2.6
	Deacidified	N/A	1.9	1.4	1.8	1.9
HO	Degummed	1.2	2.8	2.2	0.8	2.8
	Deacidified	N/A	1.9	2.3	1.5	2.4
(c) Beany flavor, $LSD_{0.05}$ = 1.9						
CO	Degummed	3.3	1.1	1.6	4.0	1.7
	Deacidified	N/A	1.5	2.4	3.4	1.1
HO	Degummed	6.9	3.8	3.0	8.0	4.8
	Deacidified	N/A	2.8	1.5	6.9	1.3
(d) Overall flavor intensity, $LSD_{0.05}$ = 2.0						
CO	Degummed	11.1	5.4	4.5	8.6	3.4
	Deacidified	N/A	2.5	2.6	5.4	2.2
HO	Degummed	10.2	5.3	4.5	10.2	5.1
	Deacidified	N/A	4.0	3.0	7.6	2.4
(e) Desirability, $LSD_{0.05}$ = 2.0						
CO	Degummed	8.7	5.4	6.3	9.6	4.3
	Deacidified	N/A	4.1	5.1	7.0	3.8
HO	Degummed	10.8	7.9	6.4	11.1	8.3
	Deacidified	N/A	6.4	4.3	9.0	3.1

[a]Sensory scores range from 0 to 15, with lower values indicating less strong or more desirable.
[b]CO denotes commodity oil and HO denotes high–oleic acid oil.
[c]LSD denotes least significant difference.
[d]N/A indicates samples had strong unpleasant flavor and were not included in sensory evaluation.

Applications of Minimally Refined Soybean Oil

According to 2000–2001 soybean utilization statistics for the United States (21), 13%, 38%, and 48% of soybean oil produced is used in margarine, shortening, and cooking oil, respectively. Therefore, the applications of soybean oil in cooking and deep-fat frying are very important.

Bread Frying

Deep-fat frying with soybean oil is commonly used for food preparation because of its simplicity and the desirable flavors and textures produced in fried foods. To evaluate frying applications of minimally refined soybean oils, deep-fat frying using white bread cubes and sensory evaluation of the bread cubes were conducted (22).

Degummed commodity oil (DCO), Magnesol-treated commodity oil (MCO), and Magnesol-treated HO (MHO) oil were gas-purged with N_2 at 150°C for 1 h. Bread cubes were deep-fat fried with these oils and a commercial oil (Com) was used as a control. The fried cubes were evaluated at the fresh stage (after frozen storage) and after accelerated oxidation treatment (at 60°C) for sensory properties. These frying oils were also heated for an extended period of time (30 h) and then used to fry another batch of bread cubes. Sensory evaluation was conducted similarly, and the results are summarized in Table 13.6.

Strong toasty/nutty flavors may be produced through the Maillard reaction in the bread cubes, masking the toasty/nutty flavors from the oils. Beany flavor was not affected by any of the treatments. The frying operation itself resembles steam deodorization, and the volatile off-flavor compounds may easily be carried out by the vigorous evaporation of the moisture contained in foods being fried.

Oxidized flavor was significantly affected by oil type and oxidation stage. After accelerated oxidation, bread cubes fried in fresh DCO/N_2 and MCO/N_2 oils were significantly more oxidized than the others. These results correlated with the initial oxidative stability index (OSI) values of the oils. Bread cubes fried in commercial oil after 30 h of heating and accelerated oxidation were significantly more oxidized than the others. It was interesting to note that fresh commercial oil produced more stable fried cubes, but the heated commercial oil produced more unstable fried products compared with those fried in minimally refined E-E oils. The reason may have been the much higher total tocopherol content of the minimally refined oil compared with the commercial oil (950 vs. 500 ppm). After extended heating at high temperature, the tocopherols of commercial oil may have been largely depleted, but significant amounts of tocopherols may have remained in the minimally refined oils. Therefore, when the bread cubes were oxidized under accelerated conditions, the cubes fried in the commercial oil oxidized faster than those fried in the minimally refined oils. Similar trends were observed for overall flavor intensity and desirability. In general, this study showed that minimally refined E-E soybean oils can be used for deep-fat frying and can produce freshly fried products that have sensory qualities similar to those of products fried in conventionally processed commercial oil.

Frying Performance of Physically Refined E-E Soybean Oil

A frying study was conducted at the Food Protein Research & Development Center of Texas A&M University (College Station) to evaluate the frying performance of a non-GM E-E soybean oil refined at the Thumb Oil Processors Cooperatives (TOPC) refinery (Ubly, Michigan), which is a 30-MT/d continuous physical refining plant (Fig. 13.10). The following oils were used in this study: degummed soybean oil, physically refined soybean oil, physically refined soybean oil with 250 ppm of added

TABLE 13.6
Sensory Qualities of Bread Cubes Fried in Various Oils[a]

	No prior heating				
Storage temperature, °C	Com	DCO	DCO/N_2	MCO/N_2	MHO/N_2
(a) Toasty/nutty flavor, $LSD_{0.05}$ = 2.9					
–10	5.8	6.6	5.2	6.4	4.7
60	7.0	7.3	6.0	5.0	5.8
(b) Beany flavor, $LSD_{0.05}$ = 3.0					
–10	3.8	5.3	2.6	2.9	2.4
60	1.7	2.3	3.7	3.0	3.9
(c) Oxidized flavor, $LSD_{0.05}$ = 3.0					
–10	4.0	4.3	2.9	3.4	2.6
60	2.6	3.0	7.2	11.6	3.3
(d) Overall flavor intensity, $LSD_{0.05}$ = 2.7					
–10	6.9	8.4	5.5	6.0	4.4
60	5.6	6.9	8.1	11.5	6.1
(e) Desirablity, $LSD_{0.05}$ = 2.4					
–10	7.0	6.5	5.5	5.4	6.5
60	4.1	4.4	8.6	12.8	4.7

[a]Values are means of 10 replications and represent the distances measured from the left end of the line (the graphic rating scale) to the line marked by the panelist. Sensory scores range from 0 to 15, with a lower value indicating less strong or more desirable.

natural tocopherols, and a commercial liquid frying oil, used as a control, in which chicken strips and French fries were fried.

Four fryers were loaded with 7 L of oil and the temperature was set at 177°C to fry 800 g of chicken strips and 600 g of frozen French fries. The frying time was 3.5 min with 3.0 min draining time between successive frying trials. Fresh oil was added to keep the oil level constant during frying. These conditions were set to simulate frying practice in restaurant/food service situations. A total of 30 frying cycles were carried out for each product.

The values of various quality parameters increased as oil deteriorated with progressive frying. The ratios of the values at final and initial frying cycles were used as indicators of frying life. For example, a ratio of 2.0 for any given parameter indicated a twofold increase in that parameter over the total frying cycle. In the case of OSI, the values decreased with progressive frying. In this case, the ratio of the initial to the final value was used as an indicator of frying life. In all cases, the lower numbers indicate better frying life. Table 13.7 presents frying life indicators calcu-

30 h heating				
Com	DCO	DCO/N_2	MCO/N_2	MHO/N_2
5.5	7.4	6.5	6.4	4.8
5.0	7.2	6.9	7.5	7.3
3.4	2.5	2.9	2.4	3.8
4.1	2.7	2.4	1.9	2.3
4.5	3.9	4.6	3.5	5.9
12.5	4.3	5.3	4.3	5.3
6.9	6.6	6.6	6.6	7.1
11.6	7.3	6.8	6.8	8.4
7.0	6.3	5.5	4.6	8.7
13.8	5.8	6.5	5.5	6.0

Figure 13.10 Physical refining facility of the Thumb Oil Processors Cooperatives (TOPC), located in Ubly, Michigan, which is dedicated to processing non-GM and organic soybeans.

TABLE 13.7
Frying Life Indicators for Oils as Calculated from 30 Consecutive Frying Cycles of Chicken Strips

	Frying life indicator			
Quality test	TOPC degummed oil	TOPC physically refined oil with tocopherols	TOPC physically refined oil	Commercial liquid frying oil
Free fatty acid	2.80	4.46	6.00	7.75
Peroxide value	4.27	4.43	3.22	5.33
p-Anisidine value	22.42	42.15	23.72	30.75
Absorbance at 520 nm	2.06	10.0	16.19	26.36
Color-Lovibond (R)	1.28	2.67	2.67	3.25
Color-Lovibond (Y)	1.35	3.50	3.07	3.75
Polymerized TAG	2.10	2.22	2.55	2.62
OSI	1.12	1.19	1.28	1.32

lated for each of the parameters tested for chicken tenders. Table 13.8 shows the frying life indicators for French fries. For sensory evaluation, the products fried during the first and the last frying cycles were subjected to evaluation by a trained taste panel. Panelists ranked the products on a hedonic scale of 1–10. A rank of 10 indicated "like very much" and a score of 1 indicated "dislike very much."

For frying chicken strips, all TOPC physically refined E-E oils performed better than did the control for most of the quality parameters, except for anisdine value. The trend observed for French fries was very similar to that for chicken strips. *Trans* fatty acid was not detected in any of the four oil types tested.

Sensory analysis showed that both the chicken strips and French fries fried in the first and final frying cycles of the TOPC E-E oils had better sensory scores than

TABLE 13.8
Frying Life Indicators of Oils as Calculated from 30 Consecutive Frying Cycles of French Fries

	Frying life indicator			
Quality test	TOPC degummed oil	TOPC physically refined oil with tocopherols	TOPC physically refined oil	Commercial liquid frying oil
Free fatty acid	2.47	4.00	4.00	6.00
Peroxide value	3.55	4.43	3.78	5.33
p-Anisidine value	45.48	32.69	17.36	22.69
Absorbance at 520 nm	1.92	9.35	12.85	25.45
Color-Lovibond (R)	1.22	2.83	2.67	8.75
Color-Lovibond (Y)	1.50	5.00	3.67	4.50
Polymerized TAG	1.90	2.06	3.14	4.05
OSI	1.02	1.02	0.96	1.01

those fried in the commercial oil. Physically refined E-E oil produced from this facility gave excellent frying performance.

Conclusions

E-E processing and low-cost refining procedures offer opportunities for small farmer cooperatives to produce value-added soybean products. In the past, small E-E producers lacked marketing clout with large oil refineries, and these refineries usually purchased the small and infrequent loads at discounted prices despite their oils being of good and possibly superior quality. Coupling these new small-scale soybean processing technologies with identity preservation to take advantage of specialty markets or specialty products offers unique opportunities that may not be filled by the large-scale operations designed to process commodity soybeans and focused on producing commodity products.

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