

# Processing of Soybean Oil for Food Uses

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Soybean oil is the major edible oil in use in the United States and is a labeled ingredient of premium food products. This has not always been true. In the early 1940s, soybean oil was considered a poor oil for industrial paints and not suitable for edible use. During World War II, due to shortages of other fats and oils, it was added to margarines with an absolute limit of 30%. The transformation of soybean oil from a minor edible oil in the 1940s to the dominant edible oil of the 1980s occurred through the cooperation of government research and industrial implementation of research findings (1).

## Research History

The first significant milestone in this research was the development of objective methods to assess flavor and odor (2,3). Use of these identified the susceptibility of soybean oil to oxidative deterioration catalyzed by trace metals—as little as 0.3 ppm of iron or 0.01 ppm of copper (4). Industry responded by the removal of brass valves in refineries, installation of stainless steel deodorizers, and blanketing oils with inert gas (nitrogen) at all high-temperature steps and in final packaging. Citric acid added to oil in the deodorizer was also found to retard flavor deterioration, and the industry immediately adopted this or other methods of metal deactivation (4). Early in the 1950s, taste panel research further identified the precursor of soybean oil off-flavors as the 7% linolenic acid component, which was highly susceptible to oxidation (1). The immediate solution to minimizing the amounts of linolenic acid present was nickel-catalyzed hydrogenation. This, in combination with a winterization process, produced a soybean salad oil containing only about 3% linolenic acid, which was marketed in the early 1960s as a specially processed soybean oil and essentially captured the U.S. edible oil market in the next few years.

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More recent research has shown that antioxidants are ineffective for enhanced storage stability of soybean oil, with the result that soybean-based salad/cooking oils are now formulated without antioxidants (5). Unhydrogenated oils have been shown to be stable during storage and use at room temperatures, leading to the marketing of "natural" soybean salad oils (5). In terms of packaging, soybean salad and cooking oils have been shown to be stable when packaged in plastic containers (6), and the industry has rapidly eliminated glass bottles. Other research having significant potential for future industrial response includes the use of ultrasonic energy during hydrogenation, which permits major reduction in the amount of nickel catalyst used in the process (7), and the addition of ppm quantities of beta-carotene to finished soybean oil for enhanced stability to light-initiated flavor deterioration (8). Finally, the most recent milestone is the success of an extended breeding program to modify the fatty acid composition of soybean oil (9). Low-linolenic-acid oils extracted from new genotypes have been shown to have improved room odor characteristics in sensory panel tests with commercial soybean cooking oils (10).

## Soybean Oil Processing

Processing of soybean oil is designed to convert the crude oil as extracted from the bean into a finished product free of impurities and amenable to a variety of food formulations. Traditionally, oils have been processed through stages of degumming, alkali refining, bleaching, and deodorization. Hydrogenation of the oil is practiced to improve stability and

modify the physical nature of the oil from a liquid to a solid.

**Degumming.** The principal method of degumming employed in the United States is a batch treatment of the oil with 1–3% of water, based on oil volume (11). The mixture is agitated for 30–60 min at 70–80°C. The hydrated phosphatides and gums are separated by centrifuging. About 90% of the phosphatides are removed from the oil by water degumming (12). Although most of the remaining phosphatides are removed during alkali refining, vegetable oils often contain some phosphatides that are not removed by hydration. Most commercially produced oils will contain less than 5 ppm phosphorus.

**Refining.** Refining of vegetable oils is practiced to remove free fatty acids, phosphatides and gums, pro-oxidant metals, coloring matter, insoluble matter, settlings, and miscellaneous unsaponifiable materials. The treatment has little effect on the triglycerides of the oil. The first step in the conventional process is called caustic refining (Fig. 1). A crude oil to be caustic refined is usually treated with 300 to 10,000 ppm of food-grade 75% phosphoric acid at ambient temperature at least 4 hr prior to the refining step to increase the efficiency of phosphatide removal during caustic refining (11). Oil refining is usually a continuous process. A 15 to 20% sodium hydroxide solution, based on the free fatty acid content of the oil plus 0.10–0.13% excess, is proportioned into the crude oil, mixed in a high shear in-line mixer, and then held for 3 to 15 min in a slow-speed mixer. The soap-oil mixture is heated to 75–80°C and then separated

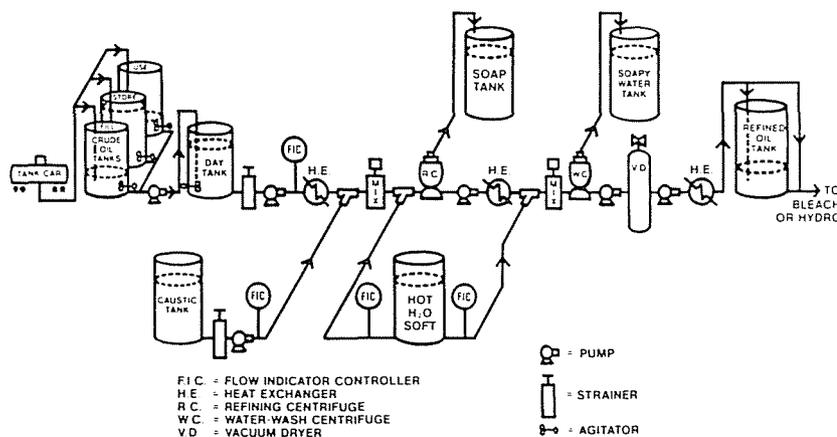


Fig. 1. Flowsheet for alkali refining. Source: Carr (13).

into refined oil and soapstock by centrifuging. Refined oil is washed once or twice with 10–20% (w/w) of soft water at 90°C.

**Bleaching.** Bleaching of alkali-refined oils removes entrained soaps and reduces color bodies in the oil; it is more appropriately referred to as adsorption treatment. Batch or continuous vacuum bleaching is generally practiced; this consists of agitation of the oil with 0.5–1.5% acid-activated earth at 90–95°C for 15–30 min at a high vacuum (3.10 mm of Hg absolute pressure), followed by filtration to give a clean, clear oil. It has been suggested that bleaching removes peroxides and secondary oxidation products and that this added function is responsible for the improvement in flavor scores that is actually observed (14). Such removal is by chemisorption and subsequent chemical reaction on the surface of activated clays, involving decomposition and dehydration or pseudoneutralization of peroxides. Careful selection of the type of bleaching clay can give a bleached oil having a peroxide value of zero for subsequent deodorization.

**Deodorization.** Deodorization is the last process step used to improve the taste, odor, color, and stability of the oil by removal of undesirable substances (Fig. 2). All commercial deodorization, whether in continuous, semicontinuous, or batch units, is essentially a steam-stripping of the oil for removal of free fatty acids and other volatile materials. Deodorization is conducted at 1–6 mm Hg and 210–274°C for 3–8 hr in batch, or 15–120 min in continuous or semicontinuous units, with 5–15%, or 1–5% stripping steam, respectively (15). The goal of deodorization is to produce a finished oil that has a bland flavor, a maximum free fatty acid content of 0.05%, and a zero peroxide value. The deodorization process will not produce a good quality finished oil unless the previous treatment of that oil was correct. As mentioned previously, citric acid is now added to the oil at the cooling stage in the deodorizer to protect it against oxidation by chelating pro-oxidant metals.

After deodorization, all soybean oils are subject to oxidation when the oil is in contact with air, whether or not hydrogenated. Finished oils are generally packaged with nitrogen sparging or blanketing. Crude oils processed from normal soybean refine satisfactorily and give high-quality salad oils after bleaching and deodorization. Such oils are bland, or have mildly beany, buttery, or nutty flavors, and will receive flavor scores in the 7 to 8 range on a 10-point flavor-intensity scoring scale where 10 represents the extreme in blandness. A flavor score of 6 is generally considered the breakpoint between satisfactory and unsatisfactory oils.

**Hydrogenation.** When soybean oil is to be used as a cooking oil or in the formulation of margarines and shortenings, it must be partially hydrogenated to improve high-temperature stability and to physically harden the oil (16). Most hydrogenations are performed as batch processes; however, continuous systems have been patented and are in use (17). Conditions of hydrogenation range from 0.01 to 0.1% Ni catalyst at 140–225°C and at pressures of 0.05–0.60 MPa. Soybean oil is generally hydrogenated to an iodine value of 110–115 for use as a cooking oil, 80–90 for margarine base stock oil, and 60–70 for shortenings (18).

Partial hydrogenation of edible oils is practiced to increase stability by the selective reduction of linolenic acid. Commercially, a dual purpose salad/cooking oil is prepared by hydrogenation of soybean oil with Ni catalysts under selective conditions, such as 35 to 97 × 10<sup>5</sup> Pa, with 0.05% catalyst at 177°C. The oil is hydrogenated to an iodine value of 110 to 115 and must be winterized to meet the requirements of the standard American Oil Chemists Society cold test (19). This test calls for the oil to remain clear for a minimum of 5.5 hr at 0°C. Stearine, high melting glycerides, and palmitic and stearic acid fractions are removed by the winterization process (20). Oil is chilled slowly to about 6°C during a 24-hr period; cooling is then stopped and the oil/crystal mixture allowed to stand for 6 to 8 hr. The yield of liquid oil is approximately 75 to 85%. By-product stearine is generally used for shortening manufacture. Although lowering of the linolenic acid content does provide increased stability during use of soybean oil as cooking oil, it is still only a partial solution to the problem, and thermal oxidation will eventually produce objectionable odors and flavors.

**Lecithin.** An important by-product of soybean oil processing is the “lecithin” which is obtained during the degumming of the oil. The sludge which is obtained from the degumming centrifuges contains 40 to 50% water, and is dried to a moisture content of about 1% in continuous, agitated-film evaporators, operating on either a vertical or horizontal axis. The horizontal axis type is preferred since the tendency for the lecithin film to break is reduced (21). The commercial soybean lecithin produced contains about 35% soybean oil and 65% phosphatides, carbohydrates, and moisture (22).

Lecithins are used in many food applications in which advantage is taken of their surface-active effects. Lecithin products have both a lipophilic and a hydrophilic group in the same molecule and therefore act at the boundary between immiscible materials (23). The major functions of lecithin in food uses are in colloidal dispersion, wetting,

lubrication and release, crystallization control, and starch complexing.

## Shortenings

In the United States, soybean oil constitutes about 64% of the fat used in the manufacture of shortening, while the other major fats (24%) are edible tallow and lard (24). Shortenings are used in the preparation of many foods, and in particular to impart a tender quality to baked goods, enhance the aeration of leavened products, and promote a desirable grain and flavor. They also assist in the development of flakiness in products such as pie crusts, Danish, and puffed pastry products; modify the gluten, particularly in the development of yeast-raised doughs; and act as emulsifiers for the retention of liquids (25). Shortenings perform two chief functions in baked goods: leavening and creaming, and lubricating. In icings and fillings, large volumes of air bubbles are entrained, producing a fine, delicate structure. Large quantities of shortenings are used in frying, by deep fat and by pan and grill methods. Fats play a dual role by aiding in the transfer of heat to the food being fried and by being partially absorbed by the food, contributing to nutritive value and to flavor and texture.

**Steps in Shortening Manufacture.** The basic steps in shortening manufacture include preparation of the individual base stocks and hard fats, formulation of the fat blend and other ingredients, solidifying and plasticizing the fat blend, packaging, and tempering when necessary. Tempering generally is limited to the plastic shortenings and margarines used for baking.

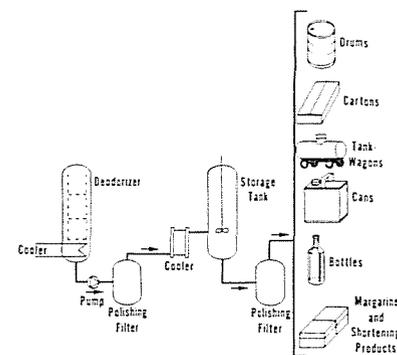


Fig. 2. Deodorization and packaging.

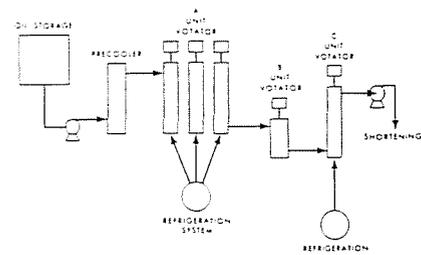


Fig. 3. Flowsheet for plasticizing fats. Source: Thomas (26).

**Solidifying and Plasticizing.** As outlined in Figure 3, plastic shortenings generally are solidified and plasticized in Votators or other scraped-surface heat-exchanger equipment (often referred to as the A units) (26). The melted fat plus optional ingredients are chilled rapidly from 46–49°C (115–120°F) to 16–18°C (60–65°F) in one or more A units to produce numerous nuclei for crystal formation. The supercooled melt then is piped to a worker-type B unit wherein the shortening is agitated as the crystals grow and the mass partially solidifies. From 10 to 20% (v/v) air or an inert gas is added and dispersed in the shortening as small bubbles. In this form, the air improves the whiteness of the product and sometimes contributes to its creaming ability. The plastic mass is pumped through a homogenizing valve and then to package fillers. The packages vary in size from 0.45-kg (1-lb) tins that are

sealed after filling to open-end 172-kg (380-lb) drums with covers.

**Tempering** consists of holding the shortening for 24 to 72 hr in a room maintained at a constant temperature, usually somewhere between 27 and 32°C (80–90°F). The holding time is determined by factors such as container size and type of shortening. Crystallization continues slowly during the tempering step. Tempering stabilizes the crystal structure against changes that might otherwise occur during subsequent temperature variations encountered in normal handling and storage.

### Margarines

Margarine, originally developed as a butter substitute, is recognized as a high-quality, nutritious product available in several forms for table use, and is no longer considered a substitute (27). Regular margarine contains 80% fat and

about 16 to 18% aqueous phase. Cow's milk, pure water, or water plus some edible protein—such as nonfat dry milk solids or soybean protein—may constitute the aqueous phase (28). Other ingredients are 2–3% salt (except for salt-free margarine); emulsifiers, such as mono- and diglycerides and/or lecithin; preservatives; flavoring; coloring (usually beta-carotene); fortifiers (e.g., 15,000 USP units of vitamin A and sometimes 2,000 USP units of vitamin D); and optional ingredients such as butter, nutritive sweeteners, and fat antioxidants.

Until 1955, stick or brick-type margarines were the only table-grade products available. By 1976, these constituted only 22% of the market and several other types of margarine and manufactured spreads were available. As indicated in Table I, products for the consumer retail market dominate margarine production.

**Steps in Margarine Manufacture.** The basic steps in margarine manufacture, as outlined in Figure 4, include formulating the margarine oil blend, preparing the aqueous phase, preparing the emulsion, solidifying the emulsion and controlling its plasticity, packaging, and tempering the packaged margarine if necessary.

**Formulating the oil blend.** The melting point, fatty acid composition, and structure of the individual triglycerides influence the structural, nutritional, and lubricity aspects of the margarine. Stick margarines usually are made from a blend of two or three intermediate fats, or of a low-iodine-value fat and a liquid oil. Soft and fluid margarines contain progressively higher proportions of liquid oil. The fats and oils selected for the margarine oil blend are mixed in the proper proportions, heated to 38°C (100°F) or higher, and the oil-soluble ingredients added. These additives include emulsifiers, usually mono- and diglycerides and sometimes lecithin, plus specified amounts of vitamins and desired flavoring and coloring ingredients.

**The aqueous phase.** The aqueous phase is prepared separately. A milk phase is prepared by adding dried protein such as whey or nonfat dry milk solids to water and culturing, then pasteurizing and cooling the mixture. Water-soluble ingredients, usually salt and preservatives, are also added (14).

**Preparing and cooling the emulsion.** The oil formulation, the manner and degree of super-cooling the emulsion, and the extent of mechanically "working" the supercooled emulsion during the crystallizing stage are all used to control margarine plasticity. If the emulsion is rapidly supercooled and allowed to solidify without agitation, the resulting margarine will become quite firm and have a narrow plastic range, but the plastic range can be extended by mechanically working the emulsion while the fat is crystallizing from the super-

Table I. U.S. Margarine Production in 1985<sup>a</sup>

Type of Margarine	Quantity (thousands of tons)	Percent of Total
Consumer retail products		
Sticks, 1/4 lb. (0.11 kg)	503.8	
Soft tubs, 1 lb (0.45 kg)	134.8	
Country patties	10.4	
Solids or rolls	64.4	
Spreads	220.4	
Diet and imitation, all sizes	43.5	
Subtotal, consumer retail	977.3	82.3
Food service products		
Solids or rolls, 1 lb (0.45 kg)	72.6	
Individual servings	14.9	
Subtotal, food service	87.5	7.4
Bakery and industrial products		
Bulk sizes over 1 lb (0.45 kg)	96.7	8.2
Total production	1180.6 <sup>b</sup>	100.0

<sup>a</sup>National Association of Margarine Manufacturers based on data reported by U.S. Bureau of Census (personal communication, 1986).

<sup>b</sup>The sum of margarine packaged by package sizes does not agree with the total production because some margarine is not packaged during the same month in which it is produced.

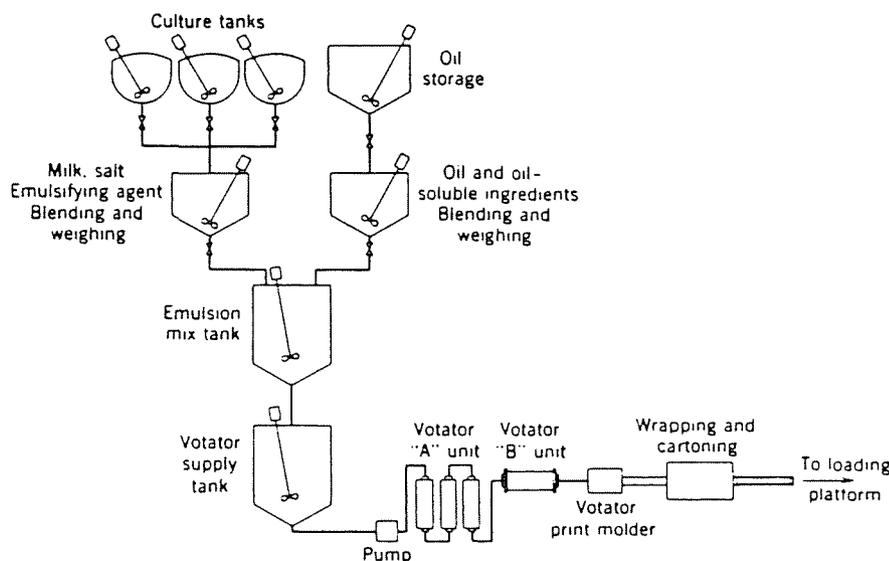


Fig. 4. Flowsheet for semicontinuous margarine production. Source: Wiedermann (14).

cooled state (14).

In the batch-continuous process, the oil and aqueous phases are prepared in separate tanks, then blended; the resultant emulsion is solidified on a continuous basis, as will be described later. Blending of the two phases is done in a premix tank that often is referred to as a churn. Holding time in the churn is kept to a minimum because the temperature (30°C) is ideal for bacterial growth. If automatic proportioning equipment is used, the two phases can be prepared on a continuous rather than a batch basis if proper temperature control is employed. Most margarine manufacturers in the United States prefer to weigh the major ingredients into the churn (29). The oil and aqueous phases are emulsified to the proper degree as, or just before, the blend enters the first of three heat-exchange chilling tubes of the continuous processing unit. Water in the emulsion is dispersed as droplets and then kept from coalescing by the emulsifiers. The emulsion is cooled in a matter of 5 to 10 seconds by refrigerant in the jackets of the heat exchangers. Scrapers continually remove solidified fat from the inner wall of the heat exchangers (often referred to as the A units) to promote rapid heat transfer. Small crystals form as the emulsion is supercooled (e.g., to 45–50°F or 7–10°C).

**Stick-type margarine.** For regular (stick-type) margarine, the supercooled-but-still-fluid melt is piped to either of twin crystallizers, referred to as B units. These are enlarged cylinders wherein the emulsion remains stationary (typically for about 2 min) until crystal development proceeds to a point where the product is sufficiently firm to withstand the forces applied in extruding, shaping, and wrapping in high-speed, automatic machinery. The emulsion can remain stationary in one of the twin crystallizers while the other is being filled. The temperature increases several degrees in the B unit because of the heat of crystallization.

**Whipped and Soft Tub Margarines.** Whipped margarines are produced by incorporating nitrogen into the emulsion ahead of one of the heat exchangers or at the suction side of the feed pump, followed by vigorous mixing in the B unit to limit the extent of crystal development. For this process, the B unit is a worker-type crystallizer with radial pins on a rotating central shaft that intermesh with stationary pins protruding from the cylinder wall. The soft, semifluid mass is packaged immediately in specially designed machines that squeeze out little or none of the nitrogen. The gas increases the margarine's volume by 50% and makes it softer and easier to spread at refrigerator temperatures. Soft tub margarines containing as much as 70 to 80% liquid oil are produced by chilling the emulsion in a single A unit and then

mixing the chilled mass in a large, agitated crystallizer to prevent the fat crystals from growing into a firm network. The soft, fluid margarine is packaged in plastic tubs by a liquid-filling machine, then tempered by holding 24 hr or more at about 7°C (45°F), so that the crystal structure can become fully developed and stabilized (29).

#### Other Food Uses

As indicated in Table II, salad and cooking oils constitute the largest single volume usage of soybean oil. In addition to the partial hydrogenation already referred to, blending soybean oil with an

oil containing little or no linolenic acid such as cottonseed oil, is also done to lower the linolenic acid content (30). Some dual-purpose salad/frying oils contain an antifoaming agent, usually a silicone compound (31,32).

Soybean oil is the major oil used in mayonnaise and prepared salad dressings. Most mayonnaises contain 77 to 83% oil (33). A thicker product containing 80 to 84% oil is often used in institutions. While oil is the major component, mayonnaise is an oil-in-water emulsion—that is, the oil is the dispersed rather than the continuous phase. Prepared salad dressings use mayonnaise as the base and include other ingredients such as minced

Table II. Fats and Oils Used in the Foods in the United States in 1986<sup>a,b</sup>

	Shortening (Baking and Frying Fats)	Margarine	Salad and Cooking Oil	Totals, by Type of Fat or Oil
Vegetable Oil				
Soybean	3,440	1,735	4,686	10,004
Corn	113	200	524	834
Cottonseed	202	...	373	627
Palm	303	60	...	364
Peanut	333	...	137	137
Sub total	4,392	1,995	5,720	11,969
Meat Fat				
Edible Tallow	1,016	...	...	1,021
Lard	299	59	...	355
Sub total	1,315	59	...	1,376
Totals. All Fats and Oils, by usage	5,707	2,054	5,720	13,345

<sup>a</sup>Source: Institute of Shortening and Edible Oils (22).

<sup>b</sup>Usage stated in millions of lb.

onions, minced green peppers, chopped stuffed olives, hard-cooked eggs, or chili sauce (34). Imitation mayonnaises contain considerably more water and only 14 to 40% oil. Spoonable salad dressings must contain at least 30% oil. Both of these products use a starch paste as a thickener (33,35). Most commercial pourable salad dressings contain 55 to 65% oil, whereas low-calorie dressings have a low oil content in the range of 4 to 14% (36).

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