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NUTRITIONAL IMPROVEMENT OF FOOD AND FEED PROTEINS

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SOY PROTEIN UTILIZATION IN FOOD SYSTEMS

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ABSTRACT

Soy protein products are utilized in food systems as whole beans, flours and grits, concentrates and isolates, and textured products. Soy proteins play a significant role in food systems as a source of supplementary and complementary protein and contribute functional properties such as solubility, water absorption, viscosity, emulsification, texture, and antioxidation. Whole soybeans are processed into snack foods, beverages, and fermented foods. Soy protein is an ideal supplement for cereal protein because it corrects lysine and other amino acid deficiencies. Blends of soy flour or grits with cereals such as corn, wheat, or sorghum are widely used in world feeding programs. The blends are also valuable in domestic food systems such as breakfast cereals and baked foods. Concentrates and isolates are utilized in processed meats and baby foods. Isolates are employed as whipping agents and coffee whiteners. Thermoplastic extrusion of defatted flours or protein concentrates produces an expanded type of textured protein. Isolated soy protein is converted to meat analogs by a spun fiber process. Textured soy protein products are used to extend or replace meat products in food systems.

INTRODUCTION

Soybean products have been consumed for centuries in the Orient. A variety of soybean foods including tofu, shoyu (soy sauce), miso, and tempeh have been developed (Hesseltine and Wang, 1972). Processes used include cooking, grinding, extraction, fermentation, and even sprouting. In contrast to these well-established food patterns in the Orient, it was not until the 20th Century that the Western World recognized soybeans for their human food value. In the last few decades, the soybean has become a major element of world commerce. By 1973, soybeans were the No. 1 cash crop in the United States.

Soybeans are now our major source of edible oil. Introduction of the solvent extraction process, replaced the expeller to yield the maximum amount of oil and also produced a higher quality oil and defatted meal (Weiss, 1970). Most of the extracted oil is consumed in the form of salad and cooking oils, shortening, and margarine. Of the approximately 18-19 million metric tons of defatted soybean meal produced annually in the United States, the majority is utilized in animal feeds. Only about 3% of the defatted meal is used directly in human food.

In 1973 (Lockmiller), soy proteins in food systems were increasing at the rate of about 5-7% per year. Currently the annual growth rate is estimated to be about 10% (Anton, 1975). New product types with a wide range of functionality, high nutritive value, and low costs relative to animal proteins contribute to this growth. Slower market growth rates are found in some high quality soy products that require specialized processing which puts the product in the same cost range as animal protein. Although use of soy proteins is still relatively small, many of the major food companies are now incorporating them into some of their products. This paper will consider various soy protein products and characteristics relative to their application in food systems.

PRODUCTION OF COMMERCIAL FORMS OF SOYBEAN PROTEINS

Soybean proteins available to the food industry are conveniently classified into three major groups based on protein content. Flour and grits are further classified into products based on fat content (Wolf, 1970). Typical analyses for these products are shown in Table 1. The products range from flours and grits to textured isolates.

Full-fat products. Several methods can be used to produce full-fat soy flour. In one, soybeans are treated with live steam in a conveyer, followed by cooling, drying, and milling to flour (Horan, 1967). In another (Bookwalter et al., 1971a), milled grits are dry heat-treated at 105° for 6-8 min to inactivate lipoxygenase. Then the grits are adjusted to about 20% moisture and extrusion-cooked at about 135°, 1.25 min retention time, followed by cooling, drying, and milling to flour. Cooking of soybean products is necessary to inactivate lipid enzymes and antinutritional factors. Foods in which the whole soybean is used, including the seed coat, have been described by Nelson et al., 1971. Whole soybean food prototypes such as canned chicken and soybeans have been prepared. Whole soybeans can also be roasted for use as a snack food (Lockmiller, 1973).

TABLE 1

Commercial forms of soybean proteins and their analyses* (Wolf, 1970)

Form	Protein %	Fat %	Moisture %
Flours and grits			
Full-fat	41.0	20.5	6.0
High-fat	46.0	14.5	6.0
Low-fat	52.5	4.0	6.0
Defatted**	53.0	0.6	6.0
Lecithinated	51.0	6.5	7.0
Concentrates**	66.2	0.3	6.7
Isolates**	92.8	<0.1	4.7

*"As is" basis.
**Base materials for textured protein products.

Defatted flours and grits. Defatted soy flour and grits are processed from cleaned, whole soybeans which have been dehulled, flaked and then defatted by hexane. Precise control of the heat treatment given the defatted soy flakes during the desolventizing process and during subsequent steps is critical in that both the nutritive value and functionality are directly dependent upon the degree to which the product is heat treated (Kellor, 1974). An untoasted, defatted soy flour retains high protein solubility and is useful for preparation of concentrates, isolates, and as a base material for thermoplastic extruded textured protein. A fully toasted soy flour is low in protein solubility, but the antinutritional factors are minimized. Defatted soy flour of various combinations of heat treatment, with various levels of added fat and lecithin, are produced for special uses (Table 1). Defatted soy flour proteins are also hydrolyzed by acid, enzymatic, or fermentation treatment to break them down into amino acids, peptides, and polypeptides. The products, hydrolyzed vegetable proteins, are useful as flavoring agents (Lockmiller, 1973).

TABLE 2

Typical composition (%) of soy flours, concentrates, and isolates* (Horan, 1974)

Component	Defatted flour	Concentrates	Isolates
Protein	56.0	72.0	96.0
Fat	1.0	1.0	0.1
Ash	6.0	5.0	3.5
Oligosaccharides (soluble)**	14.0	2.5	0
Polysaccharides (insoluble)†	19.5	15.0	0.3
Fiber (cellulose)	3.5	4.5	0.1

*Moisture-free basis.
**Sucrose, stachyose, raffinose, verbascose.
†Acidic polysaccharides, arabinogalactan, starch.

Protein concentrates. Soybean protein concentrates are refined forms of defatted soy flour (Table 2). The undenatured, 50% protein, defatted flakes are upgraded to the higher protein product by leaching out soluble carbohydrates, the oligosaccharides (sucrose, stachyose, raffinose, verbascose), part of the ash, and some of the minor components. This is done by washing the defatted flakes with either 60-80% aqueous alcohol or dilute (pH 4.5) acid. Another method involves moist heat to insolubilize the proteins, followed by a water wash (Horan, 1974). Several new modifications of these methods are described by Wolf (1976). Protein concentrates are useful in food systems to contribute functionality and also as a base material for thermoplastic extruded textured protein.

Protein isolates. The most refined forms of soybean proteins are the isolates, which contain 90% or more protein (Table 2). They are prepared by removing the water-insoluble polysaccharides, as well as the water soluble oligosaccharides and other low-molecular-weight components that are separated in making protein concentrates. Defatted flakes are treated with a mild alkaline solution to dissolve the proteins, and the insoluble carbohydrate residue is separated. The proteins are then acid coagulated into a curd at the isoelectric point (pH 4.5). By this treatment the proteins are separated from the soluble carbohydrates. The precipitated proteins are then washed and dried to give the isoelectric protein which is insoluble in water (Horan, 1974). Usually the protein is neutralized before drying to yield the proteinate form which is water dispersible. Isolates are now available which have processing modifications to make them suitable for different food applications (Wolf, 1976). Isolated soy protein is utilized as a base material for the production of textured vegetable protein by the spinning process.

Textured soy proteins. Defatted soy flours, concentrates, and isolates can be transformed from a flaky or powdery material to one which has "chewiness" and a fibrous texture. Two principal processes are utilized, thermoplastic extrusion and fiber spinning. In the thermoplastic extrusion process, either defatted soy flour, concentrates, isolates, or combinations of these are blended with steam and water, flavors, colors, or chemical additives to control density or structure (Atkinson, 1970; Reinhart and Sair, 1975; Puski and Konwinski, 1976). While mixing, mechanical heat is developed, and steam heat is applied which causes a high pressure near the die outlet. Then as this mixture is extruded rapidly into atmospheric pressure, the moisture expands to form tiny air pockets throughout the mass. It is the thin wall structure between these air pockets which creates the texture of the product. Isolated soy protein is converted to textured protein by a spinning process. Isolated soy protein is solubilized in an alkaline medium and passed through a spinnaret to form fibers by coagulation in an acid bath and then stretched by means of a series of rolls revolving at increasing speeds. Bundles of fibers are held together with edible binders and treated with other ingredients such as colors, flavors, seasonings, and supplementary nutrients to give fabricated slices, cubes, bits, or granules with an oriented fibrous structure to simulate animal tissues (Horan, 1974).

More recently, meat-like textures have been produced with pressure-molded mixtures of thermoplastically extruded concentrate, stabilized fat, binder, and flavor (Howard, 1976). Chewy meat-like textures also result from precipitating soy protein isolates into meat-like pieces, followed by heating in an oil bath, cooling, and stabilizing in a water bath (Kumar, 1976). Levinson (1976) produced a fibrous chewy texture by placing compacted defatted soy grits in a mild acidic solution containing propylene glycol which was heated to 120°, followed by filtration and drying.

CHARACTERISTICS RELATIVE TO FOOD USES OF SOYBEAN PROTEINS

Flavor and color. The bitter flavor of raw legumes, including soybeans, is readily eliminated by mild cooking (Moser et al., 1967). The residual "beany" flavor of soybean proteins is more difficult to remove and has been a limiting factor to their use in food systems. The objective of soy protein manufacture is the production of a bland material, but this has not always been the case (Kalbrener et al., 1971). New processing methods are being developed to minimize "beany" flavor characteristics. A combination of toasting and hexane:ethanol azeotrope extraction can be used to produce soy flours and concentrates with flavor scores which are similar to wheat flour (Honig et al., 1976). Azeotrope extraction effectively removes residual lipids (Sessa et al., 1976) which have been associated with undesirable flavors in soy products. Substantial progress has been made toward soy proteins with improved flavors. For example, soy protein isolates are being substituted for milk proteins in coffee whiteners, a food system which requires a bland flavor and light color.

In addition to flavor, the dark color of soy flours had previously limited their application in some food systems. For instance, the use of soy flours of the mid-1940's in bakery goods resulted in poor colored finished products (Hoover, 1975). Considerable improvements in product color have been brought about through process developments such as carefully controlled desolventizing and toasting, chemical treatments, and further purified products such as concentrates and isolates.

Biological and physiological factors. The diverse biological and physiological characteristics of soy protein products have been reviewed by Rackis (1974). The flatulence element has prompted considerable research interest. The gas-producing factor resides mainly in the low- molecular-weight carbohydrate fractions, soy whey solids, and aqueous alcohol extractives. These fractions contain 60-80% water-soluble, alcohol-soluble oligosaccharides, primarily as sucrose, raffinose, and stachyose. Thus, the removal of oligosaccharides in the production of concentrates and isolates also removes the flatus factor. The production of intestinal gas appears to be related to the intake levels of soybean products which contain the oligosaccharides. Flatulence was not indicated in a feeding study of a cereal blend containing 38% full-fat soy flour (Graham, 1973). During 11 years of feeding cereal blends fortified with as much as 27.5% defatted, toasted soy flour, no cases of flatulence have been reported. Little or no flatus activity is present in the hulls, fat, protein, or the water-insoluble high-molecular-weight polysaccharides.

Nutritional aspects. Raw soybean meal contains antinutritional factors such as trypsin inhibitor and other heat-labile components (Rackis, 1974). The adverse effects of these factors have been demonstrated in rat feeding studies. Although their effects on humans are unknown, soybean protein products are heat-treated to optimize their nutritional value. The relationship between heat treatment, nutritive value, and activity of antigrowth factors is shown in Table 3. With increased heat, protein efficiency ratios increase as the antigrowth factors decrease. The decrease in protein dispersibility indicates heat denaturation of the protein. In food systems which require a further cooking step after formulation, it may not be necessary to use a fully cooked soy protein.

TABLE 3

Relationships between heat treatment, nutritive value, and activity of selected antigrowth factors in soybean flour (Kellor, 1974)

Heat treatment			Antigrowth factor activity*	
Degree	PDI**	PER†	SBTI	Hemagglutinin
Untoasted	85+	1.31	500	52
Lightly toasted	60-75	1.59	150	51
Fully toasted	20-40	2.19	15	14

*SBTI = soybean trypsin inhibitor.
**PDI = protein dispersibility index.
†PER = protein efficiency ratio (corrected to 2.50 casein control).

TABLE 4

Essential amino acid content of soybean proteins (Wolf, 1970)

Amino acid	Grams amino acid per 16 grams nitrogen		
	Defatted flour	Concentrate	Isolate
Lysine	6.9	6.6	5.7
Methionine	1.6	1.3	1.3
Cystine	1.6	1.6	1.0
Tryptophan	1.3	1.4	1.0
Threonine	4.3	4.3	3.8
Isoleucine	5.1	4.9	5.0
Leucine	7.7	8.0	7.9
Phenylalanine	5.0	5.3	5.9
Valine	5.4	5.0	5.2

The essential amino acid compositions of defatted flour, concentrate, and isolate are shown in Table 4. Processing has little effect on the essential amino acid distribution. Although the essential amino acids are well balanced, methionine is the first limiting amino acid of soybean proteins (Coppock, 1974). Fortification with 0.48% DL-methionine to full-fat soy flour results in significantly higher protein efficiency ratios (Bookwalter et al., 1975). Soybean proteins being high in lysine, the first limiting amino acid in cereals (Kato and Muramatsu, 1971), are useful as supplementing blends. Soy flours are a major factor in producing nutritious food mixtures with cereals such as corn, wheat, sorghum, and oats (Bookwalter, 1977; Crowley, 1975; Horan, 1973). Table 5 lists cereal-based blended food mixes which are supplemented with various defatted, toasted, or full-fat soy products in the form of flours, flakes, and grits. These commodities are donated to nutritionally deprived people overseas under Public Law 480. In addition to increasing the protein content, the protein quality also improves by combining cereal with soybean proteins. By addition of 15% soy flour to degermed corn meal, protein efficiency ratios (PER) increase from about 0.4 to 2.0 (Bookwalter et al., 1971b). Addition of the same level of soy protein to sorghum meal results in a PER increase from about 0.3 to 1.8 (Bookwalter et al., 1977). PER does not respond to the addition of DL-methionine in these and other tests (Bookwalter et al., 1975), which indicates that adequate sulfur amino acids are supplied by the cereal components. In 12% soy-fortified bread, the PER value is 1.95 compared to 1.00 in regular white bread (Marnett et al., 1973). Human feeding studies by Graham et al. (1972, 1973) indicate satisfactory biological values for cereal-soy blends. Other food systems, such as breakfast cereals, pasta products, specialty breads, and snack items utilize the complementary effects of soy protein (Wolf and Cowan, 1975).

Textured flours, concentrates, and isolates have been used extensively in the human diet with meat products. Wilding (1974) reported on hydrated textured soy protein at levels of 0, 12, 21, and 30% in chicken patties, meat loaf, meat balls, and other meat preparations. PER values at levels of 12-30% were higher than casein. With human subjects, Kies and Fox (1971) compared textured vegetable protein (TVP) and TVP containing 1% DL-methionine with ground beef at 4.0 or 8.0 g of nitrogen per person daily. At the 4.0 g

TABLE 5

Cereal-based blended food mixes* supplemented with soybean protein products

Commodity	Soybean protein	
	%	Type
Soy-fortified corn meal	15	DT**-flour
Corn-soy blend	22	DT-flour-E†
Corn-soy-milk (CSM)	17.5	DT-flour-E
Instant CSM	23.7	DT-flour-E
Instant CSM, sweetened	27.5	DT-flour-E
Soy-fortified bread flour	12	LT‡-flour
Soy-fortified bulgar	15	DT-grit
Soy-fortified sorghum	15	DT-grit
Soy-fortified rolled oats	15	DT-flake
Wheat-soy blend	20	DT-flour

*Public Law 480, Title II commodities.
**DT = defatted, toasted.
†E = equivalent (full-fat) soy flour optional.
‡LT = defatted, lightly toasted.

nitrogen intake level, beef was superior to TVP on the basis of nitrogen balance. Methionine fortification was partially effective in improving the nitrogen balance, demonstrating that it is the first limiting amino acid in TVP. However, at 8.0 g of nitrogen intake, no significant differences were observed between nitrogen balances of subjects who consumed one of the three sources of nitrogen. It was concluded from these studies that below a critical level of intake, soy proteins had a lower protein value than beef; but at more liberal levels, soy proteins could meet the protein requirements of adult men. Greater quantity of soy protein compensated for lower quality.

Soy proteins are also being utilized in special dietary foods. In infant formulas, they provide nutrients for infants who are allergic to cow's milk (Decock, 1974). Soy proteins are also utilized to fabricate foods for segments of the population who require a low cholesterol diet such as simulated meats derived from spun fibers or in dietary wafers which provide balanced nutrition along with controlled caloric intake (Kolb, 1974).

Functionality. The soy flours, concentrates, and isolates are further modified into a large number of other products for specific functional and nutritional uses (Smith and Circle, 1972; Wolf and Cowan, 1975). The functional properties of the specialized soy protein forms enhance their usefulness and generally limit their application to specific food systems. Table 6 lists the wide range of functional properties which may be achieved with various forms of soy protein and their contribution to food systems. Functional properties such as emulsification, fat absorption, water absorption, solubility, texture, dough formation, and film formation are utilized in food systems such as bakery goods, meats, infant formulas, pasta products, and specialty items.

TABLE 6

Functional properties of soybean proteins in food systems

Functional property	Protein* form used	Contribution to food system
Emulsification	F, C, I	Formation and stabilization
Fat absorption	F, C, I	Promotion or prevention
Water absorption	F, C	Controlled uptake and retention
Solubility	I	Homogenous, nonsettling
Texture	F, C, I	Viscosity, gelation, formation of chips, chunks, shreds, and fibrils
Dough formation	F, C, I	Cohesion, elasticity
Film formation	C, I	Packaging (e.g. frankfurters)
Color control	F	Bleaching or browning
Aeration	I	Whippability, foam stabilizer
Antioxidation	F, C, I	Rancidity protection

*F, C, and I represent flours, concentrates, and isolates, respectively.

In bakery items, soy flours improve the water absorption of bread doughs, cake batters, and other products. Moisture retention after baking is also improved and this results in longer shelf life. Inclusion of soy proteins increases the rate of browning and crust color is improved (Levinson and Lemancik, 1974). Lipoxygenase-active full-fat soy flour is also available which will produce a whiter crumb color through bleaching when added to bread doughs (Cotton, 1974). Defatted soy flour added to bread doughs has been found to decrease the mixing requirements and fermentation time (Hoover, 1975). Soy proteins improve the cohesion and elasticity of bread doughs and pie crusts. This results in improved pliability and reduced stickiness which facilitates high-speed machine handling (Levinson and Lemancik, 1974). However, decreased loaf volume, coarse grain and texture, and darker crumb color results from the addition of high levels of defatted soy flour to bread formulas. High-quality bread containing as much as 12% soy flour is facilitated by the addition of dough conditioners such as sodium stearoyl-2-lactylate (Marnett et al., 1973) or fatty esters of polyalkoxylated polyol glycosides (Bookwalter and Mehltretter, 1976). In doughnut mixes, soy flour (defatted, full-fat, or lecithinated) is added to decrease fat absorption during frying. Soy flours, concentrates, and isolates contribute emulsification in cake batters. Cake formulations containing soy flour are more tolerant to process and ingredient variations (Cotton, 1974). It is interesting to note (Table 6) that soy proteins function to prevent fat absorption in doughnut frying while promoting fat absorption in other food systems. The reasons for this are not clear, but illustrates the necessity for testing each specific application for functionality.

In meat systems, flour and grits, concentrates, and isolates are utilized for a variety of functional properties. Soy flour and grits have been utilized for many years as meat extenders. It was recognized early that soy flour has the advantage of holding both the meat juices and fat. Soy flour is used in sausage and nonspecific loaves while soy grits are utilized in coarse ground meat products (Rakosky, 1974). Concentrates and isolates are incorporated into processed meat products such as frankfurters, luncheon loaves, patties, meat loaves, and meat balls, and meat-in-sauce items (Meyer, 1971). Concentrates are used both for meat extension and functionality. In the formation and stabilization of emulsions, the absorption of fat and water provide a juicy texture and reduce shrinkage during cooking. Soluble isolates are used in processed meat products for their emulsifying capacity, emulsion stabilizing effect, and increased viscosity and gel formation on heating. Soy proteins provide a natural film which is formed during the processing of frankfurters. Isolates are suitable for canned meats because they are not adversely affected by high processing temperatures. During heat processing there is an additional stabilizing effect which results from gelling. Fat globules are entrapped to prevent their coalescence (Schweiger, 1974).

Methods of providing texture include chewy gel formation (Anson and Pader, 1959), curd formation (Watanabe et al., 1974) and yuba film formation (Wu and Bates, 1975). However, the development of textured proteins through thermoplastic extrusion and fiber spinning provided a new dimension of functionality for soybean proteins. These products are finding application in food systems based on meat (Horan, 1974). Extruded soy flours and concentrates can be produced in chips, chunks, flakes, and a variety of other shapes. The extruded textured soy protein has a "crunchy" or "chewy" texture along with fat and water absorbing properties and may be used in a wide variety of product applications, either flavored or unflavored. The flavored dry form may be added to salads or dips. The unflavored form is often hydrated when used in meat applications such as patties, loaves, meat balls, tacos, chili, meat spreads, and many others. The extruded textured protein functions as an extender and retains the desirable juices and flavors that would be lost during cooking. In meat-like products, textured proteins improve the consistency and appearance by reducing the floating fat and increasing the meat-like texture (Wilding, 1974). The fiber spinning process requires an isolated soy protein with high solubility. Soy proteins textured by this process are fabricated into analogues. These products are engineered to resemble conventional meat, poultry, and fish products in flavor, color, texture, and appearance. Spun-fiber type textured proteins are also used as extenders in combination with traditional products. Of the textured products, the spun-fiber type more closely simulate the structural and textural characteristics of animal protein (Rosenfield and Hartman, 1974).

Soy proteins provide functionality in a wide variety of other food systems. In soups and gravies, flours, concentrates, and isolates furnish viscosity or thickening. Caramels and toffee-type confections containing soy flour are less sticky on a high-speed wrapping machine. In fudge, soy flour will slow the rate of rehydration and thereby aid in preventing sugar crystallization (Levinson and Lemancik, 1974). Pasta products containing soy flour are firmer after being subjected to long cooking periods (Paulson, 1961). Soy protein isolates may be modified with pepsin to improve water solubility and aeration properties. The modified isolates are useful as coffee whiteners (Claus, 1974) or can be aerated to produce whipped toppings. Modified isolates utilize the ability to produce stable foams in nougats, frappes, mazettas, and marshmallows. They are also used in the foam mat drying of fruits (Levinson and Lemancik, 1974). The solubility of soy protein isolates is utilized to provide simulated milks (Circle, 1974) and infant formulations (Decock, 1974; Johnson, 1975). Dehulled soybeans or an extracted lipid-protein concentrate can be processed into dry, water-dispersible beverages (Mustakas et al., 1971; 1974).

Soybean proteins also provide antioxidant activity in food systems. Soybean flour has been shown to be a basic source of such antioxidant compounds as isoflavone glycosides and their derivatives, phospholipids, tocopherols, amino acids, peptides, as well as compounds of uncertain origin and/or composition. Residual antioxidant activity has been reported in food systems containing soy protein concentrates, isolates, textured proteins, and protein hydrolyzates (Hayes et al., 1977).

TABLE 7

Estimated production of edible soy protein products and future projections in millions of pounds

	1974			
	I*	II**	1980*	1985**
Soy flour and grits	300	900	600	2000
Textured soy proteins	160	100	1080	450
Soy protein concentrate	175	70	350	600
Soy protein isolate	75	60	400	450
Soy milk-type products	---	nil	---	200
Total	710	1130	2340	3700

*Anton, J. (1975).
**Johnson, D. (1976).

FUTURE PROSPECTS

U.S. Department of Agriculture projections cited by Milner (1975) estimated that the demand for U.S. soybeans will increase 73% by 1985 over the 1970-1972 average annual production of about 35 million metric tons. Soybean production may increase to 85 million metric tons per year by the year 2000. As shown in Table 7, Anton (1975) and Johnson (1976) predict that 1974 production of 0.71 and 1.13 billion pounds of edible soy protein products, respectively, could more than double by 1980 and 1985.

Although the potential for increased utilization of soy proteins in food systems is enormous, further research and development are necessary. The concept of proper usage demands increased product application studies coupled with technical service support efforts. Further flavor studies are needed to increase the compatability of soy proteins in a wider range of food systems. Additional research is also required on detection methods for soy in foods, antinutritional factors, color, flatulence, solubility, and sulfur amino acid content.

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