

# Processing and Utilization

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## I. INTRODUCTION

The utilization of soybeans began in the Orient where both medicinal and food value was assigned to this legume. Various types of foods were prepared from it including beverages, pastes, curds, and fermented flavorants, some

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resembling milk, cheese, and meat. Soybeans were believed to be necessary, along with five other grains, for the existence of the Chinese civilization.

Processing of soybeans into oil and meal started in relatively recent times. Demand for the soybean cake by Japan after 1895 for use as a fertilizer resulted in a sudden demand for this product. The defatted cake was the principal product of the oil mill industry. Although processed soybean oil and meal were introduced into Europe in the 1700's, little interest developed until after the Russo-Japanese War (about 1908) primarily because of its inferior quality compared to the native oil and meal products.

Soybeans were introduced to the Eastern United States in the late 1800's. Production spread to the midwest by 1920. Through the early 1930's, the soybean was grown primarily as a pasture and forage crop. By 1947, however, 85% of the crop was harvested for further processing of the seed.

The initial processing of soybeans into oil and meal consisted of simply pressing the oil from the seed. Solvent extraction of the oil then was found to be a more efficient method for oil recovery and was later adopted.

Soybeans in the United States were considered primarily as an abundant source of inexpensive, edible oil. The oil was used in products such as salad dressings and shortenings where the source of the oil could be hidden. Today, soy oil supplies approximately 60% of the edible oils needs of the United States. The defatted soybean meal served initially as a fertilizer and cattle feed. Its nutritional value in swine and poultry feeding was recognized after World War II and has been used extensively. Today, most of the meal is utilized in animal feeds.

Processing of defatted meal into edible protein products has been limited. The utilization of soybean protein products in human foods is expected to increase dramatically, however, because of the population pressure on the food supply. Apparent consumer acceptance of soybean proteins in foods was demonstrated during the food shortage of 1973-1974. Products such as meat

TABLE I

The Proximate Composition of Soybeans and Seed Parts<sup>a</sup>

|                | Percentage of<br>whole | Protein | Fat | Carbohydrate | Ash |
|----------------|------------------------|---------|-----|--------------|-----|
| Whole soybeans | —                      | 40      | 21  | 34           | 4.9 |
| Cotyledon      | 90                     | 43      | 23  | 29           | 5.0 |
| Hull           | 8                      | 9       | 1   | 86           | 4.3 |
| Hypocotyl      | 2                      | 41      | 11  | 43           | 4.4 |

<sup>a</sup> Wolf and Cowan (1971).

analogues, meat extenders, and dairy substitutes met a receptive market. Functional soy proteins having emulsification, aeration, and texture building properties are now being used by various food processors in bakery, dairy, and meat products.

The following is a general review of the processing and utilization of soybeans. An attempt is made to provide basic information on the commercially important constituents of the soybean and on the conversion of those constituents into marketable products. The review is divided into composition, processing, and utilization sections.

## II. COMPOSITION OF THE SEED

### A. Proximate Composition

The soybean seed consists of proteins, lipids, carbohydrates, and minerals. The proteins and lipids are the principal parts of commercial interest, accounting for approximately 60% of the seed. These reside mainly in the cotyledon as shown in Table I. Variations, caused by both environmental effects and varietal differences, result in protein levels ranging from 30 to 46% and in oil from 12 to 24%.

The bulk of the protein resides in storage sites called protein bodies or aleurone grains. These subcellular structures are 2–20  $\mu\text{m}$  in diameter and are nearly 75% protein. Protein bodies account for 60–70% of the total protein in the seed. The lipids are concentrated in spherosomes dispersed among the protein bodies and are 0.2–0.5  $\mu\text{m}$  in diameter.

### B. Protein Composition

The amino acid composition of defatted soy flour is shown in Table II. Based on human requirements, the essential amino acids are equal to or exceed the levels found in egg protein except for the sulfur-containing amino acids. Methionine is the first limiting amino acid. There are little or no significant differences in the amino acid composition among the soybean cultivars. Soy protein has a high lysine content when compared to most other plant proteins and can be used to increase the nutritional value of plant protein combinations.

Most of the soybean proteins are globulins that are insoluble at their isoelectric point but solubilize upon addition of salt. The isoelectric point occurs at pH 4.2–4.6. Extraction of soy flour with water near neutral pH followed by ultracentrifugation resolves the proteins into four major fractions based on their sedimentation coefficients: 2, 7, 11, and 15 S. Each fraction

TABLE II

Amino Acid Composition of Soybean Protein<sup>a</sup>

| Essential amino acids | Meal | Nonessential amino acids | Meal |
|-----------------------|------|--------------------------|------|
| Lysine                | 6.9  | Arginine                 | 8.4  |
| Methionine            | 1.6  | Histidine                | 2.6  |
| Cystine               | 1.6  | Tyrosine                 | 3.9  |
| Tryptophan            | 1.3  | Serine                   | 5.6  |
| Threonine             | 4.3  | Glutamic acid            | 21.0 |
| Isoleucine            | 5.1  | Aspartic acid            | 12.0 |
| Leucine               | 7.7  | Glycine                  | 4.5  |
| Phenylalanine         | 5.0  | Alanine                  | 4.5  |
| Valine                | 5.4  | Proline                  | 6.3  |
|                       |      | Ammonia                  | 2.1  |

<sup>a</sup> Grams amino acid per 16 grams nitrogen. Rackis *et al.* (1961).

includes all proteins having similar sedimentation rates. The general composition of each is given in Table III.

The 2 S fraction predominates during early seed development, but by 23 days after flowering the ultracentrifuge pattern is similar to that of the mature seed. At least five proteins have been shown to be present in the 2 S fraction, making up about 20% of the seed protein.

The 7 S fraction represents slightly over one-third of the total soluble proteins. The 7 S globulin, about one-half the 7 S fraction, is a glycoprotein consisting of twelve glucosamine and thirty-nine mannose residues per

TABLE III

Approximate Amounts and Components of Ultracentrifuge Fractions of Water-Extractable Soybean Proteins<sup>a</sup>

| Fraction | Percentage of total | Components         | MW              |
|----------|---------------------|--------------------|-----------------|
| 2 S      | 22                  | Trypsin inhibitors | 8,000-21,500    |
|          |                     | Cytochrome c       | 12,000          |
| 7 S      | 37                  | Hemagglutinins     | 110,000         |
|          |                     | Lipoxygenases      | 102,000         |
|          |                     | $\beta$ -Amylase   | 61,700          |
|          |                     | 7 S Globulin       | 180,000-210,000 |
| 11 S     | 31                  | 11 S Globulin      | 350,000         |
| 15 S     | 11                  | —                  | 600,000         |

<sup>a</sup> Wolf and Cowan (1971, p. 35).

mole. The 7 S globulin consists of nine subunits which dissociate into 2 S and 5 S proteins at low salt concentrations and pH. At high pH, the 7 S globulin will dissociate into a 0.4 S protein. Disulfide-linked polymers will form with the 7 S globulin resulting in insolubilization of the protein. These occur both in the meal and in pure protein preparations. Mercaptoethanol is used to prevent the disulfide polymerization in laboratory preparations.

The 11 S fraction makes up about one-third of the total soy protein and has only one protein component. It is, therefore, the major protein of soybeans with a molecular weight of 350,000. Twelve subunits, both acidic and basic with approximately 22,300-37,200 MW, make up the 11 S protein. The 11 S fraction can be easily prepared by making a concentrated water extract of soybean meal at 25°-40°C, then cooling the extract to near 0°C. The precipitate that forms is 69-88% 11 S fraction.

The 15 S fraction is only one-tenth of the total protein and may be a polymer of other proteins. Molecular weights of a half million or more have been found. The 15 S protein is also precipitated by chilling of water extracts, as with the 11 S protein.

Soybean proteins are denatured by heat, extremes in pH, and by organic solvents and detergents. During heating at 100°C, the protein approaches a minimum solubility, after which the solubility increases with continued heating. High molecular weight aggregates are formed during heating with gels appearing at protein concentrations near 8%. At 8-12% concentration, the gels will break down at 125°C.

Decreasing the pH of soy protein solutions from 3.8 to 2.0 results in the formation of 2-3 S and 7 S fractions. This is dependent upon the ionic strength. Aggregation appears to be more sensitive to ionic strength in the acid pH ranges. The tendency of the 11 S to dissociate into subunits is counteracted by increasing ionic strength. At pH 12, 14.5% protein solutions form gels. The protein mixtures assume a 3 S sedimentation rate.

Pure organic solvents are less effective in denaturing soy proteins than their aqueous solutions. Alcohols denature the protein more effectively as hydrocarbon chain length increases. The 7 S fraction appears to be the most sensitive to alcohol and the 2 S the least sensitive.

### C. Enzymes

The enzymes found in soybeans are listed in Table IV. Commercially, the lipoxygenases are considered of major importance. These catalyze the oxidation of lipids, forming fatty acid hydroperoxides. The hydroperoxides undergo scission and dismutation resulting in the development of off-flavors and aromas. The lipoxygenases are specific for lipids containing a *cis*, *cis*,-1,4-pentadiene system. Only the 13-hydroperoxide is formed with linoleic

TABLE IV

Enzymes Found in Soybeans<sup>a</sup>

|                              |                       |
|------------------------------|-----------------------|
| Allantoinase                 | Lipoperoxidase        |
| Amylases                     | Lipoxygenase          |
| Ascorbicase                  | Malic dehydrogenase   |
| Chalcone—flavanone isomerase | $\alpha$ -Mannosidase |
| Coenzyme Q                   | Peroxidase            |
| Cytochrome <i>c</i>          | Phosphatases          |
| Glycosyltransferase          | Phosphorylase         |
| Hexokinases                  | Transaminases         |
| Lactic dehydrogenase         | Urease                |
| Lipases                      | Uricase               |

<sup>a</sup> Smith and Circle (1972, p. 159).

acid as the substrate. The 9-hydroperoxide isomer is formed as a result of autoxidation. At least four lipoxygenases are present; two of the lipoxygenases are specific for free fatty acids. Crystalline lipoxygenase from soybeans has been reported to contain no prosthetic group and requires no metal activator or coenzyme. Recent evidence indicates a requirement for an iron activator.

Hydroperoxides, formed as a result of lipoxygenase activity, readily bleach carotenoid pigments through a coupled, free radical mechanism. The bleaching effect of lipoxygenase is utilized in the bleaching of bread dough by incorporation of enzyme active soy flour. Up to 0.5% soy flour, based on weight of the bread flour, is used in white bread. This is the only commercial application of the enzymes in soybeans.

Other lipid related enzymes present are lipoperoxidase and lipases. Lipoperoxidase activity destroys fatty acid hydroperoxides and is similar to cytochrome *c* in that preformed linoleate hydroperoxide is used to bleach  $\beta$ -carotene. Lipases catalyze the development of free fatty acids. Soybeans contain two separate lipases. These hydrolyze soybean oil at a faster rate than other vegetable oils.

The  $\alpha$ - and  $\beta$ -amylases of soybeans show greater activity to highly branched carbohydrates. Immature seeds contain only 34% of the amylase activity of mature seeds. Their function in mature soybeans is unknown since mature soybean seeds reportedly do not contain starch. Starch, however, may be present. Commercial utilization of the amylases is prevented because of difficulty in isolating pure amylases from the soybean.

Both water-soluble and -insoluble proteases are present in soy. Extraction of the proteases require vigorous agitation during extraction to free the proteases from the meal. The proteases exhibit papain-like activity, acting on

interior peptide bonds of proteins. None have been found having trypsin-like activity.

Urease activity, which catalyzes the hydrolysis of urea to ammonia and carbon dioxide, varies with cultivar and growth conditions. Its activity also increases with maturation. Urease is readily inactivated by moist heat and is used as a guide to determine the degree of heat treatment given to the various soy products.

#### D. Lipid Composition

The lipids of soy include both the triglycerides and phospholipids. Minor components that are lipid-soluble include pigments, tocopherols, sterols, and triglyceride-derived products. Lipids have been, traditionally, the most commercially important constituent of soybeans.

The triglyceride portion represents approximately 95% of the hexane extractables from the seed. The fatty acid composition is shown in Table V. The iodine value of the oil varies with cultivar and climatic environment during growth. The average iodine value is 130. Iodine values as low as 103 to as high as 152 have been found.

Soybean oil belongs to the linolenic acid group of oils along with linseed and hempseed oil. The glyceride composition conforms to an even distribution pattern. The triglycerides, then, each contain two unsaturated fatty acids based on the fatty acid composition. Randomization of the fatty acids increases the melting point of soybean oil.

TABLE V  
Fatty Acid Composition of Soybean Oil<sup>a,b</sup>

| Fatty acid  | Percentage |
|-------------|------------|
| Myristic    | 0.1        |
| Palmitic    | 11.0       |
| Palmitoleic | 0.1        |
| Stearic     | 4.0        |
| Oleic       | 23.4       |
| Linoleic    | 53.2       |
| Linolenic   | 7.8        |
| Arachidic   | 0.3        |
| Behenic     | 0.1        |

<sup>a</sup> Saponification value range, 188-195; iodine value range, 125-138.

<sup>b</sup> From Durkee Industrial Foods Group (1970).

Soybean oil has a tendency to develop off-flavors when exposed to air or light. The development of off-flavors is caused by autoxidation and is referred to as "reversion." The flavors have been described as grassy, fishy, or painty. The major precursor is linolenic acid. A large number of compounds develop during reversion. Some that occur are 2-pentylfuran, ethyl vinyl ketone, pentanol, 4-*cis*-heptanol, 3-*cis*-hexanol, and diacetyl.

Soybean oil is a drying oil. "Drying" refers to the transformation of an air-exposed, thin film of oil from a liquid to a firm, tough solid. The process involves a polymerization of the oil through condensation reactions. The "drying" ability of soybean oil is less than obtained with other oils such as linseed and has somewhat limited its industrial applications.

The principal phospholipids of soybean are phosphatidylcholine, phosphatidylethanolamine and phosphatidylinositol. The phospholipids make up 1.5-5% of the crude hexane extractables. Although originally discarded as a sludge, the phospholipids have become valuable additives to food and industrial products. Some of the functional properties of phospholipids include emulsification, wetting, dispersing, and antispattering. Commercially, the phospholipids are marketed as "lecithin." Commercial lecithin, a mixture of phospholipids, is distinguished from chemical lecithin, the choline ester.

Phospholipids are insoluble in acetone, unlike the triglycerides. The acetone insolubility index is used to quantitate phospholipids present in an oil mixture. Acetone extraction can also be used to produce oil-free "lecithin."

Crude soybean oil contains various sterols, the aglycone varieties being campesterol, stigmasterol, and  $\beta$ -sitosterol. Free sterols are the major form found. Sterols are present also as esterified glucosides and acylated glucosides. The distribution of the sterols between the different classes do not change from early seed development through maturity. The sterols are acetone-soluble and are usually present in the crude phospholipid fraction from the oil.

Tocopherols exhibit both vitamin E activity and antioxidant activity in crude soybean oil. Those present in oil include  $\Delta$ -,  $\gamma$ -, and  $\alpha$ -tocopherol. The lecithin fraction from the oil contains approximately 0.1% and the vegetable oil distillate contains approximately 2.5-3.0% tocopherols.

### E. Carbohydrate Composition

Soybeans contain about one-third carbohydrates which vary with environmental and varietal differences. Both water-soluble and water-insoluble fractions are present. Defatted soybean flakes contain about 11.6% total soluble sugars. The principal sugars consist of 5% sucrose, 1.1% raffinose, and 3.8% stachyose. Glucose, fructose, galactose, rhamnose, arabinose,



glucuronic acid, and verbacose, a pentasaccharide, are also present. Raffinose, a trisaccharide, and stachyose, a tetrasaccharide, cause flatulence in humans because of the absence of  $\alpha$ -galactosidase enzymes.

The seed coat comprises the major portion of the insoluble carbohydrates. The insoluble polysaccharides consist of galactomannans, acidic polysaccharides, xylan hemicellulose, and cellulose. Lignin probably is also present. The insoluble carbohydrates of the cotyledons are a mixture of acidic polysaccharides and arabinogalactan. The acidic polysaccharides are regarded as belonging to the pectic group of substances.

#### F. Biologically Active Constituents

Soybeans contain biologically active constituents that are toxic when fed to various animals. Raw soybean meal will cause inhibition of growth, reduce fat absorption, decrease metabolizable energy of the diet, cause enlargement of the pancreas, and stimulate hypersecretion of pancreatic enzymes in chicks, mice, and rats. Toasted soybean meal does not exhibit these adverse nutritional properties. Trypsin inhibitors are the principal antinutritional agents present. Other biologically active agents present are phytic acid, hemagglutinins, saponins, and phenolic constituents.

There are seven to ten proteinase inhibitors in soybeans. Their biological significance in the bean may be as a metabolic defense against insect or bacterial invasion or for the control of protein hydrolysis during storage or germination. Several trypsin inhibitors (TI) have been isolated from soybeans. Two of these, the Kunitz TI and the Bowman-Birk TI, have been better defined than the other inhibitors. Raw soybean meal contains 1.4% Kunitz and 0.16% Bowman-Birk inhibitor. The Bowman-Birk inhibitor exhibits heat stability due to stabilization through disulfide linkages. The weight loss from trypsin inhibitor activity is caused most likely by loss of the amino acids in the enzymes secreted by the hyperactive pancreas. In addition to the competitive inhibition of trypsin, the Kunitz TI inhibits thrombin and the Bowman-Birk TI inhibits chymotrypsin. TI activity of soy is readily inactivated by heating at 100°C for 15 minutes or by atmospheric steaming at 25% moisture for 20 minutes.

Phytic acid, the hexaphosphoric acid derivative of inositol, exists in soy as a complex calcium-magnesium-potassium complex referred to as phytin. Phytin affects calcium and zinc nutrition through formation of an insoluble, non-nutritionally available complex. Interaction of phytin with proteins also reduces protein solubility. The protein interaction is pH sensitive. At pH 3.0, the interaction occurs through the cationic groups of the protein. Multivalent cation chelates of phytin form at pH 8.5 and the chelate complex binds with the protein.

The hemagglutinins in soy promote clumping of red blood cells *in vitro*. Hemagglutinins are glycoproteins present at about 3.0% in defatted soy flour. There is no evidence for agglutination of red cells on ingestion of hemagglutinins presumably because of its inactivation by pepsin in the stomach.

Soybean saponins, present in the meal at 0.5%, are glycosides of triterpenoid alcohols. Enzyme inhibition by saponins is nonspecific. Saponins are not absorbed upon ingestion.

The phenolic compounds in soy, genistin and daidzin, exhibit estrogenic activity. Because their estrogenic activity is low, it is doubtful sufficient amounts are present in the soybean to elicit an estrogen-like response in feeds. Conversion to more active compounds during processing or fermentation could possibly occur.

### III. PROCESSING

#### A. Oil Extraction

Approximately 95% of the soybean crop is marketed for processing or exported for processing overseas. With a total annual processing capability in the United States of approximately one billion bushels, large storage facilities are required to assure a continuous supply to the processors throughout the processing year (Fig. 1). Maintenance of quality during storage is essential to avoid economic losses.

Prior to storage, the soybeans are cleaned and dried. At 12% moisture, the beans can be stored for 2 years without loss in quality. At 14% moisture, the beans are usually dried before adding to the silos. Incorrect storage conditions result in various physical and chemical changes to the bean, contributing to inferior quality oil and meal. High moisture generally promotes mold-

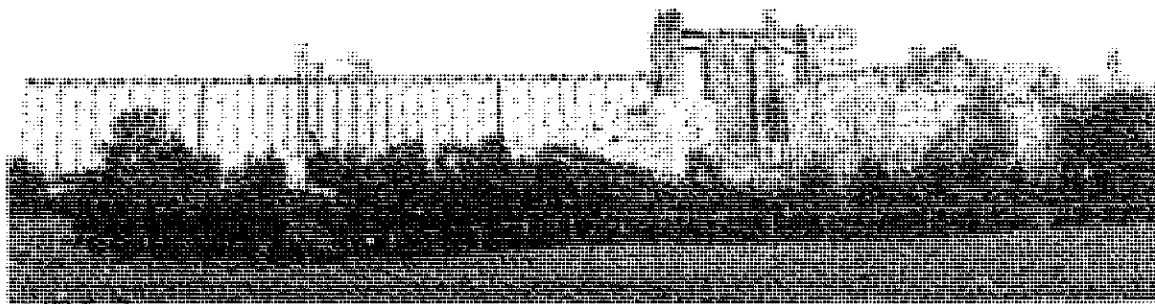


Fig. 1. Soybean processing plant. Note the large number of storage silos. (Courtesy of A. E. Staley Manufacturing Co.)

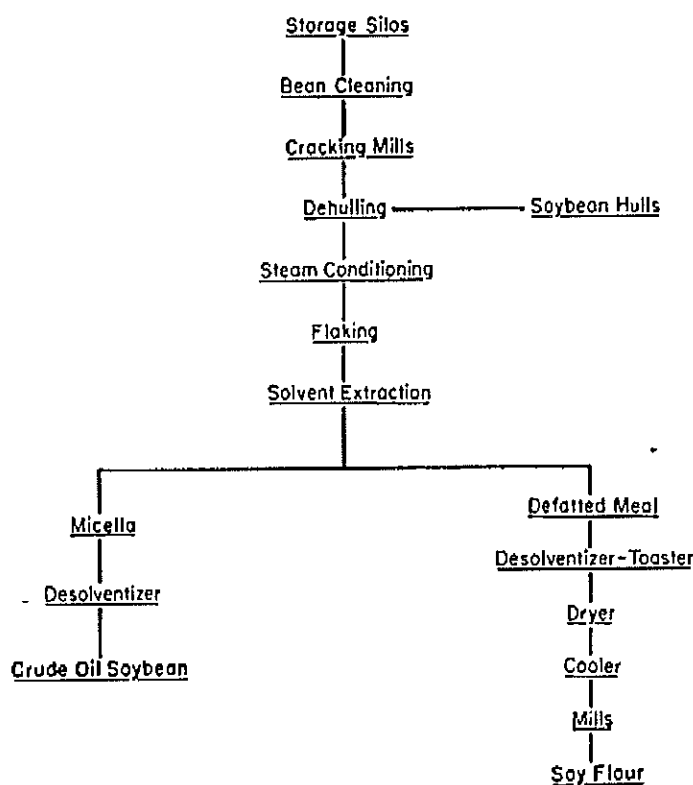


Fig. 2. Process flow for soybean extraction plant.

ing, high free fatty acid oil, and even charring from heat generation. Aeration is used to prevent moisture condensation. Molding has caused concern over possible development of aflatoxin by *Aspergillus flavus*. Little or no aflatoxin production has been found in moldy soybeans.

The initial products from soybean processing are crude oil and defatted meal or flakes. The processing steps are outlined in Fig. 2. As shown, the beans from storage are cleaned, cracked, dehulled, and flaked prior to oil extraction. Cleaning consists of passing the beans through a magnetic separator to remove iron and steel objects and over various size screens to separate seeds and foreign particles. The beans are cracked by rollers having spiral cut corrugated cylinders. Two to three pairs of rolls crack the beans into six to eight pieces and loosen the hulls. Hull removal by aspiration is necessary to improve extraction efficiency and to decrease the fiber content of the defatted meal intended for edible or poultry feeds. For high fiber feeds, the hulls are added back to the meal after extraction to obtain a 44% protein meal. The defatted, dehulled meal contains 49–50% protein.

The cracked beans are conditioned to about 11% moisture at 63°–74°C, then flaked by passing through differential rolls set at 0.25–0.40 mm clearance. Flaking ruptures the cells of the bean improving solvent contact and overall oil extraction efficiency. Hexane (B.P. 66°–69°C) is generally used for

extraction of oil from the flakes. Other solvents and solvent combinations have been proposed to improve extraction efficiency and decrease the flavor of the defatted meal intended for edible uses. Several types of extractors are manufactured although almost all utilize countercurrent extraction. The flakes are conveyed to the extractor and loaded into the extraction baskets. The rate of extraction and solvent temperature influence the residual oil content of the meal. Less than 1% residual oil is desired. Generally, the hexane is kept near 50°C during contact with the flakes.

After extraction, the solvent plus solubilized crude oil, referred to as micella, is first filtered to remove the suspended fines, and the solvent is stripped from the oil by a combination of thin film evaporators and stripping columns. Steam is injected during the final stages of stripping to ensure complete removal of the solvent. The solvent vapors are condensed for reuse and the solvent stripped crude oil is pumped to storage tanks for further processing. Crude soybean oil, because of the presence of natural antioxidants, principally the tocopherols, is storage stable.

The hexane laden flakes are passed through a desolventizer toaster which recovers the solvent and toasts the flakes to obtain optimum nutritional and functional characteristics. The desolventizer toaster consists of a series of steam jacketed compartments with revolving center blades which move the flakes through the unit. Steam is injected during desolventizing to aid solvent removal and adjust the moisture content to 13–15%. The temperature is slowly adjusted to as high as 110°C. After drying and cooling, the flakes are ground into meal.

## B. Oil Processing

Crude soybean oil contains from 1–3% of hydratable compounds, primarily the phospholipids (lecithin). Upon addition of warm water to the crude oil the phospholipids form a dense, gum-like, hydrated mass. Commercially, about 1% water is added to the crude oil at 71°C. The hydrated lecithin "gums" are continuously separated from the oil using disk-type centrifuges. The wet gums which contain about 25% moisture are vacuum dried at 100°–110°C. The dried gums are sold as commercial lecithin. Commercial lecithin contains approximately 30% oil and 70% phospholipids as determined by the acetone insolubility method. The dark colored lecithin may be bleached by addition of hydrogen peroxide prior to drying. Partial hydrolyzates are prepared to increase the water dispersibility of the lecithin. Granular, oil-free lecithins are produced by extraction of the entrained oil using acetone. Additional products have been manufactured based on alcohol solubility differences.

Degummed soybean oil contains about 0.02% phosphorus, 0.75% free fatty acids, 1.5% unsaponifiables, and about 0.3% moisture and volatiles. A

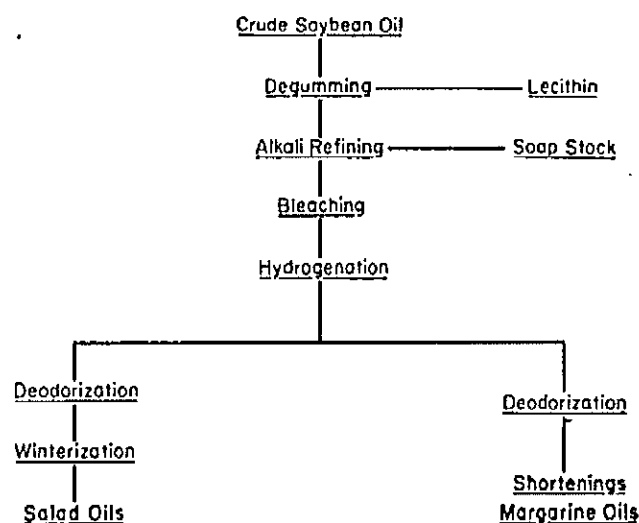


Fig. 3. Process flow for production of edible soybean oil products.

clear, bland-flavored oil is required for use in edible products. The steps for the conversion to edible oils as shown in Fig. 3 consist of refining, bleaching, and deodorization. Further processing consists of hydrogenation to impart desired physical properties and/or winterization to remove high melting glycerides from liquid oils.

Removal of the free fatty acids, refining, is the initial step in processing the oil. Alkali is added to the oil for conversion of the free fatty acids to water-soluble soaps. The fatty acid soaps plus excess alkali are then removed by water washes. The alkalis used are sodium hydroxide, sodium carbonate, or a combination. The alkali is added to 60°–70°C oil, mixed, and the soaps removed by centrifugation. Excess alkali is then removed by additional water washes, and the oil is vacuum dried. The free fatty acids in the oil are reduced to 0.05% or less. The recovered fatty acid soaps are referred to as soapstock. Soapstock may be dried as such or acidulated prior to drying. The soapstock, as a byproduct, is used for feed and industrial purposes. The bleaching step after refining improves both the color and flavor stability of the oil. Natural bleaching earths such as Fuller's earth or bentonite and activated carbon is mixed with the oil at 105°–110°C, followed by removal in filter presses. Less than 1% bleaching earth is required. Carbon black is normally used for green oils containing chlorophyll extracted from frost damaged or immature soybeans. The color of the oil is determined using a Lovibond Tintometer which is a graded series of yellow and red glass disks. The color is reported as a given red and yellow value.

The volatiles are removed after bleaching by heating the oil to about 260°C under high vacuum. The deodorization uses vacuums as low as 1–3 mm mercury. Air entering the oil during deodorization results in high color and poor stability and must be minimized. Steam injection is used to speed the

process. Deodorization is a continuous process where the oil is allowed to flow over shallow trays within an enclosed chamber. During the initial stages, the temperature is increased to the maximum required. Incoming oil is used to cool the deodorized oil in the final trays. During the latter stages of deodorization, citric or phosphoric acid is added to the oil at about 0.005%. These chelate the traces of heavy metals present which may act as prooxidants. Antioxidants other than metal chelators also are usually added in the final deodorizer tray.

The condensed volatiles obtained from the oil during deodorization contain tocopherols, sitosterol, and stigmasterol and are a primary source for vitamin E and sterol-derived products. These vegetable oil distillates are purchased by the pharmaceutical industry for conversion into marketable products.

After deodorization of the oil, it is filtered prior to storage. Nitrogen gas is used to blanket the oil to prevent oxidation. Antioxidants such as butylated hydroxyl toluene (BHT), butylated hydroxyanisole (BHA), and tertiary butylhydroquinone (TBHQ) may be added to a maximum combined level of 0.02% to prolong the shelf-life of the oil.

Most or the bulk of the soybean oil is sold as refined, bleached and deodorized oil. However, for specific functional and stability properties soybean oil must be hydrogenated. Hydrogenation is usually performed just prior to the deodorization step.

Partial saturation of the highly unsaturated fatty acids results in oxidatively stable soybean oil whereas greater degrees of hydrogenation is used to obtain semi-soft, plastic shortenings. The stability of an oil is usually characterized as the number of hours required to reach a given degree of peroxide equivalents. The active oxygen method (AOM) consists of holding the oil at 100°C with constant bubbling of air and determining the number of hours required to reach 100 meq peroxide value. For example, soybean oil has an AOM of about 10 hours compared to a lightly hydrogenated oil AOM of 25 hours.

The functional properties of hydrogenated oils are characterized by the ratio of solid fat to liquid oil. The solid, high melting glycerides present in hydrogenated oil, is determined by dilatometry. The percentage of high melting glycerides or solids in a fat or oil over the temperature range of 10°–44°C is referred to as the solids fraction index (SFI). The SFI can be manipulated by hydrogenation conditions, blending of oils, and randomization of the fatty acids within the glycerides of various oils.

Hydrogenation most usually is performed with a nickel catalyst. The new copper chromite catalysts are being used to hydrogenate the most highly unsaturated fatty acids more selectively for production of high stability liquid oils. The addition of hydrogen to the double bond of unsaturated fatty acids during hydrogenation is a complex reaction. Upon contact of the fatty acid with the catalyst, hydrogen may add to the double bond, or a transformation

from the native "cis" to the "trans" form may occur without hydrogen addition. The position of the double bond also may move within the fatty acid chain. Therefore, in addition to saturation, positional and geometrical isomers occur. Each isomer plus degree of saturation affects the melting properties of the oil and, subsequently, its functional characteristics.

The degree of selectivity during hydrogenation or the preference for hydrogenation of the most highly unsaturated fatty acids followed by the next most highly unsaturated fatty acid is determined by choice of catalyst and hydrogenation conditions. Highly selective catalysts saturate preferentially the most highly unsaturated fatty acids. For instance, to obtain high stability salad oils, it is desirable to partially saturate only the linolenic acid. Hydrogenation resulting in a high level of positional or geometrical isomers, because of their high melting points, is undesirable since salad oils must remain clear and fluid at refrigerator temperatures.

Batch and continuous hydrogenators are used. Batch converters range from 40,000- to 60,000-pound capacity with approximately a 4-hour cycle. Batch hydrogenators exhibit greater flexibility in hydrogenation conditions whereas continuous units are more suited to large quantity production of a single product type. The temperatures used during hydrogenation vary from 125° to 200°C with hydrogen pressures from 0.5 to 3 atm. Higher temperatures or catalyst concentration generally increases the selectivity. Rapid agitation or starving the catalyst by low hydrogen pressures decreases the selectivity.

Because complete selectivity is generally not obtained in the commercial hydrogenation of soybean oil, some high melting triglycerides are formed. These cause a cloudy haze during cooling of the oil to refrigerator temperature. Commercially, the crystals are filtered from the oil during "winterization." Winterization involves cooling the oil slowly to 13°C over a 12-hour period followed by additional cooling to about 5°C for 18 hours. After holding for 12 hours, the oil is filtered. The filtered oil will remain clear for 20 hours at 0°C.

### C. Processing of the Meal

The principal types of defatted meal products based on protein content are shown in the tabulation below.

| Product         | Percentage protein ( $N_2 \times 6.25$ ) |
|-----------------|--|
| Meal            | 44                                       |
| Flour and Grits | 49                                       |
| Concentrates    | 70                                       |
| Isolates        | 90                                       |

The 44% meal is prepared by adding back the soy hulls to the defatted flakes after extraction of the oil. Primary use of the meal is for animal feeds.

The soy flour and grits differ according to their particle size (see tabulation).

| Product | Mesh size | Opening (mm) |
|---------|-----------|--------------|
| Grits   |           |              |
| Coarse  | 10-20     | 2.00-0.84    |
| Medium  | 20-40     | 0.84-0.42    |
| Fine    | 40-80     | 0.42-0.177   |
| Flour   | 100-200   | 0.149-0.074  |

In addition to particle size, both flour and grits are manufactured with varying degrees of heat treatment. The treatment of the flakes after leaving the extractor generally determines the properties of the final products and their ultimate use.

Time, temperature, and moisture during desolventizing are the primary variables affecting the product characteristics, principally the protein solubility. Moist heat results in insolubilization of the proteins. The extent of protein insolubilization is determined by various methods although the protein dispersibility index (PDI) or nitrogen solubility index (NSI) are most generally used (Table VI). Examples of various protein solubility ranges of commercially available products are given in Table VII. The NSI of the various products usually range from a low of 7-10 to a high of 90%.

Partially refatted soy flours are prepared for special bakery applications. Low fat flours have up to 6.5% soybean oil added back to defatted flour or may be prepared by blending defatted meal with full fat flour. Full fat flours are processed by steaming whole soybeans to inactivate enzymes, drying to less than 5% moisture, cracking, dehulling, and grinding or extrusion cooking. Lecithinated flours have up to 15% lecithin added to defatted flours.

The grassy, beany, bitter flavor of soy flour results at least partially from oxidation of lipids and from the presence of phenolic compounds. A tremendous amount of effort by many investigators has been made to remove these flavors. The intensity of the off-flavors can be decreased by alcohol extraction or small additions of acetic or other acids. Specialty flours having low flavor profiles are being marketed. The competitive pricing policies of soy flour has limited the extent of the pretreatment that can be made to soy flour. Conversion of flour to higher protein products with better profit margins is economically justified.

Protein concentrates, having 70% protein, were originally produced for nonfood applications such as substitution for casein in paper coatings. Con-



TABLE VI

Terminology of Solubilities and Heat Treatment of Soy Flours<sup>a,b</sup>

| Term  | Abbreviation | Calculation   |
|---|--------------|---|
| % Water soluble nitrogen <sup>c</sup>       | WSN          | $\frac{\text{ml alkali} \times N \times 0.014 \times 100}{\text{Wt of sample}}$             |
| % Nitrogen solubility index <sup>c</sup>    | NSI          | $\frac{\% \text{ WSN} \times 100}{\% \text{ Total nitrogen in sample}}$                     |
| % Water soluble protein <sup>c</sup>        | WSP          | $\% \text{ WSN} \times 6.25$  |
| % Protein solubility index <sup>c</sup>     | PSI          | $\frac{\% \text{ WSP} \times 100}{\% \text{ Total nitrogen in sample} \times 6.25}$         |
| % Water dispersible protein <sup>d</sup>    | WDP          | $\frac{\text{ml alkali} \times N \times 0.014 \times 100 \times 6.25}{\text{Wt of sample}}$ |
| % Protein dispersibility index <sup>d</sup> | PDI          | $\frac{\% \text{ WDP} \times 100}{\% \text{ Total nitrogen in sample} \times 6.25}$         |

<sup>a</sup> Wolf and Cowan (1971, p. 39).<sup>b</sup> Calculations are based on Kjeldahl analysis of extracts where  $N$  = normality of alkali, 0.014 = millequivalent weight of nitrogen, and 6.25 = nitrogen to protein conversion factor.<sup>c</sup> Based on AOCS Method Ba 11-65. American Oil Chemists' Society (1975).<sup>d</sup> Based on AOCS Method Ba 10-65. American Oil Chemists' Society (1975).

TABLE VII

Commercially Available Soy Flour and Grits Based on Nitrogen Solubility Index (NSI)<sup>a</sup>

| Product | NSI Range |       |     |
|---------|-----------|-------|-----|
|         | 20-40     | 60-70 | 85+ |
| Grits   |           |       |     |
| Coarse  | X         | X     | —   |
| Medium  | X         | X     | —   |
| Fine    | X         | X     | —   |
| Flour   | X         | X     | X   |

<sup>a</sup> From Johnson (1976).

concentrates are prepared by removal of the low molecular weight components, mainly the soluble sugars, from soy flour. The remaining carbohydrates consist of an acidic polysaccharide, arabinogalactan, and cellulose. Processing involves immobilization of the proteins and leaching of the soluble components. Immobilization and leaching can be accomplished by: (1) aqueous alcohol extraction, (2) isoelectric extraction, and (3) aqueous extraction of heat denatured flour. Extraction of the soluble carbohydrates from whole soybeans prior to oil extraction is also used.

The composition of the various concentrates is very similar regardless of the extraction method used. Variations in the degree of protein denaturation or insolubilization depends upon the process and the heat treatment. Isoelectric extraction at pH 4.5 causes the least protein insolubilization. The NSI of concentrates, made by the aqueous-alcohol extraction technique, can be increased by various solubilizing treatments. Soy protein concentrates are marketed in particle sizes similar to the flour and grit products.

Soy protein isolates are the purest form of soy proteins available and contain 90% protein. Isolates were initially produced as a milk casein replacer for industrial uses. Isolates are prepared by aqueous or mildly alkaline extraction of defatted flakes or flour having a high protein solubility. The pH of the extraction is usually in the 7 to 9 range. Extraction above pH 9 leads to hydrolytic and rheological alterations of the protein. The extract is separated from the insoluble residue and the clear extract adjusted to pH 4.5 using sulfuric, hydrochloric, or phosphoric acids to precipitate the protein. The insoluble protein is washed, neutralized to pH 6.5-7.0, and spray dried. NSI of isolates can be as high as 90-95%.

Other extraction methods used for soy protein isolate production are isoelectric pH extraction using salt to adjust the ionic strength to solubilize the protein and neutral extraction of flour with water, followed by isoelectric precipitation. The yield of the protein from the meal is highest using alkaline extraction techniques. Yields of 65% or more of the protein are obtained.

#### IV. UTILIZATION

##### A. Soybean Oil

The bulk of the soybean oil produced is consumed as a salad oil. Slightly hydrogenated oil is preferred to meet longer shelf-life requirements. Selective hydrogenation is used to limit the formation of saturated, high melting point triglycerides. The iodine value is decreased to approximately 105-110. The hydrogenated salad oils require winterization. Cooking oils from soybean oil are similar to salad oil although a slightly greater degree of satura-

tion is used. Iodine values are usually in the 90-100 range. In both salad and cooking oils, the linolenate content is decreased to 3% or less. Development of solids in cooking oils are not as undesirable as in salad oils. In some instances, nearly plastic cooking oils are prepared, supposedly to give a less "greasy" appearance to the finished product.

Shortenings for bakery applications require wide-melting point, plastic fats. To obtain the desired melting and plasticity characteristics, soybean oil is combined with palmitic acid-containing fats, such as cottonseed, lard, or palm oil. The plasticity plus high temperature stability are also dependent upon selectivity during hydrogenation and the ratio of the blends. Fully hydrogenated soybean oil stearine, 0-5 iodine value, may be added to increase the high temperature stability. The solids at 10°C for a shortening would be in the 40% range and at 44°C in the 5-15% range. Higher solids at the high temperature range are desired for fermentation stability and for initial high temperature stability. The high temperature solids also aid in the development of the air cell structure of the baked product. Low temperature plasticity of the shortening plus a crystalline form are needed for ease of creaming into the dough.

Liquid bakery shortenings are manufactured by slowly crystallizing 4-20% of high-melting point glycerides plus emulsifiers and dough conditioners in a liquid oil. Refined and partially hydrogenated soybean oil are used for the liquid oil fraction. The short shelf-life of many bakery products allows the use of the less stable oils. Ease of shipping, storage, and use are contributing to the market acceptance of these industrial products for the baker.

Margarine oils consist of a blend of hard and soft oil fractions. The hard fraction is hydrogenated under nonselective conditions to obtain a high solids profile with rapid melting near body temperature. The soft fraction requires more selective hydrogenation. After combination, cooling results in the formation of a continuous crystalline network of the hard fraction.

Both margarines and shortenings are tempered to develop crystalline forms having the desired melting characteristics and crystal size. The smaller crystals or  $\beta'$  crystals usually are preferred in shortenings for optimum creaming and air incorporation into a dough. Crystallization of shortenings into the desired crystal form is accomplished with the use of swept surface heat exchangers. Initially, the melted shortening is shock-cooled to about 12°-16°C. A second swept surface unit works the supercooled fat for further development of a fine crystalline network. Tempering is completed by storage for up to 3 days in a 26.6°C room. Margarines are tempered after emulsification of the fat, milk ingredients, salt, and other minor ingredients. The degree of crystallization depends upon the product being made. Conventional stick margarine is continuously formed in units with static mixers, and semi-soft products may be filled similar to shortenings.

TABLE VIII

Solid Fraction Indexes of Various Hydrogenated Soybean Oil Products

| Temperature (°C) | Solids content (%) |       |       |
|------------------|--------------------|-------|-------|
|                  | No. 1              | No. 2 | No. 3 |
| 10               | 25                 | 40    | 52    |
| 21.1             | 12                 | 23    | 38    |
| 26.7             | 8.0                | 16    | 32    |
| 31.1             | 1.5                | 3     | 16    |
| 37.8             | —                  | —     | 7     |
| 44               | —                  | —     | 0     |

Numerous specialty oils based on soybean oil are prepared for formulation of frozen desserts (mellorines), cookie shortenings, confections, icings, ice cream coatings, whipped toppings, and coffee whiteners. The oil portion for each product is prepared to a specific solids fraction index plus melting point for edibility and functionality. The solids profile is obtained by special hydrogenation conditions, blending of oils, or interesterification of mixtures. Examples of various hydrogenated products based on soybean oil are shown in Table VIII.

The industrial uses of soybean oil includes soap manufacture, paints, resins, and drying oil products. Soybean oil is too highly unsaturated for soaps and requires modification. Soybean oil is generally considered a semi-drying oil and has been used in mixtures with stronger drying and faster gelling oils in making varnishes and bodied oils. Soybean oil reacted with maleic anhydride is used for coatings where the maleation improves both the drying and film forming properties of the alkyd resin. Heat bodied, blown, or sulfurized soybean oil is utilized in varnishes for paper, enamels, inks, and stains. Bodying of the oil refers to the processes of taking the oil through the initial stages of polymerization.

## B. Protein Products

Utilization of the defatted meal is generally as a protein nutrient for animal or human foods. The forms of protein products presently being marketed are soybean meal, soy flour, soy protein concentrate, and soy protein isolates. Additionally, textured and modified soy proteins are marketed.

Defatted soybean meal was first prepared in the United States in 1915 by expeller pressing. The meal became an important feed ingredient because of the large annual production and high quality protein present.

The composition of defatted soybean meal is shown in the tabulation below.

| Composition | Percentage |
|-------------|------------|
| Protein     | 44-47      |
| Fat         | 0.5-1.2    |
| Fiber       | 5.5-6.5    |
| Ash         | 5.5-6.0    |
| Calcium     | 0.3-0.33   |
| Phosphorus  | 0.62-0.65  |

Widespread utilization of the meal in poultry rations began when observations on heat inactivation of antinutritional factors in raw beans improved feed efficiency in poultry nutrition. Nutritional investigations showed the most efficient growth rate was obtained using a 20% protein ration for broilers. The advantages of soybean meal for swine was later shown. The use of soybean meal in animal feeds accounts for almost 98% of the processed products.

Human food usage of soybean protein products accounts for only about 2% of the total meal production. Several forms of protein products are available. These generally are classified as: (1) flours and grits, (2) concentrates, and (3) isolates.

Utilization of soy proteins in foods is for functional properties as well as nutritional fortification. The functional properties along with various applications are outlined in Table IX. Functionality of soy is related to the surface active properties of the protein, gelation, and fat and water absorption.

The surface-active properties are derived from the tendency of the protein to orient at the oil-water interface of emulsions resulting in a lowering of the interfacial tension. The protein also increases the viscosity of the emulsion aiding in the prevention of fat droplet coalescence. Generally, the high NSI soy protein products are required, although the relationship of NSI to emulsification power is not absolute. Soy protein emulsification is useful in food products such as soups, gravies, sauces, and meat products.

Soy protein isolates will form a gel when heated to 70°-100°C for 30 minutes. Disulfide bonding is involved in the gelation. The conversion of soy proteins to a gel structure is, unlike gelatin, irreversible under the above conditions unless temperatures of about 125°C are used. The irreversible gelling is especially important for texture building in simulated or extended meat products. Soy protein concentrates and isolates are used to replace nonfat milk solids in comminuted meat products because of the gel-forming character and emulsion stabilizing function.

TABLE IX

Functional Properties of Soybean Proteins<sup>a</sup>

| Property                   | Protein form used <sup>b</sup> | Food system   |
|----------------------------|--------------------------------|---|
| Emulsification             |                                | Frankfurters, bologna, sausages   |
| Emulsion formation         | F,G,C,I                        | Breads, cakes, soups  |
|                            | F                              | Whipped toppings, frozen desserts   |
|                            | I                              | Frankfurters, bologna, sausages   |
| Emulsion stabilization     | F,G,C,I                        | Soups   |
|                            | F                              |   |
| Fat absorption             |                                |   |
| Promotion                  | F,G,C,I                        | Frankfurters, bologna, sausages, meat patties, simulated meats            |
| Control                    | F,I                            | Doughnuts, pancakes   |
| Water absorption           |                                |   |
| Promotion                  | F,C                            | Breads, cakes, confections, simulated meats                               |
| Control                    | F                              | Macaroni  |
| Retention                  | F,C                            | Breads, cakes, confections  |
|                            | C                              | Meat patties  |
| Texture                    |                                |   |
| Viscosity                  | F,C,I                          | Soups, gravies, chili   |
| Gelation                   | F,C,I                          | Ground meats  |
|                            | I                              | Simulated ground meats  |
| Shred formation            | F,I                            | Simulated meats   |
| Chip and chunk formation   | F                              | Simulated meats, fruits, nuts, and vegetables                             |
| Fiber formation            | I                              | Simulated meats   |
| Spongy structure formation | I                              | Simulated meats, dried tofu   |
| Dough formation            | F,C,I                          | Baked goods   |
| Adhesion                   | C,I                            | Sausages, luncheon meats, meat patties, meat loaves and rolls, boned hams |
| Cohesion                   | F,I                            | Baked goods   |
|                            | F                              | Macaroni  |
|                            | I                              | Simulated meats   |
|                            | I                              | Dried tofu  |
| Elasticity                 | I                              | Baked goods   |
|                            | I                              | Simulated meats   |
|                            | I                              | Gels  |
| Film formation             | I                              | Frankfurters, bologna   |
| Color control              |                                |   |
| Bleaching                  | F                              | Breads  |
| Browning                   | F                              | Breads, pancakes, waffles   |
| Aeration                   | I                              | Whipped toppings, chiffon mixes, confections                              |

<sup>a</sup> Wolf and Cowan (1971, p. 52).<sup>b</sup> F,G,C, and I represent flours, grits, concentrates, and isolates, respectively.

The water/fat absorption property is probably the most useful function of soy protein. Soy flour absorbs two times or more its weight of water and concentrates will absorb three to five times. Water absorption is related to the hydrophilic nature of the protein. Water absorption is least near the isoelectric pH. Addition of soy flour to bread dough increases the dough yield, permits addition of more water to the dough, and improves dough handling. Addition to ground meats increases frying yield because of the water holding power. The mechanism of fat absorption is not well known although it may relate to the emulsification properties. Fat binding by soy flour in extended meats decreases cooking losses of the fat and provides a more tender, flavorful product. Conversely, soy flour use in some products limits fat absorption during deep frying, for example, in doughnuts and batter mixes. Apparently an impermeable film of denatured protein is formed between the dough and the oil.

On the basis of analysis, soybean protein is of high nutritional quality. However, not only quality but digestibility, species involved, and presence of inhibitors can affect the nutritional value of soy protein. The superior quality of heated versus raw soybean meal has been noted. Toasting of soybean meal for animal feeds is of less significance than for food uses of soy. Edible soy requires functional properties which are generally lost upon toasting.

The protein efficiency ratio (PER) of soy flour, compared to casein at 2.50, is about 2.20. Fortification of soy flour with methionine, the first limiting amino acid, increases the PER to nearly equivalent to that of casein. The PER is somewhat dependent on degree of toasting since high NSI flours may have a PER as low as 1.80.

Soy protein concentrates, based on analysis, do not differ significantly from flour in amino acid composition. Wide variations in PER between processors of concentrates do occur, most likely because of differences in heat treatment of the flour and in the processing of the concentrate. Soy protein concentrates are available with PER nearly equivalent to toasted flour. Methionine fortification, similarly to flour, can result in a PER equivalent to casein.

The nutritive value of commercial protein isolates is highly variable. During preparation of isolates, fractionation of the protein occurs and, since particular care is taken to ensure protein solubility, proteinase inhibitors may be present. The PER of isolates ranges from approximately 1.1 to 1.8.

### C. Textured Proteins

Textured soy proteins refer to modified proteins having meat-like textures. The textured products are used for preparation of pet foods simulating

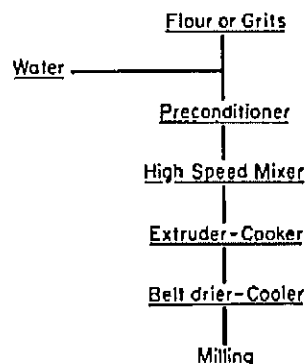


Fig. 4. Process flow for extrusion of soy protein products (Smith and Circle, p. 315, 1972).

meats, extension of meats, and simulated edible meats. Textured soy flour in the United States school lunch program alone consumes approximately 40 million pounds annually, primarily as a ground meat extender. In addition to textured flours, concentrates and isolates are manufactured having a chewy, resilient texture and appearance for extension of flaked-formed meats, emulsion meats, and ground meat.

Various methods are used to texturize soy products. The primary process is extrusion (Fig. 4). Extrusion texturization involves mixing soy flour, concentrate, or isolate with water, feeding to a continuous cooker-extruder, heating under pressure, and extruding. The heated, compressed mass expands on extrusion resulting in a sponge-like mass. After hydration, the textured product has a chewy, resilient texture similar to meat. Various sizes, flavors, and colors of textured soy proteins are marketed.

Soy proteins can be texturized using a process similar to the spinning of synthetic fibers through a multiholed spinneret die. The protein is solubilized in an alkaline solution and forced through the spinneret die immersed in an acid coagulating bath. Only protein isolates can be used because nearly complete solution of the protein is necessary. The protein immediately coagulates when issuing from the die, giving a continuous protein filament. The filaments are stretched to orient the proteins within the fibers, giving control over the toughness of the filaments. Filament diameters are approximately 75  $\mu\text{m}$ .

The filaments after grinding are used as meat extenders. Groups of filaments, when mixed with binders such as egg white, and suitable flavors and colors, followed by compressing and heat setting, form imitation meats such as chicken, ham, or beef.

Additional methods that are being used to texturize soy proteins include extrusion through spinneret dies avoiding the alkaline solubilization step, high temperature compression, and freeze-thawing of gelled proteins.



These methods are used to a lesser extent than either extrusion or alkaline spinning.

#### D. Modified Soy Proteins

Modified soy proteins are used as adhesives, coatings, and aeration aids. These are intended to replace or extend animal-derived proteins such as casein, gelatin, or egg albumin. Competition from petroleum derived products has limited the industrial markets for proteins, whether animal or vegetable based, but the recent price increases in petroleum products has brought renewed interest in industrial modified soy proteins.

The soy proteins marketed for paper coatings are hydrolyzed under alkaline conditions, precipitated at pH 4.5, and dried. The alkaline hydrolysis alters the quaternary structure of the protein and hydrolyzes some of the covalent bonds with liberation of ammonia and sulfites. In use, the modified protein is solubilized using ammonium hydroxide. High solids solutions of up to 30% are formulated without gelling of the protein. Specific rheological and adhesive properties are dependent upon the pH, time, and temperature of hydrolysis. Low-, medium-, and high-viscosity grades of industrial soy proteins for paper coatings are manufactured.

Aeration aids for extension of gelatin and egg albumin in confectionery and bakery products are prepared by pepsin hydrolysis of soy flour. These powerful aerators rapidly form foam structures in marshmallows, angelfood cakes, bar mixes, and frozen ices. The pepsin-hydrolyzed proteins do not heat coagulate or gel as do the animal-derived proteins.

#### E. Specialty Uses of Soybean Protein

Almost 7% of all infants exhibit some degree of allergenicity to cow's milk. Soy milk, although intended for usage as a nutritional replacement for cow's milk, has been an attractive alternative in infant nutrition.

Originally, soy milk was processed from whole soybeans. The beans were allowed to soak in water after a preliminary wash, and then were ground. Additional water was added to adjust the final solids to the desired concentration. The slurry was then heated to near boiling for 15-20 minutes to improve the nutritive and flavor qualities of the milk. The insoluble solids were removed prior to packaging and distribution. Flavors are generally added to improve the acceptability. Process variations in soy milk production have included the use of  $\alpha$ -galactosidase and invertase to decrease flatulence. The heat treatment and time within the process apparently controls the development of off-flavors. Lipoxidase inactivation prior to grinding of the beans is necessary.

Attempts to dry soy milk show that upon aging there is a loss in dispersibility. This is most likely caused by protein polymerization through disulfide cross-linkages. Reducing agents such as sodium bisulfite improve the dispersibility.

Special polyunsaturated cow's milk can be obtained by manipulation of the cow's diet. Simple addition of raw soybeans to the cow's diet increases the stearic acid content of the butterfat. If the dietary lipids are protected from hydrogenation in the rumen, the fatty acid distribution in milk fat is changed significantly. Formation of highly cross-linked protein capsules about the fat globules has been used to bypass the rumen. Simple grinding and homogenization of full fat soybeans followed by cooking with formaldehyde gives an effective barrier to hydrogenation of oil and results in transfer of the dietary lipids to the milk fat.

Formulated edible products also use soy proteins as a casein replacer. Particular products such as coffee whiteners, whipped toppings, and frozen desserts are marketed. Protein fortified beverages, cereals, and snack food items have been made. Fortified beverages, however, usually require acid-soluble proteins. Special enzyme hydrolysates or hydrolysate fractions have been found that have acid solubility.

## V. FUTURE PROJECTIONS

The development of markets for soybean oil and meal has led to phenomenal growth of the soybean industry in the past 50 years. The growth rate suggests that the crop will continue to expand but most likely somewhat slower than experienced in the past.

In 1974, 57% of the soybeans harvested in the United States were processed into oil and meal and utilized in the United States. The remainder was exported as whole beans, meal, and oil. Most of the oil (93%) is utilized in foods primarily as salad oils and shortenings (Table X). The remainder consists of industrial usage (3%) and foots plus losses (2%). Marketing of soybean oil has become more difficult recently and oil, in fact, has often been in surplus. In the near future, supplies of vegetable oils will probably be in excess of demand because of the increasing availability of palm and lauric oils (coconut and palm kernel). The supply of palm oil is expected to increase dramatically through the 1980's because of maturing of palm plantations. The output of soybean oil will be even more dependent upon the demand for the meal.

In recent years, the demand for meal has been stronger than for the oil. Soybean meal presently supplies approximately 61% of the world's meal consumption. This is an increase from 49% just 10 years ago. The increase in

TABLE X  
Domestic Use of Soybean Oil in 1973<sup>a</sup>

| Use                       | Amount<br>(kg × 10 <sup>6</sup> ) |
|---------------------------|-----------------------------------|
| Food                      |                                   |
| Shortening                | 1098                              |
| Margarine                 | 769                               |
| Cooking and salad oils    | 1468                              |
| Other edible              | 11                                |
| Nonfood                   |                                   |
| Paint and varnish         | 43                                |
| Resins and plastics       | 30                                |
| Other drying oil products | 1.4                               |
| Other inedible            | 9.5                               |
| Foots and losses          | 134                               |

<sup>a</sup> From U.S. Department of Agriculture (1977).

soybean meal's position occurred because of its favorable price and supply compared to other meals.

The increased overall wealth of the world has been reflected in an increased demand for meats of all kinds. Because of this demand for meats, and the increased demand for soybean meal as an animal feed, it is now the principal product of the soybean milling industry. The future demand for the meal will depend upon general world economy. Most likely, the price of the meal will have to increase significantly to offset the decreased demand for the oil.

TABLE XI  
Estimate of Soybean Proteins Produced as Food Ingredients  
in 1974 and Projections for 1985<sup>a</sup>

| Protein product   | 1974<br>(kg × 10 <sup>6</sup> ) | 1985<br>(kg × 10 <sup>6</sup> ) |
|-------------------|---------------------------------|---------------------------------|
| Flours and grits  | 409                             | 909                             |
| Concentrates      | 31.8                            | 227-273                         |
| Isolates          | 27.3                            | 180-227                         |
| Textured products |                                 |                                 |
| Flours and grits  | 40.9                            | 180-227                         |
| Isolates          | 4.6                             |                                 |

<sup>a</sup> From Wolf (1976).

The direct consumption of soybean protein in human foods accounts for only 26.5 million bushel of the 1.26 billion bushel crop (Table XI). The utilization of soybean proteins as food ingredients is expected to increase three to four times by 1985. By 1980 simulated meats and meat extenders are projected to reach a sales volume of nearly \$2 billion. But even by 1985, the expected direct food usage of soybeans will only account for approximately 5% of the crop. The remainder will be converted into meat, milk, and eggs.

The conversion of soybean proteins into animal products is inefficient. The world is faced with shortages of land, energy, water, and fertilizer. The efficiency of the direct consumption of soy proteins is obvious. Many food processors are already replacing traditional proteins in formulated food products with less expensive plant proteins. As more is learned about soybean protein and methods to instill functionality similar to the traditional animal proteins, greater and greater substitutions will be made in food products. Beyond 1985, edible proteins from soybeans are likely to continue to utilize an increasingly larger portion of the crop.

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