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SOY PROTEIN AND HUMAN NUTRITION

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TYPES OF SOY PROTEIN PRODUCTS

D. H. Waggle and C. W. Kolar

The soybean originated in Eastern Asia where it has been utilized as a food source for centuries. It was cultivated for food in China long before written records were kept and was even recommended for its therapeutic value during its early history. One can only speculate on how soybeans were first prepared for human consumption. Miso, a soy paste which is often used as a soup base, is a traditional fermented oriental product which is still popular today. Shoyu or soy sauce is a fermented product which has also been widely accepted in many western countries.

Soybeans are a relatively recent agricultural crop in the United States. Early U.S. interest in the soybean was for the oil which was pressed from beans. Hydraulic and screw presses were first used to separate the lipid fraction from the meal or cake. Much of the oil was used in paint and other industrial applications, and the meal was considered a by-product which was used primarily as cattle feed or fertilizer.

Commercial solvent extraction of the oil was initiated in the early 1930's. Coincidentally, food uses for the oil also started to develop at about that time. Processing of the soybean into food products such as soya flour, soy protein concentrate, and isolated soy protein developed in the 1950's. These forms of soy food products are marketed in a wide variety of forms, including dry powders and texturized products. Efficient extraction of the oil led to the development of refined soy proteins which were used as adhesives in the plywood industry. Today, nearly all the oil goes into food applications while the meal is regarded as a very important protein supplement for livestock and poultry.

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SOYBEAN SUPPLY

Western Hemisphere soybean production has grown by a factor of five in the last twenty-five years. The major Western producing countries today are the United States and Brazil, as shown in Figure 1. Production in the United States has been increasing at a rate of approximately 6.5% annually, resulting primarily from increased acreage, but also, to some extent, from improved crop yield. Brazil, on the other hand, has been increasing production at a compound rate of approximately 35% over the past five years. Brazil's soybean production now approximates one-fourth the size of the United States' crop. This dramatic rise in soybean production is directly related to increased prosperity around the world with the resulting demand for meat and livestock products, which is still the ma-

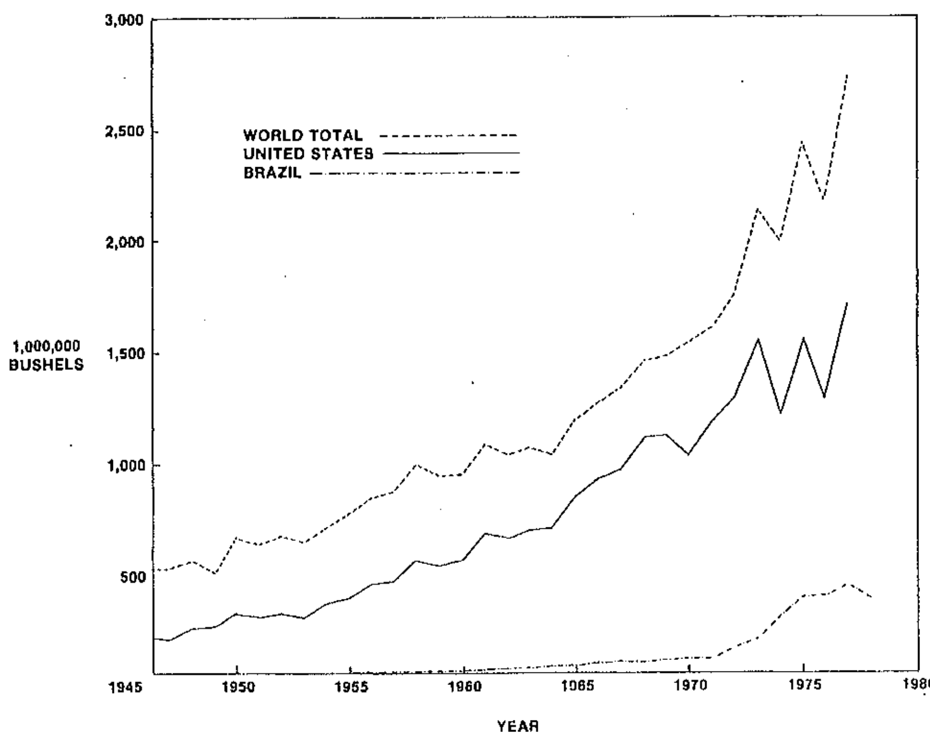

FIGURE 1. World production of soybeans from 1945 to 1977.

jor use of soybean meal. Adoption of modern, efficient feeding practices has boosted world requirements of high protein feed for expanding livestock production.

Markets for soybean meal are principally high protein supplements for poultry, hogs, and cattle, as well as for other livestock rations. These markets have been expanding much faster than those for oil, which is one of the reasons why soybeans, which have a relatively high meal to oil ratio, are preferred to other oil seeds. The demand for soybean meal as a raw ingredient in food processing applications has been growing rapidly, but this segment still comprises less than 5% of the total soybean production in the United States.

Agronomists have developed a number of commercially acceptable varieties and no single variety dominates the market. Soybean varieties are divided into ten maturity groups adapted for northern latitudes from Southern Canada, to southern latitudes for the southernmost region of the Gulf Coast.

Plant breeding for yield, disease resistance, and composition is a continuous program; therefore, major varieties are being continuously improved. Segregation of specific varieties is not practiced commercially.

Seed Structure and Composition

Soybeans are typical of legume seeds which differ in size, shape, and color depending on the variety. They range from small round beans to large oblong, flattened seeds of yellow, brown, green, black, or combinations of these colors. Common field varieties of soybeans which are agriculturally important are spherical and yellow. Typical soybeans used for food products are shown in Figure 2. A cross-section of a soybean (Figure 3) shows the major structural parts; the hull and the cotyledon. Two minor structures, the hypocotyl and plumule, are not shown. The hull is made up of an outer layer of palisade cells, a layer of hourglass cells, smaller compressed parenchyma cells, aleurone cells, and finally compressed layers with endosperm cells. The cotyledon is covered with an epidermis and is composed of numerous elongated palisade-like cells which contain protein and oil. The bulk of the proteins are stored in protein bodies which may vary from 2 to 20 microns in diameter within the cotyledon cells. The oil is located in smaller structures, 0.2 to 0.5 microns, called spherosomes which are interspersed between the protein bodies (Tombs, 1967 and Wolf, 1975).

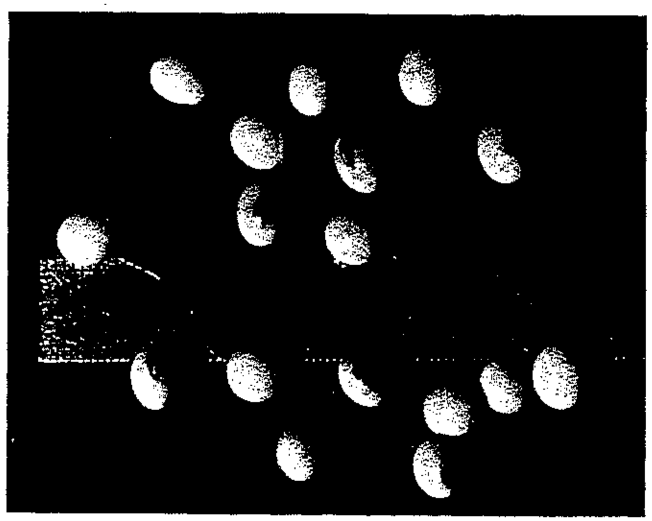

FIGURE 2. Photograph of typical U.S. soybeans utilized in production of food products.

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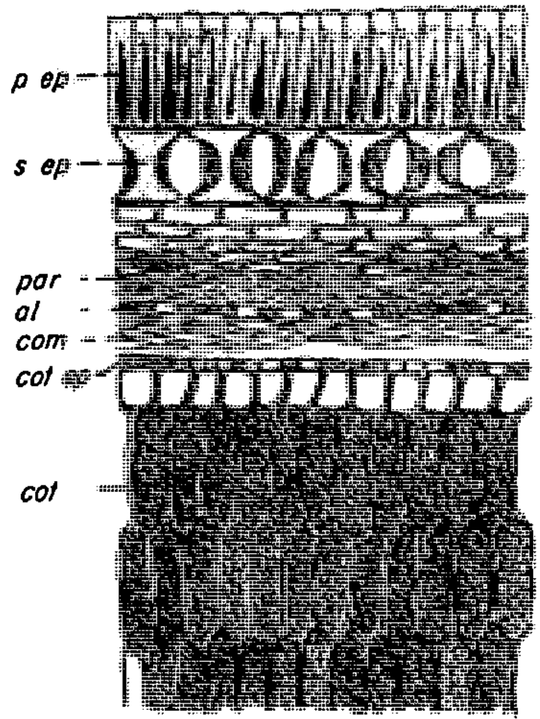

FIGURE 3. Cross section of soybean seed coat and portion of cotyledon showing: spermoderm, which consists of *p ep* palisade cells of epidermis; *s ep* hourglass cells, and *par*, parenchyma, both of subepidermis; *al*, aleurone cells; and *com*, compressed cells of the endosperm, *cot ep*, cotyledon epidermis, and *cot*, aleurone cells of cotyledon.

Composition of Source Material

The soybean is composed of three major components, the hull, cotyledon, and hypocotyl in portions approximately 8%, 90%, and 2%, respectively. Typical values of composition of the total soybean are presented in Table 1 (Kawamura, 1967). Constituents of major interest for food applications are protein and oil which are 42% and 20%, respectively. One third of the soybean is carbohydrates, which include various polysaccharides, stachyose, raffinose and sucrose (Kawamura, 1967). The balance of the materials present in soybeans is described as ash, which includes many minerals.

Table 1. Typical composition of soybeans[1]

	%
Protein (N x 6.25)	42
Oil	20
Total Carbohydrates[2]	35
Ash	5.0
Crude Fiber	5.5

[1]*Moisture-free basis.*
[2]*Includes crude fiber. (From Kawamura, 1967.)*

Storage and Handling

Soy protein products for human consumption are produced from high quality soybeans as the raw material. Soybeans are classified as cereal grains; hence, trading is regulated by the U.S. Grain Standards Act. Classification of soybeans is according to color, and yellow soybeans constitute the major commercial class. Grades are based on test weight, moisture content, percentage of split, damaged kernels, and foreign material. Table 2 lists requirements for numerical and sample grades of soybeans (Official Grain Standards, 1970). Soybeans of grades Number 1 and Number 2 are used for processing food grade protein products.

Proper receiving, handling, and cleaning of soybeans is important in producing high quality food products. Cleaning is accomplished by magnetic separators, screening, and other techniques such as air classifiication and mechanical separators. It is important to remove as much foreign matter as possible, in order to maintain a pure product and for processing efficiency. Clean soybeans will retain their quality indefinitely in bulk storage, providing the moisture content does not exceed 12%.

The general outline of the process for producing crude oil and defatted soybean products is shown in Figure 4. The cleaned beans are cracked into multiple pieces, usually six to eight, and the hull is loosened by use of corrugated rolls revolving at slightly different speeds. For food use dehulling

Table 2. *United States Standards for Soybeans*

Grade	Minimum Test Weight Per Bushel Pounds	MAXIMUM LIMITS OF: Moisture (%)	Splits (%)	Total (%)	Heat Damaged (%)	Foreign Material (%)	Brown, Black and/or Bi-Colored Soybeans in Yellow or Green Soybeans (%)
1	56	13	10	2.0	0.2	1.0	1.0
2	54	14	20	3.0	0.5	2.0	2.0
3[1]	52	16	30	5.0	1.0	3.0	5.0
4[2]	49	18	40	8.0	3.0	5.0	10.0

U.S. Sample Grade: U.S. sample grade shall be soybeans which do not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 4, inclusive; or which are musty, sour, or heating; or which have any commercially objectionable foreign odor; or which contain stones or which are otherwise of distinctly low quality.

[1] *Soybeans which are purple, mottled or stained shall be graded not higher than U.S. No. 3.*

[2] *Soybeans which are materially weathered shall be graded not higher than No. 4.*

(Official Grain Standards, 1970)

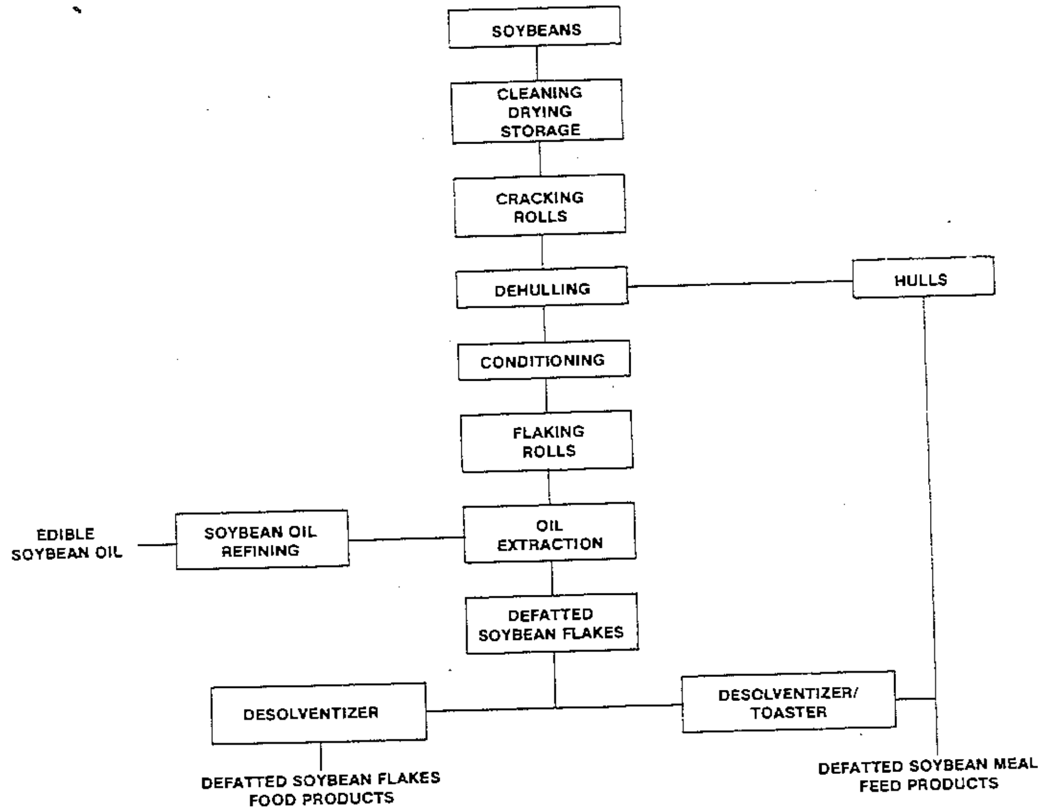

FIGURE 4. Schematic diagram for processing soybeans into edible soybean oil, defatted soybean flakes (food products) and defatted soybean meal (feed products).

is usually practiced after cracking in order to minimize the crude fiber content. Oil extraction efficiency may be improved by removing the hulls, since hulls contain very little oil. Hulls may be removed by aspiration of the cracked beans and collected to yield a product known as mill run and mill feed. Soybean hulls may also be returned to the soybean meal after oil extraction to make a 44% protein meal product.

The cracked beans are conditioned to 10-11% moisture at a temperature of 63-74°C and then flaked by passing them through smooth rolls. The clearances between the rolls are adjusted so that the flakes are a uniform 0.254 millimeters to 0.381 millimeters thick. Flaking ruptures the cotyledon cells in the soybeans and reduces the distance that the oil must diffuse, thereby facilitating extraction with organic solvents in later processing.

Soybean Oil

Soybean oil has been a principal product from soybean processing for many years. In the later 19th century, oil was recovered from soybeans by a pressing operation. While inefficient by today's standards, pressing soybeans yields about 75% recovery of the oil. In the early 20th century, a continuous oil extraction process using an organic solvent to remove oil was developed. The most common solvent used is n-hexane. These continuous extraction systems typically remove about 95% of the oil present in the soybean. Solvent extractors were introduced in the 1930's and some of these early models are still operating.

Currently, extractors employ a variety of ways to contact flakes, including a presoaking period to remove some of the oil in a stationary basket with the pumping of solvent miscella in a progressive stepwise countercurrent flow of flakes and solvent. Miscella is filtered to remove fines and the solvent is stripped from the crude oil by passage through preheaters using thermo-evaporators and stripping columns. The latter are usually packed, and they are steamed countercurrently under diminished pressure to remove the last of the hexane.

The material balance for a typical soybean oil extraction process is shown in Table 3. Soybean oil is primarily used as a starting material for a wide variety of food products such as shortening, margarine, cooking oil, and in salad dressing. A partial list of uses of soybean oil is shown in Table 4.

The most common method of removing solvent from the soybean flakes is the desolventizer-toaster. This equipment recovers the hexane and simultaneously toasts the flakes to obtain optimum nutritive value for production of soybean meal. As the flakes pass through the desolventizer, the temperature

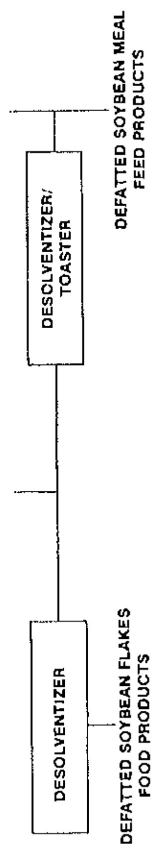

FIGURE 4. Schematic diagram for processing soybeans into edible soybean oil, defatted soybean flakes (food products) and defatted soybean meal (feed products).

Table 3. Material Balance for Soybean Processing
60 Pounds = 1 Bushel

	Pounds
Soybean Meal (49% Protein Meal)	43.3
Oil	11
Hulls	4.2
Shrink	1.5

Table 4. Food Uses of Soybean Oil

Uses
Frying Fats
Margarine
Mayonnaise
Pharmaceuticals
Salad Dressing
Salad Oil
Sandwich Spreads
Shortening

is gradually increased to 110°C which lowers the moisture content and volatilizes the hexane for efficient removal. After drying and cooling, the flakes are ground into a meal for use in feed applications.

Flash desolventization is a newer process and has the advantage of producing soybean flakes which have high protein solubility properties. Materials from this process generally have a protein dispersibility index (PDI) in the range of 70-90, depending on the processing conditions. Flash desolventizers can also be operated so as to produce products for which the protein dispersibility index value of the soybean flakes will be substantially reduced.

Food Products from Defatted Soybeans

Three general categories of food products are produced from defatted soybeans based on the protein content; soy flours and grits (minimum of 50% protein), soy protein concentrates (minimum of 70% protein), and isolated soy proteins (minimum of 90% protein). Within each general category there are a number of product types with different physical, chemical, and functional properties. The typical composition of soybeans, defatted soy flour, soy protein concentrate and isolated soy protein is shown in Table 5.

Soy Flours and Grits

Soy flours and grits are typically prepared directly from defatted soybean flakes with a minimum of additional processing required. All edible soy grits and soy flours are made from dehulled soybeans. Typical composition of these products is given in Table 6. They contain a minimum of 50% protein,

Table 5. Typical Composition of Soybeans and Soybean Products[1]

	Protein (N x 6.25) (%)	Oil (%)	Total Carbohydrates[2] (%)	Ash (%)	Crude Fiber (%)
Whole Soybean	42	20	35	5.0	5.5
Defatted Soy Flour	54	1.0	38	6.0	3.5
Soy Protein Concentrate	70	1.0	24	5.0	3.5
Isolated Soy Protein	92	0.5	2.5	4.5	0.5

[1]*Moisture-free basis.*
[2]*Includes crude fiber.*

less than 1% fat and less than 3-1/2% crude fiber. The carbohydrate fraction contains polysaccharides, stachyose, raffinose and sucrose as shown in Table 7. Stachyose and raffinose have been implicated as causative factors of flatus related to soybeans (Rackis, 1970). The processes used for production of the various types of flours and grits are outlined in Figure 5.

Table 6. Typical Composition of Defatted, Dehulled Soy Flour/ Soy Grits[1]

	%
Protein	54
Oil	1
Ash	6
Soluble Carbohydrates	17
Insoluble Carbohydrates	21

[1]*Moisture-free basis.*

Table 7. Soluble Carbohydrate Composition of Dehulled, Defatted Soybean Meal[1]

Carbohydrate	%
Hexose	Trace
Sucrose	5.7
Raffinose	4.1
Stachyose	4.6
Verbascose[2]	Trace

[1]*Kellor, 1974*
[2]*Kawamura, 1967*

OIL EXTRACTION

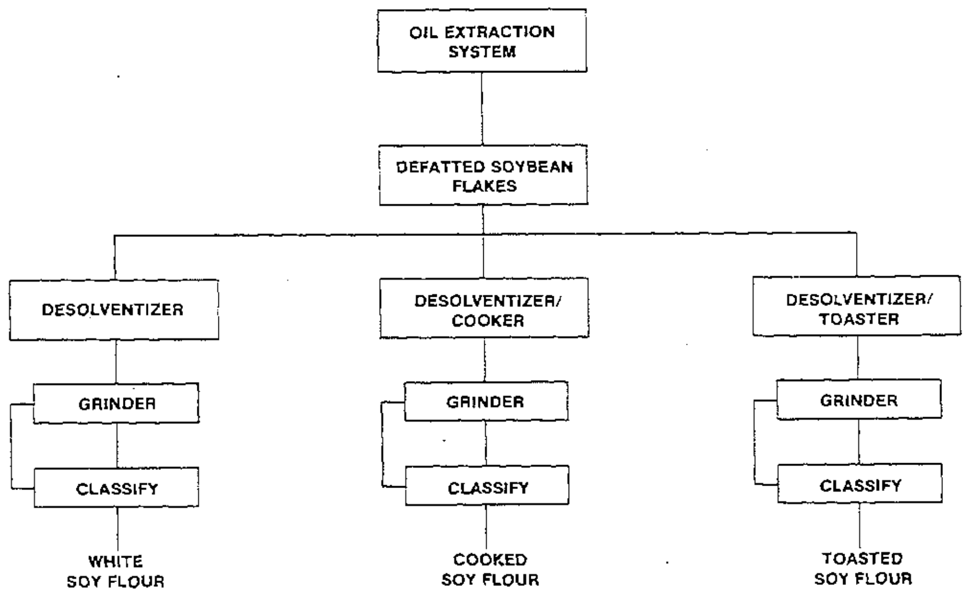

FIGURE 5. Schematic illustrating the processing of white, cooked, and toasted soy flour from defatted soybean flakes.

The range of protein solubility can be 85% and above for uncooked soy flour to less than 15% for toasted soy flour. The uncooked and lightly heat-treated products contain relatively high levels of trypsin inhibitor activity and need additional heat processing to reduce the inhibitor activity in the ultimate food application.

Soy flour and grits are classified by particle size to differentiate the various products.

Product	Mesh Size (U.S. Standard Sieves)
Grits	
Coarse	10-20
Medium	20-30
Fine	40-80
Flours	100 or finer

*U. S. Standard Screens.

Most soy flours are ground to 200 mesh with specialty flours having smaller particle sizes. Grits are obtained by coarse grinding and screening to obtain the specified particle size.

Flour and grits are used to produce a wide variety of products with varying particle size, protein solubility and fat content. The typical composition of commercially available soy flours (dry basis) are given in Table 8. The protein content of these soy flours ranges from 43% to 53% protein, depending on the oil content. The appropriate amount and type of oil or lecithin is added to defatted soy flour to produce refatted (high and low levels) and lecithinated (high and low levels) soy flour products.

Full fat soy flours which are enzymatically active are made by grinding cleaned, dehulled soybean flakes containing 19-21% natural oil. Toasted full fat soy flours can be produced by an extrusion cooking of cracked dehulled soybeans. The soybeans are heated dry to inactivate lipoxygenase, then tempered, and finally extruded. The extruded product is cooled and ground, resulting in a full-fat flour (Mustakas, 1970).

Soy flour can be textured by a number of processes. The two most common methods are the thermoplastic extrusion process (Flier, 1976 and Atkinson, 1978) and steam texturization process (Strommer, 1973). Products from these processes are produced in a wide variety of sizes, shapes, colors, and flavors, depending on the intended food application. Dry expan-

Table 8. Typical Composition of Commercially Available Soy Flour Products[1]

	Oil (%)	*Protein (%)*	*Carbohydrate*[2] *(%)*	*Ash (%)*
Defatted Soy Flour[3]	1	54	38	6
Full Fat Soy Flour[4]	20	40	35	5
Refatted Soy Flour[3] (High Fat)	15	45	33.5	6.5
Refatted Soy Flour[3] (Low Fat)	5	48	41.5	5.5
Lecithinated Soy Flour[5] (High Fat)	16.4	48.0	28.6	6.4
Lecithinated Soy Flour (Low Fat)	6	48	41	5

[1]*Moisture-free basis.*
[2]*Calculated by difference.*
[3]*Atkinson, 1978.*
[4]*Kellor, 1974.*
[5]*Smith & Circle, 1972.*

ded products are typically crunchy; however, upon hydration they become fibrous and chewy in nature.

Soy Protein Concentrates

Soy protein concentrates are defined as the major proteinaceous fraction of soybeans prepared from high quality, sound, cleaned, dehulled soybeans by removing most of the oil and water soluble nonprotein constituents. Soy protein concentrates shall contain not less than 70% protein (N x 6.25 on a moisture-free basis). Following the guidelines of this definition restricts the use of the term concentrate to only those products which contain more than 70% protein.

Soy protein concentrates are manufactured by removing the soluble carbohydrate fraction from thoroughly cleaned, defatted soy flakes or soy flour. The process is based on the principle that the cellulosic flake skeleton does not dissolve and the protein can be temporarily kept from solubilizing while most of the sugars, salts and other low molecular weight components are removed. Mechanisms used to inhibit protein solubility include: 1) leaching with aqueous and/or organic solvents with a concentration range in which the proteins are insoluble, but which extract the nonprotein solubles; 2) leaching with aqueous acids in the isoelectric range of minimum protein solubility, about pH 4.5.; 3) leaching of cooked or toasted defatted soy flakes with hot water; and 4) leaching in the presence of multivalent cations. The first three techniques tend to permanently insolubilize the protein, which inhibits protein functionality. The method of choice to maintain functionality is the acid leach process.

Since all insoluble carbohydrates, including cellular material, remain in the product, it is imperative that little extraneous matter not originating from the cotyledon of the bean, be allowed to remain in the flakes. This includes hulls, hila and the foreign materials, which are detectable through increased fiber content. Extensive cleaning along with low residual fat enhances the protein level of the flakes, which must be inherently high in order to achieve products with 70% protein.

Three processes are generally used to commercially produce soy protein concentrates: the aqueous alcohol leach, dilute acid leach, and the moist heat and water leach. The processes are outlined in Figure 6. The processes differ mainly in the methods used to insolubilize the major proteins while the low molecular weight components are removed.

The acid leach process begins by grinding defatted soy flour or soy flakes to obtain a particle size of 95% through a 200 mesh U.S. Standard Sieve. Fine particles aid in extraction of the solubles and allow the finished product to be atomized for spray-drying. The flakes are extracted with water which has been adjusted to the isoelectric point (pH 4.5) of the soy protein with a food grade acid. This technique immediately immobilizes the protein and allows only the soluble sugars and albumin to be leached during extraction. Extraction or leaching is carried out continuously for a specific period of time, which is a function of the particle size, temperature and the agitation. Separation of the soluble soy whey from the insoluble protein and cellulosic material is carried out by centrifugation, dilution and a final concentration. The pH of insoluble polysaccharide-protein mixture is raised to near neutrality and spray-dried (Moshy, 1964; Sair, 1959).

In the aqueous alcohol leach process, the nonprotein constituents are extracted with the appropriate mixture of alcohol and water, leaving the major protein fraction and the

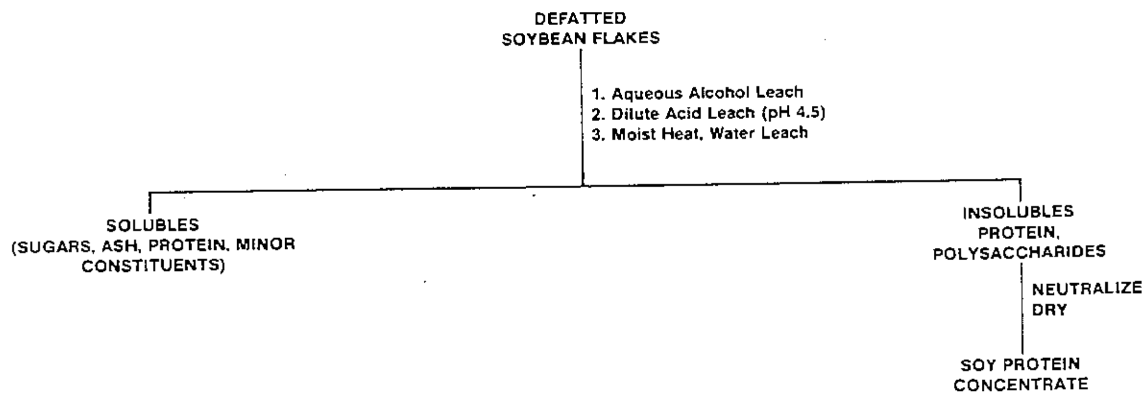

FIGURE 6. Flow diagram of process for preparing soy protein concentrates.

polysaccharides, which are desolventized and dried (Mustakas, 1962 and O'Hara, 1965).

The moist heat water leach process takes advantage of the heat sensitivity of the soy proteins. The flakes or flour are heated to insolubilize the protein. The water soluble fraction containing primarily low-molecular weight constituents is extracted. The insoluble polysaccharides and major protein fractions are dried, yielding soy protein concentrate.

The typical composition of soy protein concentrates prepared by the three processes is given in Table 9. The acid leach process results in a product with high protein solubility, whereas the alcohol leach and the moist heat, water leach processes result in products with low protein solubility.

Soy protein concentrates can be texturized by processes similar to those described earlier for soy flour, to produce a range of products of various sizes, shapes, colors, and flavors, depending on the intended food application.

The insoluble polysaccharide fraction of the dehulled, defatted soybean meal is shown in Table 10. This fraction is primarily composed of hemicellulose and cellulose.

Isolated Soy Protein

Isolated soy protein is defined as the major proteinaceous fraction of soybean prepared from high quality, sound, cleaned, dehulled soybeans by removing a preponderance of the nonprotein components that shall contain not less than 90% protein (N x 6.25) on a moisture-free basis. The process for the production of isolated soy protein is outlined in Figure 7.

The usual starting material for isolated soy protein production is defatted soy flakes or flour which has high protein dispersibility. The extraction process involves wetting the soy flakes, with a proper amount of water, controlled temperature, and mixing the necessary amounts of high quality food grade chemicals for the defined length of time. The pH is closely defined or controlled throughout this step in the process. This is critical to the overall yield. After the protein has been solubilized, it is separated from the insoluble polysaccharides and crude fiber by centrifugation. The protein extract contains the soluble carbohydrates and the major protein fractions. Food grade acid is added to adjust the pH of the extract to approximately 4.5, resulting in precipitation of the major protein fractions. The precipitated protein is commonly referred to as soy protein curd. Washing of the soy protein curd is essential to remove undesirable carbohydrates such as a raffinose and stachyose along with color and flavor components.

The soy protein curd can be spray-dried, producing an isoelectric-type isolated soy protein product.

Table 9. Typical Composition of Soy Protein Concentrates

	Alcohol Leach	*Acid Leach*	*Moist Heat Water Leach*
Protein (N x 6.25)%	66	67	70
Moisture %	6.7	5.2	3.1
Fat %	0.3	0.3	1.2
Crude Fiber %	3.5	3.4	4.4
Ash %	5.6	4.8	3.7
Nitrogen Solubility Index %	5	69	3
pH (1:10 Water Dispersion) %	6.9	6.6	6.9

(Meyer, 1967)

Table 10. Insoluble Carbohydrates of Dehulled, Defatted Soybean Meal

Hemicellulose
Cellulose
Lignin
Pectin
Other Complex Carbohydrates

The pH of the soy protein curd can be adjusted with various cations to obtain a number of isolated soy protein products. Various mechanical and physical means are employed to prepare the neutralized soy protein curd for spray drying. The dried isolated soy protein is packaged and stored. The composition of a typical isolated soy protein is shown in Table 11.

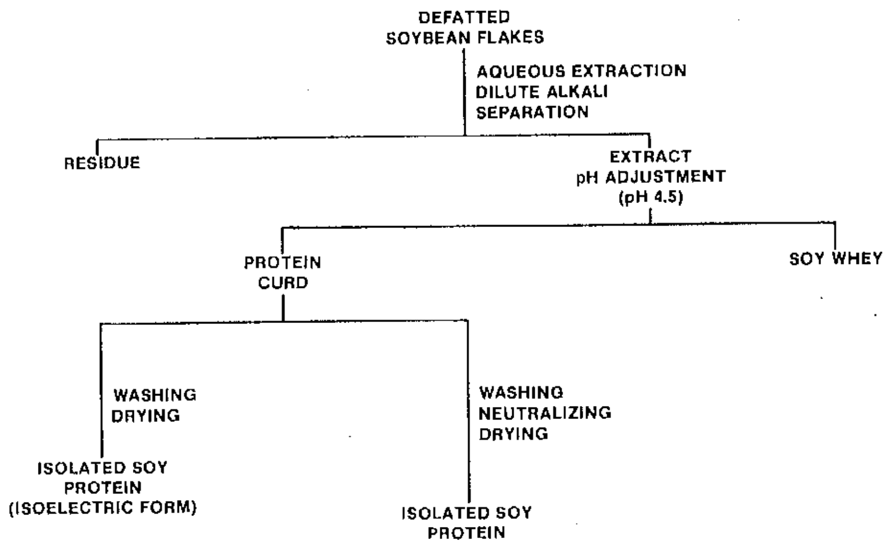

FIGURE 7. Outline of process for the production of isolated soy protein.

Table 11. Typical Composition of Isolated Soy Protein[1]

	%
Protein	92
Oil	0.5
Ash	4.5
Carbohydrates	0.3

[1]*Moisture-Free Basis*

The extractability of the proteins of defatted soybean flakes (or flour) as a function of pH, is shown in Figure 8 (Smith and Circle, 1938). This principle is employed for extraction and precipitation of major protein fractions of the soybean in the process for producing isolated soy protein. The major protein component of isolated soy protein is the globulin (Wolf, et al, 1962).

A wide variety of isolated soy protein products which have different functional properties are commercially available. The major functional properties are emulsification, fat absorption, water absorption, viscosity, gelation, fiber formation, and structure formation.

Isolated soy proteins can be texturized by several patented processes. Spun protein fibers, as described by Boyer

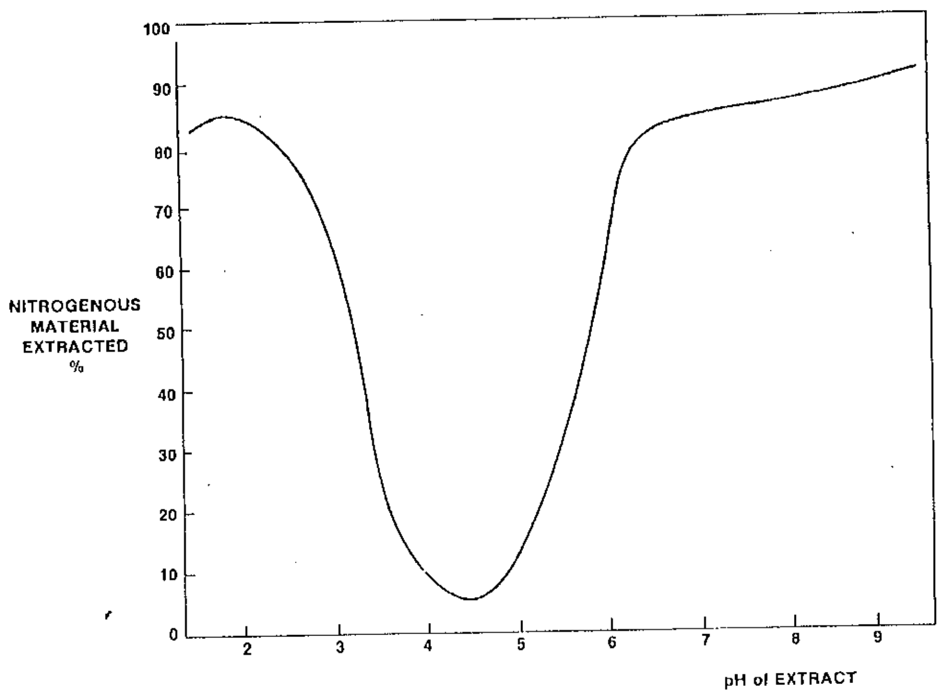

FIGURE 8. Effect of pH on the extractability of proteins from defatted soybean flakes (Smith and Circle, 1938).

(1954), are produced by passing an alkaline dispersion of soy protein through a spinnerette into an acid bath. The diameter of the fibers can range from 20 microns to 76 microns. This product is usually sold in a hydrated state.

Structured protein fibers are also commercially available and the process is described by Hoer (1972) and Frederiksen (1972). This product can be produced in a range of textural characteristics from tender to chewy, and is distributed in a hydrated (60-65% moisture) frozen state.

Amino Acid and Mineral Composition

The amino acid composition of soy protein products is important from a physical, chemical, and nutritional standpoint. The essential amino acid composition of typical soy flour, soy protein concentrate, and isolated soy protein is summarized in Table 12. The fractionation during processing accounts for differences in amino acid content between product categories. The sulfur containing amino acids, methionine and cystine, are considered to be the limiting amino acids in rat assays. The nutritional value of soy protein products will be discussed in detail in later chapters.

The mineral composition of soy flour, soy protein concentrates, and isolated soy protein is given in Table 13. These products contain nutritionally significant mineral such as calcium, iron, copper, phosphorus, zinc, and sodium.

FOOD USES OF SOY PROTEINS

Foods have unique chemical, physical and textural properties. The physical properties of meat, poultry, seafood, eggs, and dairy products are generally related to the proteins present in these products. The proteins in these foods contribute functional properties such as gelation, viscosity, emulsification, water absorption, dough formation, viscoelasticity, adhesion, cohesion, aeration, solubility, texture, flavor, and color.

The successful incorporation of soy proteins into traditional food products usually requires the protein ingredient to exhibit properties in the food product similar to that of the protein being supplemented, or replaced while not being detrimental to the overall quality. Soy proteins can also improve the characteristic properties of food products. The functionality properties of soy proteins are influenced by intrinsic variables of the food system such as pH, ionic concentration, solid content, processing conditions, etc. These

Table 13. Typical Mineral Content of Soy Protein Products

Element	*Defatted[1] Soy Flour*	*Soy Protein[2] Concentrate*	*Isolated[3] Soy Protein*
Arsenic	0.1 ppm	--	0.2 ppm
Cadmium	0.25 ppm[3]	--	<0.2 ppm
Calcium	0.22%	0.22%	0.18%
Chlorine	0.132%	0.11%	0.13%
Chromium	0.9 ppm[3]	<1.5 ppm	<1.0 ppm
Cobalt	0.5 ppm	--	<1.0 ppm
Copper	23 ppm	16 ppm	12 ppm
Fluorine	1.4 ppm	--	<10 ppm
Iodine	0.01 ppm	0.17 ppm	<10 ppm
Iron	110 ppm	100 ppm	160 ppm
Lead	0.2 ppm	--	<0.2 ppm
Magnesium	0.31%	0.25%	380 ppm
Manganese	28 ppm	30 ppm	17 ppm
Mercury	0.05 ppm[3]	--	<0.5 ppm
Molybdenum	2.6 ppm[3]	4.5 ppm	<3.0 ppm
Phosphorus	0.68%	0.70%	0.76%
Potassium	2.37%	2.1%	960 ppm
Selenium	0.6 ppm	--	0.36 ppm
Sodium	254 ppm	50 ppm	1.1%
Sulfur	0.25%	0.42%	--
Zinc	61 ppm	46 ppm	40 ppm

[1]Kellor, R. L., *J. Am. Oil Chem. Soc.*, *51*, *77A*, *1974*.
[2]Anon., *Technical Service Bulletin, Product Information Sheet:* Promosoy-*100*, *Central Soya, Chicago, Ill.*
[3]Anon., *Ralston Purina Company, 1978, Unpublished Data.*

Meat Products

One of the major uses of isolated soy protein is in comminuted or emulsified meat products, such as frankfurters, bologna and various loaves and coarse ground meat products. Isolated soy proteins are being used as complementary proteins to the meat proteins not only because of their moisture-binding, fat emulsifying and emulsion stabilizing properties in meat products, but, also, their nutritional and flavor characteristics. According to Schweiger (1974) "Soluble soy protein isolates are used mainly for their emulsifying capability, their emulsion stabilizing effect, and their property of increasing viscosity and forming gels on heating." Isolat-

Table 12. Essential Amino Acid Composition of Soy Derived Protein Products

	gm Amino Acid/100 gm Protein		
Amino Acid	*Soy Flour*[1]	*Soy Protein Concentrate*[2]	*Isolated Soy Protein*[3]
Isoleucine	4.7	4.8	4.9
Leucine	7.9	7.8	7.8
Lysine	6.3	6.3	6.4
Methionine	1.4	1.4	1.3
Cystine	1.6	1.6	1.3
Phenylalanine	5.3	5.2	5.4
Tyrosine	3.8	3.9	4.3
Threonine	3.9	4.2	3.6
Tryptophan	1.3	1.5	1.4
Valine	5.1	4.9	4.7

[1]*Kellor, R. L., J. Am. Oil Chem. Soc., 51, 77A, 1974.*
[2]*Anon., Technical Service Bulletin, Product Information Sheet:* Promosoy-*100, Central Soya, Chicago, Ill.*
[3]*Anon., Ralston Purina Company, 1978, Unpublished Data.*

variables should be incorporated into laboratory methods designed for measuring the functional characteristics of soy proteins so that relationships may be established between basic properties and the food application. However, because of the complexity of the interaction between ingredients, it is preferred to evaluate the proteins in the actual food system to determine their applicability.

Major applications of soy protein products are in processed meat and fish products, bakery products, dairy-type products, infant formulas, protein supplements, hospital feeding, meat analog products, and a variety of formulated or fabricated food products.

ed soy protein is used in comminuted meat products to supplement the myosin and actomyosin in emulsifying and encapsulating fat to prevent fat separation and to bind water and especially meat juices during cooking. The above properties of isolated soy proteins allow for the high replacement of meat proteins in emulsified meat products. The replacement of high levels of meat proteins (30%-75%) requires soy products that are capable of imparting a characteristic meat-like texture (Roberts, 1974). At high levels of replacement the soy protein product must have the functionality characteristics to emulsify fat and water and contribute a physically desirable structure to the meat product, and also retain a good nutritional and flavor profile. For example, in frankfurters and bologna-type products, the degree of resiliency and firmness during mastication are two properties which contribute to the property commonly know as "bite" (Roberts, 1974). Isolated soy proteins have the ability to contribute these organoleptic properties to emulsified meat products.

Isolated soy proteins have multiple functional properties which contribute in different ways to an emulsified meat product. They are low in flavor and odor and contribute gel-like properties to an emulsified meat product in a manner similar to that of meat proteins (myosin and actinomysin). The other soy products usually have lower solubility characteristics and are used primarily for fat and water absorption properties. Isolated soy proteins have improved flavor and odor characteristics when compared to other soy products. This becomes more important in frankfurter-type products that are being marketed in the U.S. in which up to 40% of the protein present in these products is provided by isolated soy protein. The use of soy protein products allows meat emulsions to be prepared in a wider-range of emulsion temperatures than is possible when using meat proteins only. The use of isolated soy protein may permit a manufacturer to utilize a wider variety of meat cuts while maintaining overall product quality.

Textured soy flour and concentrates are used extensively in coarse, ground meat products and convenience food items, such as frozen dinners or frozen entree items that are served at home and in institutional food service, as extenders and for the maintenance of textural properties. The textured soy products can also contribute some water and fat absorption properties to these products in addition to their chewy and other textural characteristics. They are also used in pizza toppings, chilli products, meatballs, meat patties, tacos, meat spreads, poultry products and fish patties. Isolated soy proteins are used in combination with textured soy flour and concentrate products to provide binding, adhesive and cohesive properties.

The utilization of soy proteins in extending intact muscle tissue to increase finished product yield while maintaining protein equivalency in traditional products is described by Hawley, et al (1976). This development deals with the injection or pumping of ham or other intact muscle tissues with isolated soy proteins and brine solutions. A brine is prepared with isolated soy protein, salt, sugar, and flavorings. This brine mixture is injected into the muscle tissue and then the muscle tissue is massaged or tumbled to assist in the penetration and uniform distribution of the isolated soy protein in the muscle tissue. The meat is then stuffed in a casing, smoked and cooked according to the normal process. High quality hams with yields of 135% of green weight can be prepared. This procedure is a significant advancement since it is not necessary to grind, mince, or chop meat in order to extend it with soy protein products.

New meat products employing isolated soy protein are now entering the marketplace. These products utilize the lean meat portions of the animal in combination with fatty tissue and isolated soy proteins to yield a fabricated bacon-type product. The manufacturers are taking advantage of the binding properties of isolated soy proteins to produce a bacon-type product with decreased dimensional shrinkage and cooking loss during frying or cooking (Moore, 1978).

Isolated soy proteins are used in several meat products in Japan. The isolated soy proteins are used as binders in sectioned and formed hams, as stabilizers of emulsions in fish sausage, as binders in sausage for water retention, and as protein supplements. The soy protein is also being used in extending some of the traditional Japanese foods such as fish sausages, kamaboko, chikuwa, agekama, and pressed ham. The protein must contribute a gel-like texture with viscoelastic properties similar to that obtained with fish proteins.

Poultry rolls are being prepared with structured isolated soy proteins and powdered isolated soy proteins. These two products can complement each other with one providing the textural properties for the poultry roll and the other contributing to the binding or adhesion characteristics by forming a gel. The isolated soy protein in combination with structured soy products is especially effective in upgrading mechanically deboned meats to food products with acceptable form, color, flavor, and mouth feel.

Baked Products

Significant quantities of full-fat and defatted soy flour and soy concentrates have been used in the baking industry for many years. Recently isolated soy proteins are being used in these applications. Two general categories of full-fat and defatted soy flours are used, the enzyme active and enzyme inactive soy flours. Only a limited amount of full-fat soy flours is used in the United States. A much higher level of full-fat soy flour is being used in the United Kingdom and Europe. The functional properties, such as enzymatic activity and water absorption capacity, are important to some bakery systems. Enzyme active soy flours are used to improve the crumb color of bread and other yeast raised products, especially those which are not chemically bleached. Low levels of the full-fat soy flour added to wheat flour at levels of 1/2-1% of the wheat flour allows the production of bread with increased crumb softness and improved keeping quality (Pringle, 1974).

Defatted soy flour is used in combination with dried cheese whey for the replacement of non-fat dry milk in the production of white bread. The toasted soy flours are used to retain moisture and produce a softer, longer lasting product. The full-fat flours act as natural emulsifiers and stabilizers in baked goods as well as producing a product with a softer, moister crumb.

Soy flour at levels of 6-12% of the wheat flour has been used to produce high protein specialty breads (Hoover, 1974). Usually sodium stearoyl-2-lactylate or ethoxylated monoglycerides are utilized with the soy flour to maintain loaf size and structure. Tsen and Hoover (1973), and Pomeranz, et al (1969) demonstrated that bread with acceptable volume, grain and texture could be prepared with up to 24 lbs. of soy flour per 100 lbs. of wheat flour. This is a relatively economical way of providing an increased level of protein to the world population.

Soy flours are used at varying levels in doughnut and cake mixes. The soy flour helps regulate the amount of oil absorbed during the frying stage in doughnut production. The use of soy flours at a level of approximately 2% in commercial cake formulations appears to aid in producing cakes that are more tolerant to process and ingredient variations according to Cotton (1974).

Isolated soy proteins are being used in cake and doughnut mixes as replacements of non-fat dry milk. The isolated soy protein, when combined with corn syrup solids, dried cheese whey or other carbohydrates, functions as a replacement for non-fat dry milk in many of these applications.

Soy flours are used in some varieties of crackers. It is estimated by Cotton (1974) that the soy flour content of these specialty crackers is 2-5% of the total ingredient weight.

Tsen and Hoover (1973) used soy flour to develop a high protein cookie. Presently, a high protein cookie that utilizes isolated soy proteins as the protein source is being manufactured in Canada. Soy flour added to cookie doughs improves the release properties of the dough in mechanical operations, imparts a nutty flavor to the cookie and aids in the emulsification of fats and other ingredients in the dough (Levinson and Lemancik, 1974).

Infant Formulas and Food

Milk-free diets have been developed for use in the care of infants with special nutritional requirements or that need special care. The first formulas developed during the early 1950's utilized soy flour as the source of protein. These were considered to be among the better milk substitutes available to provide the complete nutrition for the infant during its early days of life. However, infants fed these formulas often produced loose malodorous stools and this causes chafing in the diaper area (Fomon and Filer, 1974). This condition probably results from the presence of indigestible sugars. A second generation of infant formulas based on isolated soy proteins was developed during the early and mid 1960's. These formulations had improved color, odor, flavor, and seldom caused loose or malodorous stools. The indigestible carbohydrates or other irritating components are removed during the production of isolated soy proteins (Fomon and Filer, 1974). It has been estimated that in 1973 about 10% of the infants in the U.S. were fed formulas based on isolated soy protein (Fomon and Filer, 1974). The usage level is reported to be increasing each year with formulas available in both liquid (concentrated and ready-to-use) and dry form.

In addition to the milk-free infant formulas, special formulas utilizing isolated soy proteins have been developed for older infants, geriatric, hospital, and postoperative feeding. Low carbohydrate diets designed to aid in the diagnosis of disaccharidase deficiency or monosaccharide intolerance have been developed. Soy flour, soy protein concentrates and isolated soy protein can be used to increase the protein content of cereal products such as rice and wheat, when the infant begins to utilize solid foods.

Food Analogs

Several meat analog products are being produced that utilize soy flour, soy concentrate and isolated proteins. These analog products usually contain other sources of protein such as wheat gluten, egg albumin, and yeast. The soy proteins are used in both the textured and powder forms. The production of meat analog products and processing of textured products is

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A variety of analog products are available for vegetarians or people who have special dietary needs. Several products have been developed and are marketed for breakfast, lunch and dinner meals. Various meat analog products are manufactured and marketed for use as seasonings for garnishes and related dishes.

Dairy Type Foods

Soy proteins are used in dairy-type products. In addition to the use of soy protein products as replacements of non-fat dry milk in baked goods and the use of isolated soy protein in infant formulas, isolated soy proteins are also being used in critically emulsified products, such as non-dairy coffee whiteners and whipped toppings. The functional properties are especially important in these products and appear to be more critical than for their application in meat and bakery products (Claus, 1974). The functional requirement for protein in these applications requires the refinement found only in isolated soy protein.

Properties of specific isolated soy proteins allow the protein to function in these applications in an excellent manner. Considerably more stress is placed upon a dry coffee whitener than a liquid coffee whitener. The use of isolated soy protein to replace approximately 50% of the sodium caseinate in spray dried coffee whiteners is described by Cho and Kolar (1977).

Isolated soy proteins are being used in liquid, aerosol and frozen-type whipped topping products. It is being used in evaporated-type milk products. Isolated soy protein is used as a protein source in a dry product designed for addition to milk by the consumer with the resulting product supplying the nutritional needs of a complete breakfast. A considerable amount of development activity is underway in the utilization of isolated soy protein in yogurt, sour cream,frozen desserts, cheese and dip-type products.

Isolated soy proteins and soy protein concentrates are used as protein sources in milk replacers for baby animals, such as pigs, lamb, and calves. In these formulations, the primary function of the protein is to serve as a protein source to provide nutrition to these animals.

Protein Supplements

Isolated soy protein, soy concentrates and soy flours are used as protein sources in the protein supplement industry, with isolated soy protein being the protein source of choice by many of these manufacturers. Several companies manufacture products that are 80% protein or greater and contain other protein sources, vitamins and minerals, and flavorings. These products are marketed as protein supplements to the normal diet.

Isolated soy protein and skim milk powders are the most suitable sources of protein for slimming food products. (Kolb, 1974.) The selection of isolated soy proteins is based on its acceptable sensory qualities, favorable amino acid composition, high protein content with low non-protein calories and with a relatively light color. The isolated soy protein has good dispersibility, suspension properties and good storage stability.

Other Uses

Special soy protein products that are highly water soluble are prepared by an enzymatic modification. These products have the ability to form a foam when dissolved in water and whipped, and are used for the aeration of food products. The incorporation of air into a food product frequently will bring about improvements in texture and consistency. These protein based whipping agents are used in confectionery products, marshmallows, biscuits, cookies, foam heads on soft drinks, and prepared cake mixes, etc. (Mansvelt, 1974). The hydrolyzed soy protein whips faster and is more tolerant to overbeating and higher temperatures than egg albumin. It has good moisture retention which improves the shelf-life of marshmallows (Levinson and Lemancik, 1974). These soy products are used in angel food box cake mixes and provide a foaming effect in dry cocktail mixes.

Isolated soy protein and soy concentrate are being formulated in meal replacement products that are designed for breakfast and snacks. Soy protein products are used in breakfast cereals to increase the protein content and to assist in providing an overall complete nutritional breakfast.

Products manufactured from the whole bean, without defatting are being produced and are called soy nuts. These products are eaten directly as snacks and also are used in the baking industry as a replacement of the more expensive nuts.

Soy flour or isolated soy proteins have been approved for use in margarine as a part of the standards of identification for margarine products; however, the amount of soy proteins being used in this application is not known (Code of Federal Regulations, 1977).

Soy protein food products play a major role in U.S., overseas and domestic food assistance programs (Senti, 1974). Through these food assistance programs, the U.S. Agency for

International Development has donated food to many countries. Soy protein products were designed primarily for children in the developing nations. Textured soy protein products and protein fortified enriched macaroni were introduced to the U.S. school lunch program to meet part of the meat requirements in a Type Two school lunch program. In addition, a school lunch-breakfast program allowed the use of soy protein as an ingredient in protein fortified foods such as donuts, cake-like baked products and cereal-fruit products (Senti, 1974). Some of the fortified formulated food products used for distribution in foreign food programs are corn-soy blend (CSB) and corn-soy-milk mix (CSM).

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DISCUSSION

Altschul: The various fractionations that you have reported on, do they reflect the information, let's say, on the cellular location of the various fractions of the seed and on the information that is coming out about the various protein fractions, and do you see that perhaps there could be newer types of fractionations evolving out of this knowledge?

Waggle: Aaron, that is a loaded question. From the standpoint of processing into isolates, we are recovering part of the 2S, most of the 7S, 11S and 15S fractions. The 7S and 11S fractions are the major proteins present and they are likely to be the primary contributors to functionality of isolates. Of course, soy flours contain all of the protein fractions found in soybeans. In soy protein concentrates made by the acid leach process, the low molecular weight proteins are partially removed. I do forsee that the major protein fractions could be separated to make commercial products. I think this will depend on the application in the sense that the protein will have to perform a particular function in the food system.