COMPREHENSIVE REVIEWS IN FOOD SCIENCE AND FOOD SAFETY

Functional and Edible Uses of Soy Protein Products

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ABSTRACT: Consumers are becoming increasingly interested in healthful foods and are open to soy protein ingredients. Soybeans as food are very versatile and a rich source of essential nutrients. They are also an excellent source of good-quality protein, comparable to other protein foods, and suitable for all ages. Adverse nutritional and other undesirable effects followed by the consumption of raw soybean meal have been attributed to the presence of endogenous inhibitors of digestive enzymes and lectins, as well as poor digestibility. To improve the nutritional quality of soy foods, inhibitors and lectins are generally inactivated by heat or eliminated by fractionation during food processing. Soybeans provide an alternative source of protein for people who are allergic to milk protein. Soy protein is highly digestible (92% to 100%) and contains all essential amino acids. Although relatively low in methionine, it is a good source of lysine. Soy-protein products contain a high concentration of isoflavones, up to 1 g/kg. Increased acceptance of soy proteins is due to unmatched qualities like good functional properties in food applications, high nutritional quality, abundance, availability, and low cost. At present the various forms of soy proteins are primarily utilized for their functional effects rather than their nutritional properties. This article summarizes the integrated overview of the widely available, scattered information about the nutritional and functional uses of the soy proteins when applied in food systems and intends to present the most current knowledge with an interest to stimulate further research to optimize their beneficial effects.

Introduction

With the emergence of interest in healthy eating in recent years, one of the main responses has been the removal/reduction of ingredients perceived as unhealthy, such as fat, sugar, and salt. This development has become "the low and light movement." Low-fat, no-fat, and reduced-calorie foods were responses to consumers' desire to eat healthier. Although these characteristics still represent a major factor in a product's appeal, functional foods add yet another alternative for consumers to better their diets (Hilliam 1995). Soybean (*Glycine max*) is a leguminous plant related to clover, peas, and alfalfa. The plant originates from Asia, where it has 2 wild relatives. The flowers are red or violet. The beans grow in pods that develop in clusters with each pod containing 3 to 5 beans. A soybean plant produces 60 to 80 pods. The beans are round or oval. The color of the beans can vary from yellow or green to brown, violet, or even black with white spots (Carpenter and Gianessi 2000). Worldwide, 155 million metric tons of soybeans are presently grown. The United States produces 38% of the total soybean crop in the world, followed by Brazil (25%), Argentina (19%), China (7%), India (3%), Canada (2%), and Paraguay (2%), while all other countries grow only about 4%. On an average, there is 40% protein, which means every year 63.6 million metric tons of soy protein are available for consumption (ASA 2007).

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Importance of Soy Protein Ingredients

Since the 1960s, soy protein products have been used as nutritional and functional food ingredients in every food category available to the consumer. Modern agriculture has led to production of cereal crops sufficient to meet the world food energy requirements for the new century. However, protein supplementation of cereals is desirable in many instances because cereals have low protein contents and are imbalanced in essential amino acid composition. As a result, cereal grains do not supply adequate protein for satisfactory growth of infants and children or for the bodily maintenance of adults (Sarwar and others 1993). Soybean protein has been the subject of intense investigation and has played an increasing role in human nutrition over the last few decades (Riaz 2001). Soy protein products are an ideal source of some of the essential amino acids used to complement cereal proteins. At present, soy proteins are more versatile than many other food proteins in various worldwide nutritional programs.

Soybeans have a long history as a protein foodstuff in Asia. Over the centuries Asians have developed a variety of soybean foods, including tofu, shoyu (soy sauce), miso, and tempeh. Processes include cooking, grinding, extracting, fermenting, and sprouting, which are normally employed for the development of these products. Cooking or dry heating destroys the trypsin inhibitor protein, which is difficult to digest. Heat treatment increases the digestibility of the protein and enhances the nutritional quality of soybeans (Brandon and others 1991). About 38% of the beans consist of protein which is an important source of vegetable protein. About 18% of the beans consist of oil (0.5% lecithin), which is rich in polyunsaturated fatty acids (54% linoleic acid, 22% oleic acid, and 7.5% linolenic acid) and contains no cholesterol. The rest of the beans consists of moisture (14%), soluble carbohydrate (15%, sucrose, stachyose, raffinose, others), and insoluble carbohydrate or dietary fiber (15%) (ASA 2000). Soy foods can be best described as uniformly high in protein but low in calories, carbohydrates, and fats, entirely devoid of cholesterol, high in vitamins, easy to digest, tasty, and wonderfully versatile in the kitchen, which positions them as irresistible new food staples for the evolving spectrum of health diets. In the past 35 y, however, soybeans have become the major source of edible oil, and the meal provides an important source of protein for animal feeds. Food use of soybean protein in the form of defatted flours began in the 1930s. Soy protein contributes valuable functional characteristics in processing systems; it also offers full digestibility. Improved processing methods of soy ingredients mean greater functionality and blander flavor, but it also affects the level of isoflavones, a valuable phytochemical that plays a key role in soy's health benefits (Anderson and Wolf 1995).

Isolated soy proteins are sometimes referred to as the most functional of the soy proteins. As well as having excellent nutritional qualities, some isolates can emulsify fat and bind water. This allows oil to be incorporated into food products and enhances certain sensory qualities, such as moistness, without impacting on the texture contributed by other ingredients. These virtually pure, bland-flavored isolates containing a minimum of 90% protein have been designed to function in a given system in exactly the same way as animal proteins. Some isolates can be used to provide an elastic gel texture, imparting an interesting mouthfeel, while others control viscosity in drinks, making them more creamy or full-bodied. The range of soy products is just as wide as their field of application (Slaon 2000).

Soy protein supplies all 9 essential amino acids and provides many functional benefits to food processors and for a healthy diet. Soy ingredients promote moisture and flavor retention, aid emulsification, and also enhance the texture of many foods from a variety of meats to peanut butter, frozen desserts, and even cheese. Both isolated and concentrated soy proteins are easily digested by humans and equal the protein quality of milk, meat, and eggs. Moreover, soy proteins are acceptable in almost all diets containing virtually no cholesterol and are lactose-free. Commercial ingredients from soy are increasingly used by the supplement industry, in capsules and tablets, as well as by the functional foods industry for manufacturing bars, bread, crispbread, breakfast cereals, dairy products, and beverages (Neven 1996). Soybean protein products consist of good-quality protein in higher amounts when compared to other protein commodities (Table 1 and 2) (FAO/WHO 1991; Friedman 1996).

Forms of Soybean Proteins

At present, the various forms of soy proteins are still utilized primarily for their functional effects rather than for their nutritional properties. However, a number of companies are now working on foods in which soy proteins are the major source of protein and are exploiting the functional properties of the proteins in the successful development of these products. After oil removal from the soybean, the remaining proteinaceous material is referred to as defatted flakes. Three forms of soy proteins products exist as protein supplements or source of proteins and their content ranges from 50% to over 90%, namely, soy flours/grits, soy protein concentrates, and soy protein isolates (Wolf 1970).

Flours and grits

Present forms of soybean protein products used as raw materials by the food industry are conveniently classified into 3 major groups based on protein content as shown in Table 3 (Golbitz 1995). Least refined forms of proteins are flours and grits, which have varying fat contents, particle sizes, textures, and degrees of heat treatment. Flours are prepared by grinding soybean flakes to 100 mesh (0.157 mm-sieve pore size) or finer, whereas grits are coarser than 100 mesh. Minimum protein contents of these materials range from 40% to 54% depending on the fat content. Protein, carbohydrates, and ash are the major constituents of defatted flour depicted in Table 4 (Campbell and others 1985; Kolar

Table 1 — Protein and calorie contents of some commodities.

Commodity	Protein/100 g (g)	Calories/100 g (kcal)
Defatted soy flour	**53**	**329**
Textured soy protein	**60.5**	**334**
Wheat flour	10.3	364
Corn meal	8.5	366
Rice	7.1	365
Wheat soy blend	21.5	355
Corn soy blend	17.2	376
Lentils	28.1	338
Peas	24.6	341

Table 2 — Evaluation of selected protein products in human nutrition.

Product	Protein digestibility corrected amino acid score (PDCAAS)
Casein	**1.0**
Egg white	**1.0**
Soy protein concentrate	**0.99**
Soy protein isolate	**0.92**
Beef	0.92
Pea flour	0.69
Kidney beans (canned)	0.68
Rolled oats	0.57
Lentils (canned)	0.52
Peanut meal	0.52
Rice	0.47
Whole wheat	0.42
Wheat gluten	0.25

Table 3 — Proximate composition of commercial forms of soybean proteins.

Form	Protein (%)	Fat (%)	Moisture (%)
Flours and grits			
Full fat	41.0	20.5	—
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
Concentrate	66.2	0.3	6.7
Isolate	92.8	<0.1	4.7
Textured soy protein	50.0	6 to 8	9.0

and others 1985); the remainder consists of residual lipids and a number of such minor components as saponins, isoflavones, which are responsible for the typical flavors of raw soybean flour and grits. About one-half of the flour carbohydrates are oligosaccharides (sucrose, stachyose, and raffinose) while the other half is made up of polysaccharides, which are insoluble in water or alcohols (Nelson and others 1987).

Concentrates

Soybean protein concentrates are more refined than flour and grits and contain 70% or more protein on a moisture-free basis. Protein concentrates are prepared from defatted flakes or flour by removing the oligosaccharides, part of the ash, and some of the minor components in 1 of 3 ways. The 1st method involves washing defatted flakes or flour with 60% to 80% aqueous alcohol. The proteins and polysaccharides are insoluble in alcohol, while the sugars and other compounds dissolve and are removed. The concentrate is then dried at its natural pH, which is near neutrality. The 2nd procedure uses an acid leach at about pH 4.5 to remove the sugars. At this pH, the major globulins are at their isoelectric point; both the proteins and polysaccharides are insoluble under these conditions. The wet protein concentrate is then neutralized and dried. The 3rd procedure uses moist heat to denature and insolubilize the proteins in the flakes or flour followed by a water wash to remove the sugars and other minor components. Although concentrates prepared by any of these methods contain 70% or more protein, their physical properties will differ with the method of preparation (Wolf 1970). Concentrates have a reduced flavor level as compared to flours and grits because the concentration processes remove some of the flavor constituents.

Isolates

The most refined forms of soybean proteins are the isolates, which contain 90% or more protein. They are prepared by removing the water-insoluble polysaccharides, as well as the oligosaccharides and other low-molecular-weight components that are separated in making protein concentrates. Defatted flakes or flours, which have received a minimum of moist heat treatment, are extracted with water plus alkali at a pH of 7 to 8.5. The insoluble residue, containing the water-insoluble polysaccharides plus residual protein, is then separated. In the next steps, the clarified extract containing the bulk of the proteins plus the sugars is adjusted to about pH 4.5. This treatment precipitates the proteins, which are then removed by centrifugation or filtration. The precipitated proteins are then washed and dried to give the isoelectric protein. The protein is neutralized before drying. Isolates may contain more than 95% protein but contain 2% to 5% ash and 3% to 4% of minor constituents (Onayemi and Lorenz 1978). Soy concentrates and isolates provide highly concentrated protein sources, high lysine content, bland flavor, and reduction of flatulence factors and reducing sugars, and they may lead to improve overall product quality.

Texturized soy proteins

In addition, products such as full-fat soy flour, partially hydrolyzed soy proteins, and products based on traditional oriental food patterns are also available in lesser volume. The generic terms “texturized soy protein” or “TSP” typically mean defatted soy flours or concentrates, mechanically processed by extruders to obtain meat-like chewy textures when rehydrated and cooked. Coarse defatted soy particles (flakes and grits) and shaped soy protein isolates (sometimes called structuring proteins to differentiate them from extruded products) also are innovatively used to add texture and appeal to food products. Additional benefits of extrusion cooking are denaturing of the proteins, inactivation of trypsin inhibitors, control of bitter flavors, and the homogeneous bonding of ingredients that may include colors, chemicals, and other additives, which all can have an effect on appearance or textural quality (Bjorck and Asp 1983; Hayakawa and others 1988).

Nutritional and Health Aspects of Soy Proteins

Under conditions of normal dietary intake, properly processed soy protein ingredients are of good protein value for humans. Soybean proteins are used in human foods in a variety of forms, including infant formulas, flours, protein isolates and concentrates, and textured fibers. Soy foods include cheese, drinks, miso, tempeh, tofu, salami, and vegetarian meat substitutes. Consumption of soy foods is increasing because of reported beneficial effects on human nutrition and health. These effects include lowering of plasma cholesterol and prevention of cancer, diabetes, and obesity, as well as protection against bowel and kidney diseases (Hamilton and Carroll 1976). This is particularly true when soy products are utilized in combination with other protein sources, such as meat, milk, and cereal grains (Bressani 1981; Torun and others 1981). The nutritional adequacy of soy protein products has been clearly demonstrated in infant formulas, where protein requirements are most critical (Yetley and Park 1995).

Nutritional value of soy protein ingredients

Amino acid profile. Soy proteins contain all the essential amino acids required for human nutrition (growth, maintenance, and stress) (Table 5) (Lonnerdal 1994). The amino acid composition of soy proteins resembles, with the exception of the sulfur-containing amino acids (such as methionine), the amino acid patterns of high-quality animal protein sources (Wolf 1970). Digestibility studies in animals and humans have demonstrated that soy proteins are comparable in digestibility to other high-quality

Table 4—Mineral content of soy protein ingredients.

Constituent (%)	Defatted soy flour	Soy protein concentrates	Soy protein isolates	Textured soy protein
Potassium	2.4 to 2.7	0.1 to 2.4	0.1 to 1.4	2.130
Phosphorus	0.7 to 0.9	0.6 to 0.9	0.5 to 0.8	0.679
Calcium	0.2 to 0.3	0.2 to 0.4	0.1 to 0.2	0.248
Magnesium	0.2 to 0.3	0.3	0.03 to 0.09	0.275
Chlorine	0.1 to 0.3	0.7	0.13	—
Iron	0.01	0.01 to 0.02	0.01 to 0.02	0.0069
Zinc	0.005	0.005	0.004 to 0.009	—
Manganese	0.003 to 0.004	0.005	0.002	—
Sodium	0.003 to 0.015	0.002 to 1.2	0.04 to 1.2	0.004
Copper	0.001 to 0.002	0.001 to 0.002	0.001 to 0.02	0.0015

proteins such as meat, milk, fish, and egg (Wayler and others 1983; Oste 1991). Digestibility values for protein concentrates and isolates by humans fall in the range of 91% to 96%, which is comparable to values for milk (FAO/WHO/UNU 1985). In a pragmatic, double-blind, factorial placebo-controlled randomized trail recruiting 213 middle-aged men and women with untreated elevated total cholesterol or blood pressure, factors examined were the effect of giving supplies of bread, cereal bars, and cracker biscuits fortified with 2 g fish oils or 25 g soy protein for 5 wk. Overall, soy protein did not influence any of the outcomes assessed. However, in women only, soy protein increased systolic blood pressure by 5.9% (Harrison and others 2004). The effects of SPI, defatted soy, or SPI supplemented with L-methionine were examined in the Long-Evans rat with a cinnamon coat color in animal model of Wilson's disease and results showed that soy protein enhances hepatic copper accumulation and cell damage in LEC rats, so recommendations to individuals suffering from Wilson's disease to avoid consuming soy protein are warranted (Yonezawa and others 2003). Another study conducted by Luiking and others (2005) reported that casein and soy protein meals differentially affect whole-body and splanchnic protein metabolism in healthy humans. A significantly larger portion of soy protein is degraded to urea, whereas casein protein likely contributes to splanchnic utilization (probably protein synthesis) to a greater extent. The biological value of soy protein must be considered inferior to that of casein protein in humans.

Amino acid requirements. In measuring protein quality in humans, studies conducted with young male adults showed that isolated soy protein is comparable in protein quality to milk and beef, and 80% to 90% of whole egg, in spite of the fact that protein intakes were at suboptimal levels in these studies (Scrimshaw and others 1983; Wayler and others 1983; Young and others 1984). When soy protein concentrate was fed to young men, nitrogen equilibrium based on nitrogen balance was attained with a mean daily nitrogen intake of 95 mg/kg, not significantly different from that of egg protein, 92 mg/kg. When soy protein concentrate was fed as the sole source of protein for 82 d at a daily intake of 0.8 g protein/kg, mean nitrogen balances were positive for all participants. These studies, and others, in which well-processed soy proteins were fed as the sole source of protein, or provided a significant portion of the daily intake, suggest that soy protein products are of high nutritional value for humans and can serve as the sole source of protein in providing nitrogen and amino acids for maintenance in adults (Goldberg 1995).

Calories. The energy available for metabolism from soy protein products can be estimated by calculating the contributions from the carbohydrate, fat, and protein contents, taking into account the digestibility of each and their heat of combustion. Typical caloric values for soy protein products are shown in Table 6. The Food Drug Administration (FDA 1999) has estimated that for soy protein products containing substantial carbohydrates, such as soy flours and grits, 40% of the carbohydrates are digestible.

Table 5 — Essential amino acid content of soybean proteins.

Amino acid	Grams amino acid per 16 g nitrogen		
	Meal	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

Nutritional value of soy proteins in food systems

There are important applications in which soy proteins are combined with other proteins. Three cases are especially important, extension, supplementation, and vegetable protein mixtures.

Meat, poultry, and fish. At levels of 0.6 to 0.7 g protein/kg body weight, there is no difference in nitrogen utilization between meat protein and highly extended soy-beef blends. The effects of various meat-soy combinations on protein utilization will understandably differ, depending on whether the measurements are done at deficient or adequate levels of protein intake. Studies with young men using beef, fish, and 50:50 mixtures of beef, fish, or milk and isolate showed that the values for the 3 animal-soy protein mixtures equaled those of the all-beef or fish controls. These studies show that soy proteins are nutritionally excellent when used with high-quality animal proteins in the diet (Scrimshaw and Young 1979; Hopkins and Steinke 1981).

Dairy products. Amino acid, vitamin, and mineral fortification in certain products (such as milk formulas for infants, school lunch foods, and other institutionally prepared foods) are both feasible and nutritionally sound. Using soy protein in these situations offers a great opportunity for providing meals that would otherwise not be available for reasons of cost, stability, ease of preparation, or medical considerations (for example, hypo-allergenic infant formulations). Soy proteins are also a good source for special formulas in geriatric, hospital, and postoperative feeding by providing complete nutrition, specific caloric content, and a balance between calories contributed by protein, fat, and carbohydrate (Rakosky 1974).

Cereal grains. Most applications for defatted soy flours and grits involve their combination with cereals. Their addition raises both the quantity and quality of the protein in cereal products. The quality of the protein is improved in soy–cereal mixtures because soy protein is a rich source of lysine, the 1st limiting essential amino acid in most cereal proteins (Dubois and Hoover 1981; Klein and others 1995; Lang 1999).

Health and soy protein products: driving force for expansion

Soy foods have never been common foods in Western diets, whereas they are among the most popular foods in the Far East. Despite its rich history as food, unique features as a crop, and increasing annual production, soybeans until recently suffered a severe image problem in the West because of their unfamiliar aroma and taste, commonly described as beany. One approach that was taken to overcome the poor image of soy was to market soy products without using the word "soy." Thus, soy oil became "vegetable oil" and soy burgers became "veggie burgers" or harvest burgers. Entering the 21st century happened 7 y ago, however, we saw a turning point for the soy foods industry. According to a market survey conducted by Soyatech Inc., and SFH & Co.

Table 6 — Typical energy values for soy protein products.

Protein source	Energy (kcal/100 g)
Defatted soy flour	327
Soy protein concentrate	328
Soy protein isolate	334
Textured soy protein	340

(Golbitz 2000), the U.S. soy foods market is one of the fastest growing categories in the food industry.

Over the last 2 decades, researchers have documented the health benefits of soy protein, especially for those who take soy protein daily (Hawrylewicz and others 1995; Kennedy 1995). Epidemiological studies have indicated that populations that regularly consume soy foods have lower incidences of breast, colon, and prostate cancers, heart diseases, osteoporosis, and menopausal symptoms (Anderson and others 1995b; Messina 1995, 1999; Barnes 1998; Setchell and Cassidy 1999; Friedman and Brandon 2001). Isoflavones exhibit the most promising health benefits (Anderson and others 1995b; Messina 1999). The findings about the health benefits of soy have become a powerful message for improving consumer interest in soy foods and soy-enriched foods, and spurring production and sales of these foods products (Dwyer 1995).

The U.S. FDA has approved the use of a soy protein health claim on food labels in the United States. Based on scientific evidence from 43 human intervention studies, including 14 clinical trials, 1 epidemiological study, and 1 meta-analysis, the FDA has concluded that the consumption of 25 g of soy protein a day, as part of a diet low in saturated fat and cholesterol, may reduce the risk of heart disease (Anderson and others 1995b). Foods made with the whole soybean may also qualify for the health claim if they contain no fat in addition to that present in the whole soybean. These would include soy foods such as tofu, soymilk, soy-based burgers, tempeh, and soynuts. The FDA has agreed that food products which contain a minimum of 6.25 g of soy protein per serving and which are low in fat, saturated fat, and cholesterol may carry one of 2 label claims. The 1st option is 25 g of soy protein per day as part of a diet low in saturated fat and cholesterol may reduce the risk of heart disease. The other permitted claim that manufacturers may use is diets low in saturated fat and cholesterol that include 25 g of soy protein a day may reduce the risk of heart disease. Foods where no additional fat has been added during processing will qualify. Foods produced from low-fat or defatted soy protein ingredients will need to meet the low-fat requirement of 3 mg or less of fat per serving (FDA 1999). The soy health claim in the United States and in the United Kingdom for soy has boosted a strong consumer interest in soy foods. The United Kingdom also permitted a health claim for soy. The JHCI (Joint Health Claim Initiative) in association with SPA (Soy Protein Assn., U.K.) says that products must not imply that consumption of more, or less, than 25 g per day is advantageous; contain a minimum of 6.25 g of soy protein per serving; state what a serving is, and the amount of soy protein per serving; state the proportion of the daily 25 g requirement is in each serving. To aid the manufacturer, the Commission of the European Communities established a list of permitted health claims approved by European Food Safety Authority to forecast the benefits of soy in products. The EU soy health claim implies that a claim that a food is a source of protein, and any claim likely to have the same meaning for the consumer, may only be made where at least 12% of the energy value of the food is provided by protein. In the case of foods that are naturally sources of protein, the term "naturally" may be used as a prefix to this claim. High protein, a claim that a food is high in protein, and any claim likely to have the same meaning for the consumer, may only be made where at least 20% of the energy value of the food is provided by protein. In the case of foods naturally high in protein, the term "naturally" may be used as a prefix to this claim (Godfrey 2003).

Cholesterol and heart diseases. Dietary soy protein has been shown to have several beneficial effects on cardiovascular health. The best-documented effect is on plasma lipid and lipoprotein concentrations, with reductions of approximately 10% in LDL cholesterol concentrations and small increases in HDL cholesterol concentrations. Dietary soy protein improves flow-mediated arterial dilation of postmenopausal women but worsens that of men (Clarkson 2007). Studies conducted over the past several years have shown that soy protein is hypocholesterolemic and atherogenic. Many studies have found that adding soy protein to the diet, or replacing animal protein in the diet with soy, lowers blood cholesterol (Carroll 1991; Sirtori and others 1993). The cholesterol-lowering effect of soy has been attributed to isoflavones, a class of phytochemicals found in soybeans. Soy protein drinks that contain naturally occurring high levels of isoflavones reduced total cholesterol and LDL cholesterol, the so-called "bad" cholesterol, in patients who had high cholesterol levels despite consuming a low-fat, heart-healthy diet. Some studies reported very large decreases in cholesterol in response to soy protein, whereas others reported only minor effects (Carroll and Kurowska 1995). Several studies promote the cholesterol lowering effects of soy protein as a weapon in the fight against coronary heart disease (Tikkanen and Adlecreutz 2000). The incidence of coronary heart disease is lower in nations consuming soy protein products as a major component of the diet. According to Anderson and others (1995b), every 1% reduction in cholesterol values is associated with an approximate 2% to 3% reduction in the risk of coronary heart disease. Based on results observed in different studies, it can be assumed that a daily intake of 20 to 50 g of isolated soy protein could result in a 20% to 30% reduction in heart disease risk (Potter and others 1993; Widhalm and others 1993; Bakhit and others 1994). Research continues to point to the positive role soy protein can play in controlling blood cholesterol, one of the major contributors to coronary disease. Yet, with all the mounting evidence, soy remains a very small part of the diet of people in the Western world, where coronary disease is a leading killer. In another study, Nagata and others (1998) proved that decreased serum total cholesterol concentration is associated with high intake of soy protein products in Japanese men and women. Several nutritional intervention studies in animals and humans indicate that consumption of soy protein reduces body weight and fat mass in addition to lowering plasma cholesterol and triglycerides. In animal models of obesity, soy protein ingestion limits or reduces body fat accumulation and improves insulin resistance, the hallmark of human obesity (Velasquez and Bhathena 2007).

Cancer. In their findings, Lee and others (1991) point to an important link between soy consumption and a reduced risk of certain types of cancer. It is well known that Asian women, who typically eat a soy-based diet, have a much lower incidence of breast cancer than Western women (Anna and others 1998). Daidzein and genistein are the 2 primary isoflavones found in soybeans. These compounds may reduce the risk of a number of cancers, including those of the breast (Bruce and others 2006), lung, colon, rectum, stomach, and prostate (Messina and Barnes 1991). While it appears that daidzein is more bioavailable than genistein, most of the research interest in anticancer effects of soybean isoflavones has centered on genistein (Broihier 1997). Genistein is thought to act against cancer in several ways: by interfering with cancer promoting enzymes, by blocking the activity of hormones in the body, and even by interfering with the process by which tumors receive nutrients and oxygen (Coward and others 1993; Sarkar and Li 2003). Genistein is found in soy, clover, and only a few other green plants; however, soy-based foods represent the only practical way consumers can incorporate genistein in their diet. As long as isoflavones are present, any type of soy food—soymilk, tofu, tempeh, textured vegetable protein, or whole soybeans—may offer cancer prevention benefits (Broihier 1997; Duncan and others 1999).

Menopause symptoms and osteoporosis. Estrogen hormones, produced by the ovaries, are crucial for the healthy functioning of a woman's reproductive system. The decrease in estrogen production that signals menopause can produce a variety of symptoms. These may include difficulty in regulating body temperature, which results in night sweats and hot flashes. Studies indicate that consuming soy isoflavones may reduce the frequency and intensity of hot flashes in menopausal women (Anderson and others 1999; Messina 2002; Martinez 2006). The improvements in menopausal symptoms are attributed to phytoesterogenic factors in soybeans (Lu and others 2001; Chen and others 2004). In addition, Cassidy and others (1994) found significant changes in the menstrual cycle of women who were fed a soy diet. Specifically, their hormone levels were altered and the menstrual cycle was lengthened. Osteoporosis causes bones to become overly porous and brittle from the loss of calcium and other minerals. One dietary factor that increases bone calcium loss is protein. Diets high in animal protein, in particular, increase urinary calcium losses (Abelow and others 1992). It progresses without any symptoms, that is, until irreversible pain, loss of height, and bone fractures occur. Soy foods may help prevent and treat osteoporosis. Fortified soymilk made with calcium salt is a good source of calcium (Messina and Messina 2000). With the calcium, the body easily absorbs soymilk. Soy foods may play other roles in protecting bone health (Knight and Eden 1996; Anderson and Garner 1997; Chiechi and others 2002). It has been suggested that the high protein content of the Western diet is one of the causative factors. However, studies (Breslau and others 1988), have indicated that soy protein does not result in an increased loss of calcium in the urine. The isoflavones daidzein and genistein, found in significant amounts only in soybean and soy foods, may directly inhibit bone resorption (Brandi 1992; Anderson and others 1995a; Blum and others 2003; Jia and others 2003). A study conducted by Erdmann and Potter (1997) found that, after 6 mo, consuming 40 g of isolated soy protein per day significantly increased both mineral content and density in the lumbar spine. Isoflavone-rich soy protein isolate attenuates bone loss in the lumbar spine of perimenopausal women (Alekel and others 2000).

Functionality of Soy Protein Products

With certain obvious exceptions, such as infant formulations, dietary wafers, breakfast cereals, and special dietary items, soy protein products are now being used primarily for their functional characteristics, which are important to the manufacturer of conventional foods in process control, and in the design of convenience foods (Table 7) (Kinsella 1979).

General properties of proteins

Protein functionality is dependent upon the structure of the molecule. For example, the presence of both lipophilic and hydrophilic groups in the same polymer chain facilitates association of the protein with both fat and water. This results in the formation of stable oil and water emulsions when protein dispersion is mixed with oil. The multiplicity of groups attached to the polymer chain of the protein, such as lipophilic, polar, nonpolar, and negatively and positively charged groups, enables soy proteins to associate with many different types of compounds. Thus, it may adhere to solid particles and act as a binder or, when in solution, as a dispersing and suspending agent. Protein films may adhere to surfaces and, in addition, solids may be distributed and cemented together within the protein film. These properties usually require a protein with a relatively high degree of water dispersibility. Soluble proteins are also easier to incorporate into foods. In a relatively insoluble protein, these properties can be expected to occur only to a limited degree. Although such products remain highly valuable nutritionally, they may contribute only slightly to viscosity, gel formation, emulsification, binding, adhesion, and so on, or to the stabilization of emulsions and suspensions. Nevertheless, insoluble proteins do possess good water and fat absorption properties and, in that sense, they can be classified as being highly functional as well. Briefly, an insolubilized protein essentially contains the same functional groups as the native protein, the only difference being a change in the accessibility of the reactive groups (Liu 2000). Formation and

Table 7—Functional properties of soybean protein in food systems.

Functional property	Protein form used[a]	Food system
Emulsification		
Formation	F, C, I	Frankfurters, bologna, sausages, bread, cakes, soups
Stabilization	F, C, I	Whipped toppings, frozen desserts, frankfurters, bologna, sausages, soups
Fat absorption		
Promotion	F, C, I	Frankfurters, bologna, sausages, meat patties
Prevention	F, C	Doughnuts, pancakes
Water absorption		
Uptake	F, C	Breads, cakes
Retention	F, C	Macaroni, confections, breads, cakes
Texture		
Viscosity	F, C, I	Soups, gravies
Gelation	I	Simulated ground meats
Chip and chunk formation	F	Simulated meats
Shred formation	F, I	Simulated meats
Fiber formation	I	Simulated meats
Dough formation	F, C, I	Baked goods
Film formation	I	Frankfurters, bologna
Adhesion	C, I	Sausages, lunch meats, meat patties, meat loaves and rolls, boned hams
Cohesion	F, I	Dehydrated meats, baked goods, macaroni, simulated meats
Elasticity	I	Baked goods, simulated meats
Color control		
Bleaching	F	Breads
Browning	F	Breads, pancakes, waffles
Aeration	I	Whipped toppings, chiffon mixes, confections

[a]F, C, and I represent flours, concentrates, and isolates, respectively.

stability of protein-based food emulsions also depend very much on energy input. In general, the process and equipment used in making food emulsions, particularly very viscous emulsions, exert a major influence on the properties of an emulsion. While correlation between classical surfactant properties and emulsion behavior is positive in food systems, the mechanical processes used to make emulsions override these fundamental properties of proteins. These processes are achieved by the shearing, turbulence, cavitation, and mixing applied to food systems during emulsion formation.

Functionality of soy protein ingredients

The ability of protein to aid the formation and stabilization of emulsion is critical for many applications in chopped, comminuted meats, cake batters, coffee whiteners, milks, mayonnaise, salad dressings, and frozen desserts (Lusas and Riaz 1995). Functional properties are not only important in determining the quality of the final product, but also in facilitating processing, such as improved machinability of cookie dough or slicing of processed meats. These properties are generally attributed to the protein; however, other components in certain products may also contribute to functionality. For example, polysaccharides in soy flour and concentrate will absorb more water than an equivalent amount of protein. The characteristics of soy protein products can be varied by using various processing treatments. These treatments can involve the use of enzymes, solvents, heat, fractionation, and pH adjustment, or the combination of these treatments. Knowledge of the fundamental properties of proteins is essential for understanding the basis of functionality for modifying proteins to acquire needed functions, and for predicting potential applications (Kulkarni 2004).

Soy flours/grits (untextured). Full-fat soy flour applications include uses such as a source material for soymilk, tofu, and other specialty foods, and as an economical extender for nonfat dry milk in beverages (mostly in developing countries). Also, these ingredients have been exploited for their uses (baked goods) especially in Europe, Israel, and Latin America. High-enzyme flours with lipoxidase activity can cause bleaching of carotenoid pigments in doughs, thus producing whiter breadcrumbs, and are also responsible for the generation of peroxides, which strengthen gluten proteins. For defatted soy flours and grits, functionality usually relates to water and fat absorption capacity. Defatted soy flour at 2% to 4% improves water holding capacity and sheeting properties of sweet dough. The enhanced sheeting strength produces better layering during the fat roll-in process and a tenderer, finished product. These properties are primarily dependent upon the degree of protein denaturation and particle size (Friedman and others 1984). Functionality is the greatest in untoasted products and is reduced in proportion to the degree of heat treatment. To optimize the way a soft ingredient performs in a food system, it is necessary, therefore, to consider both the degree of heat denaturation and granulation. The toasted product is generally preferred in ground meats, cookies/crackers, and cereal applications, as well as in milk replacers and fermentation media. The more dispersible types are used in bakery products when added directly to the dough (for example, bread, cakes, doughnuts, pancakes). Soy flour's main disadvantage has been its taste and mouthfeel. Soy grits are identical in composition to soy flours, the only difference being its particle size. As with soy flour, toasted grits are preferred for ground meat applications and are also used to enhance the nutritional and textural quality of cookies, crackers, and specialty breads (Dubois and Hoover 1981; Johnson 1985). Another big market is for pet foods and vitamin carriers. Lecithinated and defatted soy flours are mainly used in bakery applications such as doughnuts and sweet goods (Lecithin content varies from 0.5 to 15%). The soluble versions are also used extensively in pancake and cake mixes. Nutritional improvement of soy flour through inactivation of trypsin inhibitors by sodium sulfite was investigated by Friedman and Gumbmann (1986) for better product application.

Soy protein concentrates (untextured). Since the neutralized acid leach and steam injection/jet cooking processes can result in a product that has a higher dispersibility, concentrates of these types will have more desirable functional properties in emulsion-type applications. These dispersible functional concentrates have many of the properties exhibited by neutralized isolates. Concentrates may vary as to color, flavor, particle size, and water and fat absorption. All of the soy protein concentrates, regardless of the process used, do have fat and water holding properties (partially due to their polysaccharide content), and modify viscosity and textural characteristics of the food system. The alcohol-denatured concentrates exhibit good nutritional value and are used in many applications requiring protein fortification. They may also be texturized. All concentrates have much improved flavor characteristics as compared to commercially available soy flours. In general, the greatest potential areas are where casein and nonfat dry milk are used, such as emulsion-type meat products, bakery products, nutritional powder drinks, and soup bases (Onayemi and Lorenz 1978). Baby foods, cereals, dry food mixes, milk replacers, pet foods, and snacks are just a few more examples where powdered soy protein concentrates may be used.

Soy protein isolates. Several soy protein isolates have been developed for providing different functional or physical properties to meet the requirements of various food systems. The solubility of isolates ranges from 25 NSI (nitrogen solubility index) to 95 NSI. While solubility is very important, it is difficult to predict the performance of a protein in an application based on solubility alone. Other criteria, such as emulsifying capacity, gelling, fat and water absorption, and viscosity, for example, should also be considered. The emulsion capacity of isolates can differ by a factor of nearly 4. Emulsion capacity or the ability of a protein to emulsify fat is the most important functional parameter in many food products. Isolates can emulsify from 10 to about 35 mL of oil per 100 mg of protein. On the other hand, where maximum emulsifying capacity of the proteins is not needed, and where thermal thickening and gelation occurs, initial solubility may not be too critical because stable emulsions can be formed with adequate energy input. The film-forming properties of soy protein isolates are useful in certain meat products.

Applying heat and pressure causes protein films to fuse together to form a firm, continuous textured mass that can be sliced and used as meat substitutes. Soy protein isolates vary in their ability to form gels (Petruccelli and Anon 1995). Some are designed to form gels while others will not form gels at 14% solids content, with salt content also affecting the gel strength. The viscosity properties (thixotropic) illustrate again that all isolates do not have similar properties. Some isolates will have the same viscosity at 18% solids as other isolates have at only 10% solids concentration. The application of heat and shear to the protein solutions can also alter their viscosity. Water and fat absorption properties are also utilized in meat and baking applications. Isolates have water absorption values from about 150% to 400%. Neutralized isolates are usually highly dispersible and will gel under appropriate aqueous conditions. They possess both emulsifying and emulsion stabilizing properties, and are excellent binders of fat and water, and are good adhesive agents as well. For this reason, they are used in processed meat products, both coarse and fine emulsions (as in patties, loaves, and sausages). Some of the general-purpose isolates (nondispersible) have good nutritional properties and vary mainly in their gelling and viscosity characteristics. Isolates and concentrates can also be structured to have a fibrous appearance (Lusas 1996). These products are designed mainly for poultry and meat protein replacement. The fiber-like structure, for example, adds texture and mouthfeel to poultry rolls.

Soy albumens. In contrast to the unhydrolyzed proteins, the soy albumens (partially hydrolyzed proteins) are soluble in water in both the acid and alkaline ranges, soluble in hot syrup, and can be pasteurized without coagulation. They can be used in many products as aerating agents, but in some applications are used in combination with egg albumen or with whole eggs to improve the whipping rate and stability of the whips. These modified proteins have found a limited but important place in the food industry for the preparation of confections and desserts.

Textured/structured soy protein products. For many years, the newly developed soy protein products did not make much progress in occupying a central position in the global protein nutrition picture. The 1st processed soy protein products were mainly flours or powders, which had to be "concealed" in existing foods such as bread, pasta, or beverages. The objective of a great part of the research effort was to render these powders sufficiently flavorless and white, and to counteract any change in the accepted characteristics of the "host" food caused by the incorporation of soy protein products at nutritionally and economically significant levels. A breakthrough in the utilization volume occurred in the 1960s when textured soy protein products of acceptable quality became increasingly available (Cheftel 1986).

Meat-like products processed from soybean protein offer an excellent alternative to meat in order to extend limited meat supplies and to derive the well-known health benefits of soybean. Traditionally, these products, commonly called textured soy protein (TSP), are made mainly by thermoplastic extrusion of defatted soy flour or soy protein concentrates derived from solvent extraction of soybean under moist heat and high pressure to impart a fibrous texture (Lusas and Riaz 1995). The use of organic solvents in processing may be objectionable to certain consumer groups.

There are many types of textured proteins from different processes and starting materials. Textured protein products are being prepared commercially by thermoplastic extrusion of flours, grits, and protein concentrates under heat and pressure to form chips, chunks, flakes, and a variety of other shapes. A continuous increase in barrel temperature and screw speed of the Brabender single-screw laboratory scale extruder increases the expansion, water absorption index, water hydration capacity, and hardness of the extruded products. The highest specific volume was found with higher barrel temperature and higher screws speeds (Rueda and others 2004). These products can be flavored to resemble or extend meats, such as hamburger, stew meats, and beef chili, and are widely used as meat extenders. Their structure and texture can be modified by varying extrusion parameters and by the addition of salts to the mix before extrusion. They also absorb water, and to some extent fat, so they can be regarded as having physical functions, in addition to their main role as extenders (Harper 1986). They may be incorporated in a dry, partially hydrated or fully hydrated form. The manner of incorporation is based primarily on a specific food formulation, processing equipment, and the type of ingredient used (Ferreira and Areas 1993). Obviously, textured flours require less water for hydration than concentrates. The minced or flaked form is designed for rapid hydration. These ingredients are also used in retorted products to absorb juices liberated during canning, resulting in a less sloppy or firmer final product (Lusas 1996). Examples of this type of application are beef patties, sausages, chili, Sloppy Joes, pizza toppings, taco fillings, meatloaf mixes, frozen dinners, meatballs, Salisbury steak, tamales, packaged dinners and soups, canned minced hams, meat pie fillings, hot snacks, vegetarian foods, and pet foods. Hydrated textured soy proteins should be handled like meat or any other perishable food when preparing them for meat product (Kitabatake and Doi 1992). Structured concentrates are extruded products made to have a fibrous or laminar rather than a spongy structure. In general, structured concentrates also have higher water absorption and hydration rates (2 to 5 min as opposed to 30 to 60 min) than those of textured flours and granular concentrates of 10 y ago, and their structure and texture stand up to retorting much better (Lin and others 2000).

Flavor and texture. Proteins affect the sensory properties, appearance, color, aroma, taste, and texture of foods. These are key attributes that determine consumer acceptance. The flavor of soy proteins and their interaction with both desirable and undesirable flavors (odor and taste chemicals) are extremely critical and determine the acceptability of foods containing soy preparations, and thus the application of soy proteins. Much progress has been made in reducing flavor, especially with refined products such as concentrates and isolates, but residual flavors always remain, although they are often diluted and masked when the proteins are incorporated into foods at low levels. Flavor is a particular problem in bland foods, such as dairy products. Soy proteins also suffer from the absence of desired flavors, such as those of meats. When used as meat extenders, textured soy products dilute the natural flavors of meat. Flavors are frequently added, but they are often released too rapidly. It could be misleading to extrapolate from the flavor of the product as such, or its flavor in a given food system to its probable flavor acceptability in a different food system. Most researchers who are experienced in food product development are aware of the phenomenon of flavor compatibility as a function of the total food system. Nonmeat ingredients, such as soy protein, egg, cereal flours, starch, whey protein, and fat, play a significant role in the modification of functional properties such as emulsification, water- and fat-binding capacity, and textural properties (El-Magoli and others 1996; Gujral and others 2002). Particularly, nonmeat proteins and carbohydrates are often used to enhance the texture of meat products (Hongsprabhas and Barbut 1999). In the meat industry, soy protein is the most widely used vegetable protein, due to its biological value, its properties as an emulsifier and stabilizer, and its capacity to increase water holding capacity and improve the texture of final product (Macedo-Silva and others 2001). No doubt, more research is needed to find practical methods for further reducing flavor levels in soy proteins, for developing desired flavor compounds in finished foods, and for adjusting conditions in a given food system so that flavor compatibility is optimized among all factors contributing to organoleptic sensation (ASA 2000).

Uses in Food Systems

Using soy protein successfully in traditional foods depends on formulating products in such a manner that the traditional characteristics of that product are maintained. When plant proteins replace animal proteins, it is critical that traditional food characteristics and quality not be changed (Berry 1998). In new foods, soy products must also contribute to the overall appeal of the products. Table 8 (Rakosky 1974) outlines the major food uses of soy protein products. Since the general application possibilities for soy protein products have already been mentioned under "Functionality," only principal use areas that need special highlighting are discussed in this section.

Meat food products

Because of changing attitudes of consumers, processors, and regulatory agencies, soy protein products are being used at an increasing rate in various processed meat systems. However, the world's soy landscape is analyzed; processed meats are still the major drivers for functional soy protein ingredients. Approximately 1 million metric tons of functional soy proteins are produced annually, with 55% of that tonnage used in processed muscle foods, including meat, poultry, and seafood (Hoogenkamp

2007). The largest area of current domestic food utilization is in emulsified meats (frankfurters) and coarse ground meats (ground beef patties) (Gnanasambandam and Zayas 1994).

Emulsified meats. For many manufacturers, it is important to use additional emulsifiers/binders as insurance against product failure. The nonmeat proteins must perform the same functions as the salt-soluble meat proteins. These functions include emulsification, emulsion stabilization, gelation, and fat and water binding, among others. Depending on the protein ingredient used and the meat product, usage level of soy protein isolates ranges, from 1% to 4%. Many emulsified meat formulations containing soy protein products have excellent eye appeal, good texture, no off-flavors, and result in substantial savings (reduced cooking losses and greater yields), while at the same time maintaining good nutritional quality. Soy protein isolates and "functional" (dispersible) concentrates are the most effective soy ingredients used in emulsion-type meats.

Coarsely chopped meats. In coarsely chopped meats (such as meat patties, sausages, meatballs, chili, Salisbury steaks, pizza topping, and meat sauces) textured soy protein concentrates and soy flours are the preferred ingredients to obtain the desired texture (Jindal and Bawa 1988). Usual hydration levels are about 2.5 to 3.5:1, but higher levels are possible. A good guide in hydrating soy products is to achieve a protein level in the hydrated form of about 18%. If too little water is used to hydrate the product, the extended meat product will be dry. The flaked form assures rapid hydration that makes the ingredient well suited in high-volume applications. Its meat-like appearance and mouthfeel remain intact throughout strenuous retort and freeze-thaw conditions while contributing to overall stability of the fat in the food

Table 8—Important food uses of soy protein ingredients.

Product	Soy protein isolate	Soy protein concentrate	Soy flour	Textured soy protein
Bakery products				
Milk products	X	X	X	
Bread, rolls			X	
Breads (specialty)	X	X	X	
Cakes, cake mixtures	X	X	X	
Cookies, biscuits, crackers, pancakes, sweet pastry, snacks	X	X	X	
Doughnuts		X	X	
Pasta products	X	X	X	
Breakfast cereals				
Dairy-type products	X	X	X	
Beverage powders		X		
Cheeses		X		
Coffee whiteners		X		
Frozen desserts		X		
Whipped toppings		X		
Infant formulas	X	X	X	
Milk replacers for young animals	X	X	X	
Meat food products				
Emulsified meat products				
Bologna, frankfurters	X	X		
Miscellaneous sausage	X	X		
Luncheon loaves	X	X		
Luncheon loaves (canned)	X	X		
Seafoods	X	X		
Coarsely ground meat products				
Chili con carne, Sloppy Joes	X	X	X	X
Meat balls	X	X	X	X
Patties	X	X	X	X
Pizza toppings	X	X	X	X
School lunch/military	X	X		X
Seafood	X	X		X
Whole muscle meat				
Analogs	X	X		X
Ham		X		
Meat bits (dried)				X
Poultry breast		X		
Seafood (surimi)	X	X		X
Stews	X	X		X
Miscellaneous applications				
Candies, confection, desserts	X	X	X	
Dietary items	X	X	X	
Asian foods		X		
Pet foods			X	X
Soup mixes, gravies	X	X		X

system. In supplementing ground meat in a pattie-type product, extensions can be made up to about 20% without flavor adjustment. Above this level, it is necessary to use additional seasonings to offset the dilution effect of the bland ingredient on the taste of the meat. The primary function of the protein is to improve the dimensional stability of the patties, preserve the structural integrity of the ground meat pieces during thermoprocessing, and help to retain meat juices (decrease cooking losses). When properly used, the patties or other types of ground-meat products will be tastier, will have a higher protein content and lower fat content, and thus are better balanced nutritionally (Lacomte and others 1993). Textured vegetable proteins fortified with vitamins and minerals, when prepared and served in combination with meat, poultry, or fish, may be used as meat alternates (Ray and others 1981). The effect of wheat flour, whey protein concentrate (WPC), and soy protein isolate on oxidative processes and textural properties of meatballs cooked at 70 °C and subsequently stored at 4 °C up to 7 d or at −20 °C up to 1 mo was studied (Ulu 2004). WPC and SPI were inhibitory toward oxidation in cooked meatballs. For inhibition of lipid oxidation, SPI was slightly more effective than WPC; however, WPC was more effective than SPI for inhibition of oxymyoglobin oxidation. Textured vegetable protein often is used as one of the protein ingredients in pizza toppings, along with the meat and cheese. There is also a large market in military and other types of institutional feeding, in addition to the school lunch program. In the United States the military purchases more than one-half of its beef in ground form. Soy-extended beef is used to achieve significant cost savings. The extender approved is textured or granulated soy protein concentrate, which, in a hydrated form, can be added at about the 20% level (5% on a dry basis). Varying amounts of texturized soy protein products are used also in combination with powdered functional concentrates or isolates in patties and other types of ground meat products such as meat balls, pizza toppings, taco fillings, Sloppy Joe mixes, and so on. With the advantage of increased yield obtained by these combinations, their utilization in all types precooked items and entrees has greatly enhanced. The variety of formulations in today's portion-controlled ground meat products is limited only by the food technologist's creativity and ability to machine the meat mix on high-speed forming equipment. Although more and more textured soy proteins are used in retail stores, the institutional trade is still the mainstay of current sales (Anonymous 1997). This is probably due to lack of large-scale effort to advertise the benefits of soy protein to an informed consumer market. Many previous attempts in retail marketing of soy proteins in processed meats failed, most likely because of poor positioning, pricing, or just plain misusing the ingredient (as, for example, to cover up the poor-quality meat in the formula) rather than because of the alleged unfavorable " image" of soy.

Canned meats. Soy protein ingredients (mainly textured) are also used in retorted products to absorb juices liberated during canning, resulting in a less sloppy or firmer final product. Structured concentrates have an advantage over other forms in any retorted product because they can be used at fairly high levels and they maintain their textural integrity under retorting conditions (Lacomte and others 1993). The combination of a textured soy product and an isolate or a "functional" concentrate with an emulsifier (such as lecithin) provides superior functionality over a single ingredient by not only increasing the protein content but also by resulting in a pleasing uniform texture with no fat separation.

Whole muscle meals. It is possible to incorporate an isolate or a "functional" concentrate into large pieces of muscles (ham, roast beef, poultry, fish, and others). Brine containing one of these products is injected or massaged into the muscle using conventional cured-meat technology. Alternatively, the intact muscle pieces can be injected first with brine, and then the protein incorporated by massaging or tumbling. This process can be used to increase yield of muscle meal by 20% to 40% over the green weight (original weight; free from incorporated proteins). Product quality attributes include normal appearance, improved firmness, and slicing characteristics as compared to conventional brined-cured hams, combined with less seepage under vacuum-packaging (Troutt and others 1992).

Poultry products. Poultry products are also consumed in 2 basic forms: whole muscle and comminuted. Vegetable protein ingredients, including vital wheat gluten, "functional" soy concentrates, and isolates, are being used to bind meat cuts and trimmings to make pressed loaves and poultry rolls. Poultry breasts pumped with slurries of soy protein isolate, salt, and flavors are also becoming popular. Products such as boneless turkey and comminuted chicken loaves present to the poultry processor problems similar to those faced by the sausage maker. Field reports indicate that soy proteins are being increasingly used for this purpose (Lacomte and others 1993).

Seafood products. Japanese fish-based products best illustrate the use of soy protein in traditional seafoods. These are traditional comminuted gel-like products that have been consumed in Japan for centuries and are based on a minced fish flesh ingredient called surimi. Outside Japan, soy proteins are not being widely used in traditional seafoods. Opportunities exist today, however, and soy proteins can and will impact on the seafood market. In the last few years, textured soy protein ingredients have been advocated as seafood extenders. In one use, hydrated textured material is mixed with ground or minced flesh and a matrix-forming material. The mix is extruded or molded into various shapes, usually in the form of sticks or shapes characteristic of shrimp or fish. These products are then battered, breaded, fried, and frozen. In another use, hydrated textured proteins may be used in extending items such as imitation crab and shrimp, tuna salad, fish patties, and so on (King and others 2001). The water absorption and retention properties of certain soy proteins could also be used to bind moisture in fish blocks, bind fish pieces in minced fish blocks, and pick up some of the fish moisture lost during processing.

Analogs. Complete meat analog products such as bacon crumbles, breakfast sausage, and more have been in the retail stores for several years. Flavored soy proteins for use as salad toppings and replacement for nuts and vegetable crops (bell peppers) are also being developed for the retail and institutional markets. Analogs, which are produced to resemble conventional foods in appearance, color, flavor, and texture, represent the ultimate adoption of soy proteins. All-vegetable protein analogs resembling ham, turkey, and sliced beef are being marketed in vegetarian-type foods. While these products, associated with religious groups and health fads, have a limited market, with current interest in health on a broader front there may be a new opportunity for formulating meals with lower or no animal fat in order to develop low cholesterol entrees (Lin and others 2000). Well-known soy analogs for the general population include breakfast meats, foods for backpacking, whipped cream, and imitation cheeses.

Pet foods. One should not overlook another closely related industry in an affluent society, namely, the pet food industry. Currently, most pet food products, animal diets, and animal feeds contain soy derived products as an additional source of protein and fibers. The future will very likely see a major portion of this market being supplied by textured vegetable protein products, made primarily from soy protein (Hennenger 2002).

Dairy-type products

Isolates are the most acceptable products for dairy applications because of their fine particle size and dispersibility. The functional properties of emulsification, emulsion stability, color, and flavor/odor are critical factors in dairy applications. Although isolated proteins offer much potential in the manufacture of dairy-type products, these products are not yet produced in the United States in significant volumes while Japan and China are the major producers of these products. A few, such as dry and liquid coffee whiteners, liquid whipped toppings, prewhipped toppings, and toppings of other emulsified food items to replace sodium caseinate enjoy distribution in the United States. There is considerable development effort being devoted to a broad variety of other dairy-type foods: imitation milks, convenience beverage powders, frozen desserts, sour cream, sour cream dips, and related cheese-like products. With the development of soluble concentrates and isolates, the manufacture of higher-quality soy-based baby foods became possible. These products have improved color, flavor, odor, and do not contain the flatus producing carbohydrates found in soy flours. Soy protein isolates supply almost all of the protein in the liquid formulas. Approximately 10% of the formula-fed infants are being fed formulas containing soy protein. Soy protein formulas are recommended for those infants, and others, who are allergic to milk protein and those who have lactose intolerance or lactase deficiency. The isolated soy protein-based formulas currently on the market are all free of cow milk protein and lactose, and prepared so they that provide 67 kcal/dL (AAP 1998). In addition to the milk-free or soy-based infant formulas, special formulas utilizing soy protein products are designed and manufactured for older infants and geriatric, hospital, and postoperative feeding. Soy proteins seem to have an assured role in dairy product analogs also made for people who have special health or religious diet requirements. Full-fat and defatted soy flours have been used successfully as major ingredients in low-cost replacements for milk solids in beverages for human consumption in developing countries (Ohr 1997). The worldwide market for soymilk products has been growing at a fast pace. Soy protein concentrates are preferred in milk replacers for baby animals such as calves, lambs, and pigs because of their low soluble carbohydrate content (thus do not cause gastrointestinal disturbance problems) and lower immunogenecity. The proteins are used to form fat emulsions as a method for incorporating fat into the formulation and to provide protein for nutrition.

Soy protein ingredients are now being used in emulsion-type cheeses to replace as much as 50% of sodium caseinate in some products. Fermented soy cheese-like products have been tried but there is still much research needed before the textural/rheological properties of dairy cheese can be reproduced in a satisfactory manner. One of the properties that is lacking in these products, but is important in pizza and other foods, is the "melt-down" upon baking and stringy texture which is characteristic of mozzarella cheese. Soy and milk protein blends (combined to offer protein content similar to that of milk) are sold as ingredients in bakery products, sauces, meat products, and various fabricated foods, as complete or partial replacement of nonfat dry milk (King and others 2001). Present U.S. federal and state dairy laws greatly restrict competition by modified or imitation dairy products, and retard new developments in this area. Sooner or later, however, new soy products, having better flavor and tailored-made functional properties, will play an increasingly greater role in dairy-type products.

Beverages

Soy protein concentrates and isolates are an ideal source of highly digestible protein in beverages. Soy protein is low in viscosity; therefore, it can be used in beverage applications. Soy protein helps achieve desired mouthfeel. The low viscosity contributed by soy isolate makes it ideal for other nutritious liquid products such as infant formulas, creamers, milk replacers, and spray-dried products. Soy products add fiber, minerals, and other nutrients to the formulation. Beverages seem to be an easy way for consumers to add soy protein into their diets. Special types of soy proteins are available for beverages. These are water-washed protein, so they deliver a significant amount of isoflavones and fiber (Lusas and Riaz 1995). Soy isolates are the blandest traditionally, so most soy protein drinks contain soy isolates. But new processing technology makes it possible to produce pleasant-tasting beverages with soy concentrates. New soy beverages on the market look like milk and have good sensory attributes and a clean aftertaste. Flavor systems for soy beverages depend on the source and level of the soy protein, vitamin, and minerals. Formulating soy protein into an appealing beverage is not always easy. Heat and processing may change the flavor profile of the beverage. Besides providing an alternative to traditional dairy products, soy protein is being incorporated into many of today's nutritious meal-replacement beverages, offering on-the-go consumers a way to skip a sit-down meal for the convenience that a liquid option offers. Yogurts with low concentration of soy protein (1% or 2.5%) were most similar to traditional dairy yogurts. The ability of soy flavors to overpower fermented dairy flavors and chalky texture even at concentration as low as 1% added soy protein concentrate makes soy fortification of dairy foods a particular challenge. The use of additional sweetener to overcome decrease in perceived sweetness or fruit flavors may aid in masking soy flavor or enhancing existing dairy flavors. The fortification of dairy yogurts with small, but dietary significant amounts of soy protein may provide an acceptable way to introduce additional soy protein (Drake and others 2000).

Bakery products, cereals, pasta

Unless higher protein fortification levels are necessary, there is no special reason for using soy protein concentrates in bakery products. Nutritionally and functionally, soy flours do the same job more economically. In bakery products, cereals, and pasta, soy protein ingredients are being used for a variety of economical, functional, as well as nutritional reasons (Kulkarni and others 1992). Because of price and the compatibility of particulate vegetable fiber with most bakery products, defatted soy flour is the most widely used soy ingredient in these applications as a partial replacement for dry milk (Shogren and others 1981). The greatest usage for soy proteins in bakery foods is in combination with other ingredients such as sweet dairy whey. Milk replacer blends are available at protein levels ranging from 20% to as high as 40%. The nature of the blend is dictated by the functional and/or nutritional requirements for the product in question. Defatted soy flour is the primary soy product used in these blends, but concentrates and isolates are also used as partial or complete replacements for nonfat dry milk. These blends are used partly for reasons of economy and partly because some bakers want to retain some dairy product in their bread formulas as an image builder (Onayemi and Lorenz 1978; Stauffer 2006).

Bread and rolls. When defatted soy flour is used at the rate of 1% to 3% (dry flour basis) in bread and buns, it increases absorption, improves crumb body and resiliency, enhances crust color, and improves toasting characteristics. The keeping of freshness in bread is probably due to the retention of free moisture by the soy protein that is retained even during the baking cycle. As mentioned previously, reduced crumb color can be produced with high-enzyme soy flours that have high lipoxidase activity (French 1977). Darker crust color can also be obtained with soy flours having low lipoxidase activity because of the high lysine content of the soy ingredient; and the free amino group in lysine reacts with reducing sugars to form the Maillard browning reaction. Heavily toasted grits with a PDI (protein digestibility index) of 20 to 30 are used in wholegrain, multigrain, and natural grain breads to add color and a nutty, toasted flavor (Lutzow 1996). Nutritional studies indicate that the protein quality of commercial white bread containing 3% soy flour is equal or slightly superior to bread containing 3% nonfat dry milk.

Specialty breads. The protein content of ordinary white bread is 8% to 9%. Specialty breads can be made with 13% to 14% protein by incorporating soy flour, concentrate, or isolate in the formula, along with vital wheat gluten and, if necessary, a lipid emulsifier (such as sodium stearyl-2-lactylate or ethoxylated monoglycerides). Without surfactants, incorporation of high levels of soy flour depresses loaf volume and gives poor crumb characteristics. In nonstandardized breads with higher levels of soy protein, there are dramatic changes in the nutritive value of bread (Kulkarni 1995). When 12% soy flour is used, the P.E.R. (protein efficiency ratio) increases from 0.7 to 1.95. In addition to the improvement in protein quality, the protein content is also increased by more than 50% at this level of supplementation. Soy-fortified wheat flour has been used worldwide in mass feeding and school lunch programs (McWard 1995).

Cakes and cake mixes. Soy protein products, including soy isolate-whey blends, have been evaluated in pound cakes, devil's food cakes, yellow layer cakes, and sponge cakes, in which 50%, 75%, or 100% of the nonfat dry milk can be replaced without impairing quality. Defatted and full-fat soy flours and grits are added to cake, bread, pancake, waffle, and many other baking mixes at levels of 2% to 15%. In many of these mixes, other types of soy proteins may also be added, such as isolates or concentrates, depending on individual formulation requirements. Soy protein products in these mixes help with the emulsification of fats and other ingredients (Golbitz 1995). The resulting dough is more uniform, smoother, and pliable, as well as less sticky. The finished baked products will have improved crust color, grain, texture, symmetry, and longer freshness. Lecithinated soy products are often used (3% to 5%) in heavier cakes, such as sponge and pound cakes, because of the increased richness and emulsification functions they provide. In addition, the high-fat or lecithinated soy flour may permit reduction in eggs and shortening.

Doughnuts. Doughnuts containing soy protein absorb less fat during frying, because fat cannot penetrate into the interior. This is probably due to the heat denaturation of the protein-containing surface area that acts as a harrier. This results not only in a better-quality doughnut, but also in a more economical formula, by lowering frying oil costs. Used in the range of 3% to 3.5% of the formula, soy flour gives doughnuts a good crust color, improved shape, higher moisture absorption with the resultant improvement in shelf life, and a texture with shortness or tenderness (Sipos 1994). Lecithinated soy flour is recommended for doughnut formulas with minimal egg yolk levels.

Breakfast cereals. New emphasis on nutrition in breakfast cereals has meant more use of soy proteins to increase protein quality and quantity. Soy proteins are also used in hot cereal mixes, and as components of granola bars and compounded breakfast bars (Zind 1998). Soy protein isolate in combination with wheat bran was used for the preparation of corn-based breakfast cereals extruded at varying feed moisture contents (21%, 23%, and 25%) and added sugar levels (0%, 5%, and 10%). Notably, 10% added sugar and 25% feed moisture increased sensory corn flavor while decreasing soybean flavor (Faller and others 2000).

Pasta products. Pasta products of all types, such as macaroni, spaghetti, and so on, are being fortified with soy protein to increase nutritional value. Foods of these types have been accepted by the U.S. military, government feeding programs, and school lunches. Defatted soy flours are most commonly used. These pasta products contain soy flour at the 15% level on a dry basis, with 15% to 17% protein content. If desired, vitamin enrichment can be included. Acceptable commercial-grade pasta products (such as spaghetti) can be prepared from durum semolina fortified with soy protein products, especially isolates (Tsen and others 1975). Soy protein products increase the absorption of spaghetti dough and promote firmness, a special advantage for pasta subjected to long cooking periods. Soy protein isolate usually produces the lightest color. Limroongreungrat and Huang (2007) prepared pasta products from sweetpotato fortified with defatted soy flour (DSF) and SPC at levels of 0, 15, 30, and 45 g/100 g. Addition of DSF and SPC increased the lightness (L^* value) from 40.6 to 48.7, and decreased the redness (a^* value) from 21.6 to 15.2. Substitution of DSF and SPC decreased firmness from 1.8 to 0.4 N, cohesiveness from 0.6 to 0.5, and springiness from 1.2 to 1.1 mm.

Miscellaneous baking applications: sweet rolls/cookies/pastry/crackers/snacks, pancakes, and others. The functional properties of soy proteins are the same in these applications as those described for the previously mentioned bakery products. The incorporation of a white soy flour, or a mildly lecithinated soy flour, in a pancake formulation at the 3% level will result in a golden brown product with improved light and fluffy texture, with a reduced tendency to stick to the griddle. In sweet goods, 2% to 4% defatted soy flour improves water holding capacity, sheeting characteristics, and finished product quality. In hard (snap) cookies, the use of 2% to 5% defatted soy flour improves machining and produces cookies with a crisp bite (Kulkarni 1997). "Short" pastry items such as pie crusts, fried pie crusts, and puff pastry can be machined more easily and will retain freshness longer when lecithinated soy flour is used at the 2% to 4% level. Cookies, macaroni, and burger prepared from flour mixtures using wheat, soy, and defatted sesame flour blends in various proportions were sensorially evaluated and the results revealed that products had gained acceptance (Marques and others 2000). Wheat flour and DSF blended in the ratio of 65:20, 60:25, 55:30, and 45:40 were studied with respect to dough characteristics and quality of fried savory and sweet snacks prepared from them. Farinograph characteristics of flour blends showed that as the proportion of soy flour increased there was a slight increase in water absorption and decrease in dough stability. In fried savory snacks the protein content increased gradually from 20.75% to 27.50%. When the proportion of soy flour was raised from 20% to 40% in the blend, the corresponding rise in protein content in fried sweet snack was from 15.75% to 21.75% (Senthil and others 2002). SPI also finds application in preparation of fried cookies by partial replacement with wheat flour up to 15% without diminishing acceptability. The addition of SPI caused a decrease in fat content and an increase in the moisture and protein content of cookie. Dehydration and oil absorption during frying decreased as the level of SPI replacement increased. The dough consistency, external and internal color of cookie, and textural hardness increased with the addition of SPI (Lee and Brennand 2005).

Miscellaneous foods

Miscellaneous food applications include brew flakes (soy flakes/grits); soups, gravies, and sauces; confections; imitation nut meats; and nonfermented oriental soybean foods (such as soymilk and tofu). Canned soups, sauces, and gravies often utilize soy proteins to prevent separation of ingredients and to impart thickening which is so essential to the identity of these products. Other product concepts entering the retail market are those in the dry grocery products category. These consist of a pouch pack or boxed instant dinner concept, using soy proteins as functional ingredient. The food uses of the soybean make an important contribution to the protein and fat requirements of Asians. In addition, these products have been used over the centuries to good advantage in many food preparations to give foods a desirable meaty flavor. Tofu is the most important example in this category. It is becoming more popular in Western countries. The traditional tofu is a highly hydrated, gelatinous product, containing about 88% water, and is sometimes said to resemble cottage cheese. With modern manufacturing facilities other forms are now also available (such as dry tofu). The confectionery field uses soy flour in various types of confections. Caramels and toffee-type products handle better with the inclusion of soy flour, and there is less stickiness on a high-speed wrapping machine. In fudges, soy flour will slow the rate of dehydration and thereby aid in preventing crystallization of the sugar. Partially hydrolyzed soy proteins (albumens) are used to make nougats, creams, kisses, fudge, and similar types of candy, as well as meringue powders, icings, and other confections (Sipos 1994). Aeration is aided in these products by using hydrolyzed soy protein. Because of the technology built into a complete line of soy-based textured ingredients, these can be used in an impressive array of foods, including frozen foods, salad dressings, and pizza dressings, where the ingredients retain their shape and add texture and flavor. Rayner and others (2000) developed soy protein (SP) films to reduce fat intake in deep-fried foods, and there was a significant fat reduction between fried uncoated and coated discs of doughnut mix.

Consumption Trends

The industry producing edible soy protein products for human consumption has grown enormously since the late 1950s, and its products are now available for large-volume use. Current known yearly world production is estimated to be approximately 1500 metric tons (14.98 billion kg) of soy flour, 90000 metric tons (0.91 billions kg) of soy protein concentrate, and 70000 metric tons (77.20 million kg) of soy protein isolate, which amounts to about 1.68 billion kg of edible protein for human consumption per year (Market Research Report 2006). (Since soy flour is used in many developing countries where statistical records are incomplete, the figure for this ingredient could be higher than given here.) Soy proteins appear to be the only large-volume, commercial protein ingredients that will be used in the foreseeable future for both nutritional and functional purposes as replacements for traditional animal proteins. Other plant proteins are still in the potential category and show no signs of becoming a serious commercial reality in the near future. Some do enjoy a limited market, such as peanuts and wheat gluten, the latter as a functional ingredient in baked goods, and meat analogs. A factor that has a direct effect on the price of protein ingredients is the available supply. This is an important consideration in the selection of ingredients by the food manufacturer. Vegetable proteins such as those of the soybean and wheat gluten are in a better position from the standpoint of availability than some of the animal proteins because of the large potential supply of starting materials, namely, soybeans and wheat. Only about 2% to 3% of the total U.S. soybean crop is used domestically as a direct source of protein (as opposed to the indirect use as in animal feed). Potentially, conversion of defatted soybean flakes to edible-grade protein products could likely increase several-fold without serious effects on the availability of defatted soybean meal for feeds. With the demand for meat products declining in the United States, and consumer interest in "healthy" foods increasing, new opportunities exist for the use of soy proteins in formulating low-calorie, low-cholesterol, and high-density protein items. On the other side of the spectrum, there is a tremendous food shortage in many parts of the world, both in terms of calories and protein, where protein fortification would fill a real need. The solution for this problem is economics and politics, with the nutritionist and food scientist playing only the role of advisor.

The European market is using the entire spectrum of soy protein ingredients in the same way as is the case in the United States. Notable exceptions are that more emphasis is being placed on emulsified processed meats as opposed to ground meats (patties), and less defatted soy flour is used in bakery products. On the other hand, full-fat soy flour is manufactured and used in baked goods, especially in the United States. Isolates, concentrates, and textured soy products, although originally developed in the United States, are now manufactured and/or consumed in Japan, China, India, Southeast Asia, Latin America (especially Brazil), Israel, and Europe.

Future Considerations

As consumers have become better informed about nutrition, food producers have adopted their formulas/recipes to meet the changing demands of the marketplace. Food manufacturers face the challenge of providing nutritious food, while at the same time ensuring that the product has an appealing taste, texture, and appearance.

Reasonable projections indicate that the area of diet and health will continue to increase in importance in the form of calorie-controlled and tailored nutritional foods. Soy protein will have an excellent opportunity to get the focus of attention it truly deserves as a highly nutritious and economical food ingredient. Food service is served well by the reformulation technology permitted by the use of soy proteins. Other food service benefits when using soy protein include better product uniformity and reduced cooking loss. There is no question that in this new era of "restructured" food technology soy protein products will play a key role because of their functional and texture-forming capabilities. There will also be changes in product formulation, primarily in the traditionally conservative dairy and meat industries. These industries are now ready to experiment with new product concepts. Old ideas will change as new foods will be dictated by ingredient availability, implementation of modern process technology and distribution systems, marketing requirements, and nutritional guidelines. In the long run, as farmland become more expensive to work and as feed costs rise, beef, pork, and poultry products will become more expensive.

Food processors will seek new sources of low-cost, efficient proteins such as the soybean or perhaps food from the sea. More recently, however, the demand for soy protein concentrates appears to have been growing at the fastest rate. The pet food and specialty feed markets have been identified as the single largest markets. Other fast-growing areas were soymilk, imitation cheeses, ground meat blends and extenders, and commercial bakery and confectionary ingredients. While soy proteins have largely been considered as economical substitutes for more expensive protein ingredients, they should be viewed as vital functional components that will enable the food technologists to fabricate new foods. Perhaps a new approach will emerge one day when soy foods and ingredients are marketed in their own right rather than just as imitations of other existing products. In the meantime, soy protein products will continue to play an important role in providing the nutritious foods customers demand, and will be gaining in acceptance as useful and economical ingredients in the manufacture of conventional foods and in the design of new foods.

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