Soy Applications in Food

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Preface

Soyfood utilization around the world varies widely. Asia utilizes soybeans primarily as traditional foods such as tofu, soymilk, and fermented products, whereas Western nations consume more soybeans in the form of refined soy protein ingredients used in food processing than as tofu or soymilk. The consumption in Asia is based on longstanding traditional eating habits and food production methods. In Western nations, the consumption of soybeans as direct human food is a somewhat new phenomenon, although it is gaining increased acceptance and significance. Soybeans in food applications became very popular after the Food and Drug Administration approved a soy protein health claim in 1999. The use of soy in various food applications is of major importance to food industries. Because soy ingredients are being applied in so many diverse food systems, they are increasingly being regarded as versatile ingredients. Not only are soybean ingredients healthy, but they also play a major role in food functionality.

Currently, a limited amount of information is available on the use of soybeans in food applications, even though many types of soy ingredients can be used in various food systems. Sometimes it is difficult to decide what types of soy ingredients and processing will be best for certain food applications. This book provides insights into the different types of soy ingredients and their processing requirements for food applications. It serves as a source of information to all who are involved with the production of foods containing soy ingredients. For readers new to this area, the book can further their understanding of soy ingredients and their many applications.

This book summarizes some of the fundamentals to be considered when applying soy ingredients to food systems. The text is an excellent starting point for research and development personnel, students, and food technologists and other professionals in the food processing field. It brings together in-depth knowledge of processing food with soy ingredients and practical experience in the application of soy in food. It offers a wealth of information about the health benefits of soy protein, the current soyfood market, and the processing of soybeans into different soy ingredients. Also discussed is the use of soy protein in baked goods, pasta, cereal, meat products, and food bars. Some of the material addresses how to process soybeans into soy milk, soy beverages, and texturized soy protein; how to select identity-preserved soybeans for various food applications; how to overcome the beany flavor of some of the soy products; and how soy protein is fulfilling the need for protein in underdeveloped countries. This book is a valuable resource for information on the technical and practical applications of soy ingredients and will be a useful guide for selecting the proper soy ingredients for various

applications. Most of the contributors to this book have at least 10 to 15 years of practical experience in their respective fields. The editor owes a large debt of gratitude to the many individuals who have provided information and inspiration.

The Editor

Mian N. Riaz, Ph.D., earned his bachelors and masters degrees in food technology from the University of Agriculture, Faisalabad, Pakistan, and his doctorate from the University of Maine, Orono. He is currently Head of the Extrusion Technology Program at the Food Protein Research and Development Center and a graduate faculty member in the Food Science and Technology Program at Texas A&M University, College Station. Dr. Riaz conducts research on extruded snacks, texturized vegetable protein, pet food, aquaculture feed, oilseed processing, and extrusion-expelling of oilseeds. He is also the editor of the book *Extruders in Food Applications* (Technomic) and co-author of the book *Halal Food Production* (CRC Press).

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Soyfoods: Market and Products

Peter Golbitz and Joe Jordan

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It can be eaten raw, roasted, fermented, or cultured. It can be a small, green bean or a magically transformed concoction that closely resembles hamburger, ice cream, bacon, or even a fully dressed turkey. Yes, the soybean is one of the most nutritious and versatile foods on the planet, and it is an important food platform for the 21st century.

History of Soyfoods

Even though soy is a new food for many in Western society, the Chinese have considered it an important source of nutrition for almost 5000 years. The first reference to soybeans, in a list of Chinese plants, dates back to 2853 B.C., and ancient writings repeatedly refer to it as one of the five sacred grains essential to Chinese civilization. The use of the soybean in food spread throughout the Asian continent during the early part of the last millennium, as people in each region developed their own unique soyfoods based on tradition, climate, and local taste preferences. Natto, for instance, is a product consisting of fermented soybeans that was developed at least 3000 years ago in Japan and continues to be popular in some regions of that country today.

Growth and Development in the Western World

When European missionaries and traders traveled to Asia during the 1600s and 1700s, they wrote in their journals about traditional soyfoods, such as tofu and soymilk, that they had encountered in the cultures they explored. Then, in the late 1700s, both Benjamin Franklin and a curious world traveler named Samuel Bowen sent soybean samples to the United States for cultivation. Mr. Bowen's soybean crops, grown in Georgia, were even used to manufacture soy sauce and a soy-based vermicelli substitute. But, it was not until Asians began to emigrate to Europe and North America during the 1800s that soyfoods were consistently made by and for people in the United States. Several Chinese tofu and soymilk shops were established in cities

with large Asian populations in Europe and on the East and West coasts of the United States; however, throughout the 19th century, soyfoods tended to be made in small, family-run shops and were distributed and consumed primarily in Asian neighborhoods. During the 1920s, a number of smaller companies with ties to the Seventh-Day Adventist Church (many members of which are vegetarian) began making tofu in the states of Tennessee and California. During that same time, soy flour started to gain favor in both Europe and the United States as a low-cost source of protein in the production of meat substitutes, and, during both World Wars, large amounts of soy flour were used to help offset meat shortages.

Soybean Industry Blossoms in the United States

Large-scale development of the soybean crop and processing industry began in the United States during the 1940s and 1950s, spurred on by a rapid increase in domestic and worldwide demand for both protein meal and vegetable oil. Harvested soybean acreage in the United States more than tripled between 1940 and 1955, from 4.8 million acres to 18.6 million, while total production of soybeans increased nearly fivefold, from 78 million bushels to 374 million. As the number of acres devoted to soybeans continued to grow during the 1960s, the United States became a world soybean superpower and began exporting large quantities of soybeans, as well as the basic crush products of meal and oil, to Europe and Asia. By 1970, U.S. farmers had planted an incredible 43 million acres of soybeans and produced 1.1 billion bushels. The crop would more than double in size to 2.3 billion bushels, or 62.5 million metric tons, by 1979. Industry growth has slowed in recent years due to increased competition from other producing nations, but the United States still produces roughly 75 million metric tons of soybeans each year.

Soybeans Grow Around the World

Though still the largest soybean exporting country in early 2005, the United States has lost the dominant position it once had in the global soy trade. Brazil, Argentina, and India have all become major producers as the world's demand for soy as food, vegetable oil, and animal feed has continued to increase. Given the amount of available arable land and water resources in Brazil, along with its low labor costs, it is expected that Brazil will eventually become the number one soybean-producing nation. Already, South America as a continent produces more soybeans that North America (combined U.S. and Canadian production). Growth in China, where this story began, has been plagued with inefficiencies and lags behind most major producing countries, although it is still the fourth largest soybean grower. In 2004, it was the world's largest importer of soybeans as well.

TABLE 1.1

World Soybean Production by Major Producers

	Production (million metric tons)				
	2000/01	**2001/02**	**2002/03**	**2003/04**	**2004/05**
United States	75.06	78.67	75.01	66.78	85.48
Brazil	39.50	43.50	52.00	52.60	63.00
Argentina	27.80	30.00	35.50	34.00	39.00
China	15.40	15.41	16.51	15.40	18.00
India	5.25	5.40	4.00	6.80	6.50
Paraguay	3.50	3.55	4.50	4.00	5.00
All others	9.42	8.60	9.60	10.23	11.64
Total	175.93	185.12	197.12	189.81	228.63

Source: U.S. Department of Agriculture estimates, March 2005.

Soybean Production and Utilization for Food

For the marketing year 2004/05, the world produced approximately 229 million metric tons of soybeans, enough to give each man, woman, and child 35 kg of soybeans each, or the equivalent of nearly 300 L of soymilk for a year (see Table 1.1). But, the world's soybeans are not used exclusively for humans. Each year, on average, an estimated 85% of the world's soybeans are processed (crushed) into soybean meal (used primarily for animal feed) and vegetable oil. Approximately 10% is used directly for human food and the balance is used for seed or on-farm feeding of animals or is waste material. In addition to the 10% of the crop that is used directly for human food — for products such as tofu, soymilk, natto, and miso — an estimated 4 to 5% of the soybean meal that is produced from soybean crushing is further processed into soy protein ingredients that, in turn, are further processed into various meat and food products or are used in infant formula, dairy and meat alternatives, nutritional supplements, and energy bars.

Soyfood consumption patterns around the world vary widely, with such regions as Asia utilizing soybeans primarily in such traditional foods such as tofu, soymilk, and fermented products. In Western nations, more soybeans are consumed in the form of refined soy protein ingredients (used in food processing) than in the production of tofu and soymilk. As well, Soyatech, Inc. (Bar Harbor, ME) estimates that Asian nations utilize 95% of the soybeans consumed directly as human food in the world today. The heavy consumption in Asia is based on long-standing traditional eating patterns and food production methods. In Western nations, consumption of soybeans as direct human food is a somewhat new phenomenon, although it is gaining increased acceptance and significance.

As can be seen in Table 1.2, Asian countries consume far more soybeans and soy protein equivalent per day than do Western nations. For example,

TABLE 1.2

Annual Per Capita Consumption (2001) of Soybeans for Direct Food

Rank	Country	Soybeans (kg/yr)	Soybeans (g/day)	Soy Protein Equivalent (36% Protein) (g/day)
1	Taiwan[a]	19.15	52.46	18.89
2	Korea (North)	10.67	29.24	10.53
3	Korea (South)	8.79	24.07	8.67
4	Libya	8.68	23.78	8.56
5	Japan	7.73	21.19	7.63
6	China	7.31	20.03	7.21
7	Indonesia	7.16	19.61	7.06
8	Uganda	4.71	12.91	4.65
9	Nigeria	2.76	7.57	2.72
10	Thailand	2.34	6.40	2.30
11	Myanmar	1.91	5.22	1.88
12	Yemen	1.85	5.06	1.82
13	Costa Rica	1.40	3.84	1.38
14	Peru	1.40	3.83	1.38
15	Vietnam	1.27	3.48	1.25
16	Canada	0.68	1.88	0.68
17	Zimbabwe	0.65	1.77	0.64
18	Philippines	0.51	1.39	0.50
19	India	0.41	1.13	0.41
20	Ethiopia	0.38	1.04	0.38
21	United States[a]	0.33	0.89	0.32
22	Germany	0.24	0.66	0.24
23	Egypt	0.24	0.66	0.24
24	South Africa	0.23	0.64	0.23
25	Congo, Democratic Republic	0.18	0.50	0.18
World average		2.39	6.54	2.36

[a] Soyatech, Inc., estimates.

Source: Food and Agriculture Organization (FAO) food balance sheets.

in Taiwan, per capita consumption is estimated to be as high as 19.15 kg per year, and in Japan at 7.73 kg per year. In the United States, yearly per capita consumption of soybean is just 0.33 kg per year; however, world average per capita consumption is approximately 2.4 kg per year, equivalent to around 6.5 g of soybeans per day, or an estimated 2.4 g of soy protein per person per year.

Soyfoods in Asia

Throughout Asia, the soybean is used in a wide variety of traditional and modern food products. For example, in Japan, tofu is the most popular soyfood consumed, eaten at virtually all meals in one form or another, from silken tofu in miso soup for breakfast to plain or fried tofu for lunch or dinner. Also, tofu is used in dessert products and as an ingredient in cutlets and other

prepared foods. Soymilk, after a quick rise and fall in sales in the mid-1980s, is making a strong comeback in Japan due to increased interest in functional foods and beverages and recognition of the powerful nutritive qualities of the soybean. Natto, a fermented soyfood product, has historically been extremely popular in Japan and is consumed daily by many people. Natto is prized for its unique taste and form, as well as its powerful blood-thinning and cleansing qualities. Miso, another fermented soyfood, is consumed daily by many Japanese in soup broth, salad dressings, and food toppings.

In China, tofu is also very popular, as is fermented tofu, yuba (dried soymilk skin), soymilk, and a variety of regional specialties, including soy noodles. In addition, soy powder mixes and isolated soy proteins are becoming popular as food ingredients and in consumer-oriented mixes for health. In Taiwan, the art of meat substitutes and alternatives has reached new heights with meat-, chicken-, and fish-like products made from soy proteins, yuba, gluten, and tofu. In Indonesia, tempeh is the most popular soyfood and is sold at thousands of food stands and kiosks throughout the country. It is made fresh each day by many individuals who purchase inoculated soybeans the night before and by morning have fresh tempeh to sell as street vendors. Throughout Asia, in addition to tofu and other regional soyfoods, processed and packaged soymilk has grown increasingly important in recent years and has become big business in Hong Kong, Korea, Malaysia, Singapore, Thailand, and Vietnam.

Soyfoods in Europe

European consumption of soyfoods is similar to that of the United States, with meat and dairy alternatives comprising most of the soyfood sales. Soymilk and meat alternatives sales are particularly strong in the United Kingdom, which has a relatively large vegetarian population. Wide acceptance of soymilk can also be found in Belgium, where the continent's largest soymilk producer is located. Throughout the rest of Europe, tofu is known, but it is not as popular as meat and dairy alternatives. As in the United States, soyfoods have become more of a mainstream food item, having crossed over from the natural products market to being widely available now in mainstream supermarkets.

Soyfoods in Africa

While a pan-African consumer market for soyfoods has yet to develop, certain countries in Africa have readily adopted soyfoods due to their high protein level and nutritional quality. Some of the use is a result of food aid programs where soybean products such as textured soy flour or soybean–corn meal are distributed, while in some countries feeding programs for workers and school children take advantage of the relatively low cost and high nutritive value of the soybean. In South Africa, a modern soyfoods market has developed; fresh and aseptically packaged soymilk is available,

as well as a wide array of products made from textured soy flour and sold as soy "mince," a low-cost ground meat replacement.

Soyfoods in the United States

In the United States, perhaps one of the more interesting markets for soy products has developed due to a number of supportive micro and macro trends, as well as a strong history of "Americanization" of foreign and ethnic foods. This is due to the United States being a large, immigrant melting pot that blends many different foods and eating traditions. In addition, a strong entrepreneurial spirit exists among both immigrants and those who are motivated by a desire to create livelihoods that benefit not only themselves but also the world at large. Soyfoods, due to their high nutritional value and their low environmental impact when compared to meat and dairy production, have become a rising star in the U.S. food marketplace.

Development of the U.S. Soyfoods Industry

The modern soyfoods industry in the United States has developed in three distinct phases. The first phase, one of *discovery,* took place during the 1920s, when early proponents of vegetarian diets such as Dr. John Harvey Kellogg of Battle Creek, MI, became interested in the healthful properties of the soybean. In addition to studying the usefulness of soybeans in the diets of diabetics, he also developed and marketed North America's first meat and dairy analogs made from the soybean. During those early years, soyfoods were promoted primarily among members of the largely vegetarian Seventh-Day Adventist Church and other special interest groups.

The second phase was distinctly *industrial* and paralleled the industrialization of American society. As mentioned earlier, soy flour had become an important component in food production during the Second World War, as meat shortages developed due to the increased protein and food needs of the armed forces and the disruption of farm commerce during the war years. Unfortunately, soy flour and protein processing was not a well-developed science at that time, and, as a result, most of the products had distinctive off-flavors and were tolerated at best, but not appreciated. The image of soybean-based foods became that of an inferior substitute and extender, to be used in times of crisis and shortage, rather than that of a nutritional alternative to meat and dairy foods for everyday use.

In the 1950s and 1960s and during the meat shortages of the 1970s in the United States, numerous food companies and meat processors used textured soy proteins to extend meat products. These early attempts were met with resistance by consumers who complained of poor flavor, texture, and color. Following this period, many food processors found it necessary to reassure consumers that their products contained no fillers or cereal additives. As this industrial phase ended, soybean-based foods were neither highly respected nor desired by American consumers.

It was during the 1970s that a third phase for soy emerged, a *new age*. In both the United States and Europe, a large, young counterculture had developed that began to question traditional American and Eurocentric values based on industrialization, military interventionism, and the politics of a meat-centered diet. New Age thinkers popularized the concepts of going back to the land, pacifism, vegetarianism, and the more equitable distribution of food resources. Two important publications of that era were *Diet for a Small Planet*, in which Frances Moore Lappé wrote of the misallocation of food resources and the value of the soybean, and the *Book of Tofu*, in which William Shurtleff and his wife Akiko Aoyagi wrote of, and eloquently illustrated, the beauty and tradition of soyfoods. The rediscovery of the value that the soybean could have in a modern world helped to inspire a new soyfoods movement in both the United States and Europe. During this time, hundreds of small companies were founded that were dedicated to producing soyfoods and educating the public about their use. The desire for a "right livelihood" within these companies and among their customers inspired tremendous innovation and helped to build a natural food and products industry and market.

According to statistics gathered by Soyatech, Inc., over 2000 new soyfood products were introduced during the 1980s in the United States, and many of them were made by small companies that made primarily (or exclusively) soy-based foods. Products such as tofu, tempeh, miso, tofu hot dogs, veggie burgers, tofu ice cream, soymilk, and other dairy alternatives all became common fixtures in natural food stores. As the young counterculture that founded this movement began forming households of their own, these soyfoods progressively crossed over into mainstream supermarkets.

The Americanization of Soyfoods

The pace of innovation and new product development accelerated throughout the 1990s with the continued Americanization of soyfoods into products that were more familiar and convenient, as well as healthful. In particular, the 1996 decision by White Wave, Inc. (Boulder, CO), to market its soymilk in traditional "gable-top" milk cartons in the refrigerated food cases of supermarkets led to a dramatic shift in soymilk consumption. Until that point, most soymilk was sold in natural foods stores and was packaged in aseptic packaging. Primarily vegetarians, the lactose-intolerant, and people who had ethical or religious objections to drinking cow's milk consumed it. Later, however, when White Wave positioned its Silk® brand soymilk to taste and look more like dairy milk, sales of soymilks in the United States exploded from $124 million in 1996 to nearly $700 million in 2004. Soymilk became simply another, perhaps more healthful, choice in the dairy case.

Another, broader impetus to the popularity of soyfoods was a 1999 decision by the U.S. Food and Drug Administration (FDA) to allow food manufacturers to include a claim for heart health on foods that contained more than 6.25 g of soy protein per serving (if they were also low in fat). This

TABLE 1.3

U.S. Soyfoods Market (1996 to 2005)

Year	$ (Millions)	Growth Rate (%)
1996	1244	11.5
1997	1484	19.3
1998	1747	17.8
1999	2288	31.0
2000	2769	21.0
2001	3234	16.8
2002	3648	12.8
2003	3912	7.2
2004	3996	2.1
2005 (projected)	4218	3.0

Source: *Soyfoods: The U.S. Market 2005*, Soyatech, Inc./SPINS, Inc., Bar Harbor, ME, 2005.

health claim states, "25 grams of soy protein a day, as part of a diet low in saturated fat and cholesterol, may reduce the risk of heart disease. A serving of [name of food] provides [amount] grams of soy protein." Since then, the range of foods that include soy protein has been limited only by the imagination of food scientists and marketers. In addition to soymilk and other dairy alternatives, categories that have done particularly well include tofu, energy bars, meal replacements, and meat alternatives. Categories on the rise include soy-based snacks, chips, soynuts, edamame (fresh green soybeans), and soy-enriched pasta, breads, and cereals.

The overall soyfoods industry has grown dramatically since the mid-1990s, from $1.2 billion in 1996 to an estimated $4.0 billion in 2004 (see Table 1.3). Though the industry is beginning to show signs of maturity and growth has slowed, soyfood sales are still outpacing the growth in the grocery market as a whole, with prepared convenience foods, snacks, and dairy and meat alternatives growing quickly. In the near future, the U.S. market can expect to see a wide assortment of new products, including snack foods, chips, cultured products, and a new generation of meat products that closely resemble muscle meat.

Soybean Nutritional Components

In comparison to many of today's major food sources, soybeans are truly a nutritional superpower. They contain the highest amount of protein of any grain or legume; substantial amounts of fat, carbohydrates, dietary fiber, vitamins, and minerals; and a veritable pharmacy of phytochemicals useful

for the prevention and treatment of many chronic diseases. Soybeans vary widely in nutrient content based on the specific variety and growing conditions, but typically they contain 35 to 40% protein, 15 to 20% fat, 30% carbohydrates, 10 to 13% moisture, and around 5% minerals and ash.

Soy Protein

The protein in the soybean contains all eight amino acids essential for human health, but until recently it was accepted that soy protein was lower in quality than many animal proteins. These earlier assumptions were based on an older method of evaluating protein quality, the protein efficiency ratio (PER), which is based on the growth rates of rats as measured in laboratory tests. However, rats require 50% more methionine (one of the amino acids found in soybeans) than humans do, making this particular method inappropriate for evaluating soy protein quality for human consumption. In order to make up for the shortcomings of the PER evaluations, the World Health Organization of the United Nations and the U.S. Food and Drug Administration have adopted a new method for evaluating protein quality called the *protein digestibility corrected amino acid score* (PDCAAS). This method uses an amino acid score, a comparison between the amino acid pattern of a protein and human amino acid requirements, and a factor for digestibility to arrive at a value for the quality of a protein. Using the new PDCAAS method, soy protein products generally receive scores of between 0.95 and 1.00, the highest value possible.

Soy Oil

Soybeans, in comparison to other beans, grains, and cereals, contain a high amount of fat, but, as we have come to learn, all fats are not created equal. Many of our major health problems today are due to the fact that people eat too much fat, and the fat being consumed is unhealthful and of poor quality. Fortunately, the fat found naturally in the soybean — and, by extension, in most traditionally processed soyfoods such as tofu, soymilk, tempeh, full-fat soy flour, and liquid soybean oil — can be categorized as a healthful fat. Approximately 50% of the fat in soybeans is linoleic acid, an essential polyunsaturated fat that can help lower cholesterol by bringing down blood lipid levels. In addition, soybean oil can contain as much as 8% alpha-linolenic acid, which is an omega-3 fatty acid (the healthful fat commonly derived from fish) and which is believed to be beneficial in lowering the risk of heart disease.

Carbohydrates and Fiber

Soybeans contain an interesting mix of both soluble and insoluble carbohydrates (including dietary fiber) that together constitute about 30% of the

soybean. The primary soluble carbohydrates in the soybean are sugars: stachyose, raffinose, and sucrose. Collectively, they make up about 10% of the soybean, although the amounts of these sugars vary according to the variety of soybean and its growing conditions. Raffinose and stachyose, the primary oligosaccharides (complex sugars) in soy, are significant because they are not digested or used as nutrients directly by the human body, but they are used as nutrients by the *Bifida* bacteria in the lower intestine. These types of intestinal flora are considered important for human health. It is believed that their presence can reduce the incidence of colon cancer and other intestinal disorders; however, when the bacteria break down these sugars, intestinal gas is created as a byproduct, creating discomfort and flatulence in some people. This can create a barrier to soybean consumption (especially in Western culture), but some Japanese companies are actually isolating and marketing these sugars as health supplements and food ingredients. The insoluble carbohydrates, or dietary fiber, come primarily from the outer hull and structural cell walls of the soybean and are composed of cellulose, hemicellulose, and pectin. This component contributes to the overall healthfulness of the soybean, because consumption of adequate amounts of dietary fiber has been shown to reduce the risk of heart disease and cancer, as well help to improve bowel function.

Vitamins and Minerals

In addition to providing high-quality protein, fat, and carbohydrates, soybeans are also rich in vitamins, minerals, and a number of other valuable phytochemicals. The major mineral components of soybeans are potassium, sodium, calcium, magnesium, sulfur, and phosphorus. Mineral content can vary widely due to both the type of soil and growing conditions for the soybean. Although soybeans are not considered to be very rich sources of any one particular vitamin, they do contribute to overall nutritional well-being. The water-soluble vitamins in soybeans are thiamine, riboflavin, niacin, pantothenic acid, biotin, folic acid, inositol, and choline. An integral part of lecithin, choline has been linked to the health of cellular walls and the nervous system. In 2001, the FDA formally recognized the healthful properties of choline by agreeing to allow food manufacturers to add a choline health claim to product labels. Fat-soluble vitamins present in the soybean are vitamins A and E. Vitamin A exists as provitamin beta-carotene and is present in higher levels in the immature, green vegetable soybean than in the mature (dry) soybean. Tocopherols, the most widely available, naturally occurring vitamin E compound, fill two major roles as a component of soy oil. First, vitamin E is an important element of human nutrition, although its bioactive properties have been scrutinized in recent years, and many of the health claims about vitamin E remain unproven. Second, tocopherols are antioxidants, which means that they are chemicals that prevent a substance from reacting with oxygen. Their presence in soybean oil slows down the degradation of the oil.

Isoflavones

It should come as no surprise that plants contain powerful chemicals that can have a profound effect on an individual's health or well-being. Many of the drugs used in Western medicine today originate from plant sources. Traditional medicines, such as those used by some Asian cultures, herbalists, and homeopaths, are centered on plant remedies. The term *phytochemical* is used to describe a class of plant-based chemical compounds that have an effect on the human or animal organism. The soybean is a virtual pharmacy of beneficial phytochemicals for human health and disease regulation; however, over the past few years, one particular set of compounds has gained the most attention and become the focus of hundreds of studies and numerous world conferences — isoflavones. For all practical purposes, no other food contains as significant an amount of these chemicals as does the soybean. Generally speaking, minimally processed soyfoods, including full-fat soy flour, tofu, and soymilk, have the highest levels of isoflavones. Isoflavones are also considered phytoestrogens, or plant estrogens, because they have a similar chemical make-up and effect on the human body as estrogen; however, the estrogenic effects of soy isoflavones are much (perhaps as much as 10,000 times) weaker than the human estrogen hormone. The major isoflavones in soybeans are genistein, daidzein, and glycitein. Genistein has shown some promise in preventing and treating prostate and breast cancers. Although glycitein comprises only 5 to 10% of soy isoflavones, recent studies suggest that it may have far higher estrogenicity and bioavailability than either genistein or daidzein.

Soyfoods and Protein Ingredients

As indicated earlier, approximately 10% of the world's soybean crop is used directly for human food, and a stunning array of products is made from the humble bean. Many of the following soy-based foods utilize the whole soybean, while some are made with a variety of soy protein ingredients, including isolated soy protein, soy protein concentrate, and soy flour.

Whole Dry Soybeans

Whole dry soybeans are, of course, the original soyfood. Dried in the pod while still in the field, whole soybeans contain approximately 37% protein, 17% fat, 10% dietary fiber, 20% carbohydrates, 5% ash (total minerals), and 11% moisture. Composition varies among the many different varieties of soybeans. Some seeds are larger in size and higher in protein than others, while some varieties have a brown, buff, or clear-colored hilum (the spot on the soybean where it connects to the pod). Dried, yellow soybeans are the

most commonly available type. Soyfood processors carefully select the proper varieties of soybean for the type of products they are making. For example, soymilk and tofu manufacturers prefer large, high-protein soybeans with clear hilums so their finished product yields are high, exhibit a mild flavor profile, and are light in color. Most identity-preserved food-grade varieties are sold at a premium to food processors. Dried soybeans will last over a year but must be kept cool and dry, as they begin to degrade when stored at too high a temperature or in moist conditions.

Tofu

Tofu is perhaps the most widely consumed soyfood in the world today. It is a regular part of the diet in many Asian nations. Tofu is widely available across the United States and in most other Western nations. This soft, white, almost cheese-like product is favored for its versatility, mild flavor, and high nutritional value. It is naturally processed and, as a result, retains a good deal of the important nutrients and phytochemicals of the soybean, such as the isoflavones. Tofu is especially valuable due to its chameleon-like quality of being able to take on the flavor of whatever spices and ingredients are used with its preparation. For example, in the same sitting, one could dine on a fresh green salad served with a creamy tofu dill dressing, eat a healthy serving of marinated barbecued tofu, and finish with a tofu chocolate cream pie.

When tofu is made, soaked whole soybeans are ground to produce a slurry, which is added to water and boiled. After cooking, the pulp is removed from the mixture, leaving soymilk. While the soymilk is still hot, a natural mineral coagulant — such as calcium sulfate or magnesium chloride, or a mixture of both — is slowly added to the hot liquid. Within minutes, the soymilk begins to curdle and large white clouds of tofu curd begin to form in a sea of yellow whey. After 15 minutes or so, the curds are removed from the whey and placed under pressure in cloth-lined forming boxes. The curds are then pressed to form soft, regular, firm, or extra-firm tofu. The size of the curd and length of pressing time determine the style of tofu produced. The softer the tofu, the lower the protein and fat levels and the higher the water content. Soft tofu is also usually smoother in texture than firm tofu. Firm tofu, on the other hand, is higher in protein and fat and lower in moisture and has a denser, chewier texture.

Silken tofu — the soft, smooth variety commonly sold in an aseptic package — is made in a slightly different manner. To make silken tofu, either calcium sulfate or glucono-delta-lactone is added to a thicker, richer soymilk, and the mixture is put into a package. This package, with the soymilk and coagulant mixture, is heated to the proper temperature to activate the coagulation, and the soymilk is transformed into one solid, smooth curd, right in the package.

Typically, tofu contains between 10 and 15% protein and 5 to 9% fat. It is relatively low in carbohydrates and in fiber (because the pulp was removed),

making it easy to digest. Tofu made with calcium sulfate or calcium chloride contains higher levels of calcium than those made with other coagulants and is therefore sometimes sought after by those seeking to supplement their current calcium intake. One 4-oz. serving of calcium-coagulated tofu can contain as much bioavailable calcium as one 8-oz. serving of cow's milk.

Tofu is commonly found packed in sealed, water-filled tubs, but it is also available in vacuum or aseptic packaging. Unless it is aseptically packaged, tofu requires refrigeration at or under 40°F. Tofu can also be frozen for longer storage, although it will tend to have a much different texture when thawed, becoming crumbly and more chewy. Regular, pressed tofu is best when fried, baked, grilled, or barbecued; used as a meat alternative; or added to stir fry dishes. In most cases, the best way to prepare tofu for use is to first drain the tofu on paper or cloth towels to reduce the water content. This improves the ability of the tofu to absorb flavors, reduces the amount of water that has to be removed in the cooking stage, and firms up the tofu, making it easier to handle.

Silken tofu is best used in soups or blended into vegetable spread, sauces, cream substitutes, pie fillings, puddings, or desserts. Some firm varieties of silken tofu are available, as well, and these can be used as pressed tofu in many recipes. The Japanese favor silken tofu and usually eat it prepared very simply. For example, it may be served fresh, with just a little soy sauce and scallions, or in miso soup. Silken tofu, because it is soft and lacks the cohesiveness of pressed tofu, is more difficult to handle. Many new tofu products on the market today have been flavored and then baked, fried, or smoked prior to sale. These new tofu products are "recipe ready" and easier to use for many consumers, especially those with a limited amount of time to cook or those who are unfamiliar with tofu.

Soymilk

Traditionally, soymilk is the liquid extract of the soybean, which can be used in the preparation of tofu or as a nutritious beverage, but the beverage-quality soymilks available today are usually prepared in a slightly different fashion, utilizing a number of more modern food processing techniques in order to produce a blander product with greater appeal to Western tastes. As with tofu, soymilk generally contains most of the active phytochemicals present in soybeans, including high amounts of isoflavones. Some soymilks are made with isolated soy protein as a base. Many are fortified with vitamins and minerals (such as vitamins A and D and calcium) to bolster their position as a viable alternative to cow's milk. Soymilk can be used as a direct, one-to-one replacement for cow's milk in most food formulations and recipes. Soymilk works very well in baking recipes and is an excellent cream soup or sauce base. It can be put on cereal or made into yogurt, pudding, or ice cream. A variety of powdered soymilk products can be mixed with water at low ratios if one needs a very thick, cream-like soymilk base.

Tempeh

Tempeh is a traditional, fermented soyfood that is unique in its texture, flavor, and versatility. Originally from Indonesia, tempeh has a flavor that is distinctively different from other soyfoods, sometimes described as "nutty" or "mushroom like." It is made from the whole soybean, which has been dehulled, cracked, and cooked in water with added vinegar to reduce the pH. Once cooked, the soybean is mixed with the spores of the *Rhizopus oligosporus* fungus and left to incubate for 24 hours at 88°F. At the end of this period, the tempeh is a compact, cake-like product that is completely covered with, and penetrated by, white mold mycelia. Tempeh may also be made with other grains or seeds mixed in during processing to vary the taste and texture of the final product. Tempeh contains about 19% protein, is higher in fiber than tofu, and is a significant source of vitamins and minerals. Tempeh is available fresh or frozen and is sold in plain and flavored varieties. It can be found in natural food stores and in the produce section of many supermarkets. Tempeh should be used within a few weeks of purchase but can be frozen for longer storage. It can be marinated prior to use, works very well in stir-fry dishes, and can be baked, grilled, or deep fat fried. Tempeh can also be grated and formed into patties or balls.

Soymilk Yogurt

Soymilk yogurt is made in the same manner as cow's milk yogurt. Pasteurized soymilk is inoculated with *Acidophilus*, *Bifida*, or other suitable cultures and incubated until the culture has turned the soymilk into yogurt. It tastes very similar to cow's milk yogurt, is available in a variety of styles and flavors, and is generally sold in 6- to 8-oz. and quart containers. It is very high in protein and a great source of isoflavones. These products may not be labeled as "yogurt" in the United States, as they are not made with cow's milk, but manufacturers package them in familiar yogurt containers and refer to them as "cultured soy" or "cultured soymilk."

Miso

Miso is a rich and flavorful paste made from either fermented and aged whole soybeans or soybeans in combination with wheat, barley, or rice. This salty paste is a treasured soup base and flavoring ingredient used throughout Japan, Korea, Taiwan, Indonesia, and China. Many types of miso are available in the world today, from sweet white miso, which is quite mild, to dark savory miso, which is much more robust and salty. Miso has some unique medicinal properties and is believed to help reduce the effects of radiation and other environmental poisons on the body. It contains enzymes and bacteria that can aid in digestion. It is high in protein, but it also contains high levels of sodium and should be consumed sparingly. To produce miso, whole cooked

soybeans are mixed together with koji nuggets — grain such as wheat, rice, or barley that has been cultured with a fungal starter (*Aspergillus oryzae*) — and fermented under very specific conditions for the type of miso being made. When the mash is fully ripened, it is blended and packaged for sale. Usually the longer the miso has aged, the more complex the flavor. Most of the miso sold today is pasteurized and refrigerated. Miso is sold in natural food stores and in many supermarkets along with other Asian foods. It has a long shelf life when refrigerated. Due to its distinctive fermented flavor, it can be added to recipes or blended with tofu to add a cheese-like note.

Soy Sauce

Soy sauce is the most well known and popular of the traditional soyfoods and is used extensively as a flavoring ingredient in most Asian cooking. When naturally processed, soy sauce is produced in a manner similar to that of miso. When made exclusively with soybeans, the product is called *tamari*. If it is processed with a fermented wheat starter, the product is called *shoyu*. Much of the soy sauce sold today is not naturally fermented. Instead, it is made with hydrolyzed vegetable protein (HVP), sugar, color, and preservatives. HVP is produced from soy protein using chemically induced fermentation. All soy sauces are high in sodium and should be used sparingly. Some reduced-sodium varieties are available on the market today, as well as a number of flavored soy sauce products. From a nutritional prospective, tamari contains the highest protein level of the soy sauces, followed by shoyu and then HVP-based soy sauce; however, the high amount of sodium in all of these products should preclude anyone from using soy sauce as a nutritional food. Naturally processed soy sauce is available in natural food stores; both the naturally fermented and HVP forms are sold in most supermarkets. Due to its high salt content, soy sauce has a long shelf life without refrigeration but will keep longer when stored at cooler temperatures.

Okara

Okara is the fibrous remains of the soybean after it has been processed to make soymilk. It is very high in moisture and contains the insoluble carbohydrates and dietary fiber of the soybean, as well some remaining protein and fat. When fully cooked, it has a bland flavor and makes an excellent addition to breads and other baked goods. It can also be used to make meat alternatives or processed into tempeh. It is not usually sold in stores, as it is very wet, heavy, and highly perishable.

Natto

Natto is a whole soybean product, popular in Japan, that is produced by fermenting small, cooked soybeans with *Bacillus natto* until they develop a

sticky, viscous coating. Natto is made from a number of specific varieties of soybeans and has a distinct taste and aroma that are an acquired taste for most. It is available only in Japanese food stores and is mostly imported, as very little is produced in the United States. It can be found frozen or fresh and will last about a week when refrigerated.

Soynuts

Soynuts are roasted soybeans that have been prepared by the dry or oil roasting of whole or split soybeans that have first been soaked in water. They can be sold with a coating of salt or other flavoring ingredients. Soynut pieces can be blended with other nuts and used in baking applications and other food preparations. Soynuts are high in protein, fiber, and the isoflavones found naturally in whole soybeans. Soynut butter is a paste of ground soynuts that is prepared in a manner similar to that of peanut butter and may have salt, sweeteners, and additional oil added. Soynuts and soynut butter can be found in many natural food stores and in some supermarkets.

Meat Alternatives

This is a broad product category, as literally hundreds of products are made from tofu, tempeh, textured soy flour, textured soy concentrate, isolated soy protein, and wheat gluten. Products take the shape of burgers, hot dogs, sausages, luncheon meats, chicken, fish, and ground meat. Most products are made with a combination of vegetable protein ingredients to achieve the best texture and are flavored for a particular use. Most are low in fat, and many are completely fat free. Meat alternatives are sold fresh and frozen and can be purchased in natural food stores, supermarkets, and, increasingly, in restaurants. Recent innovations include improved flavor and texture, as well as a new generation of extruded products that resemble muscle meat.

Cheese Alternatives

A wide range of cheese alternatives is made from soymilk, tofu, and other vegetable protein ingredients. These products can be found flavored to taste like American, mozzarella, cheddar, Monterey Jack, parmesan, and other cheeses. Most of these processed cheese products are made with a combination of soy and casein protein (from cow's milk). Casein is used because it is the protein responsible for the melting action common in cheese when it is heated. Without added casein, soy cheese alternatives would soften when heated but not melt or stretch. It also adds a flavor note that is associated with cheese. Some soy-based cheese alternatives have either had the fat replaced with vegetable oil or completely removed. These products are usually lactose and cholesterol free, as well. Soy cheese alternatives are also used as an ingredient in prepared frozen pizzas, stuffed in pasta, and added to frozen entrees.

Nondairy Frozen Desserts

This product category was one of the first to prove to Americans that products made from tofu and soybeans could taste good. Popularized by products such as Tofutti® brand (Tofutti Brands, Inc., Cranford, NJ) frozen desserts in the mid-1980s, this category has seen a recent reemergence due to the increased popularity of soymilk and premium dessert products. Nondairy frozen desserts are essentially ice cream products that are made using soymilk, tofu, or soy protein in place of dairy milk or cream. Both hard-pack and soft-serve styles exist, as well as novelty ice cream pops and sandwiches.

Green Vegetable Soybeans (Edamame)

This simple and nutritious soyfood is really just the whole soybean picked at its peak of maturity, at a time when it is high in sucrose and chlorophyll. It is harvested in the pod and is sold either in the pod or shucked, after being blanched and frozen. Because they are picked when their sugar levels are high, green vegetable soybeans are very sweet and pleasant tasting, and they have a firm texture. The common and traditional Japanese names for the green vegetable soybean are *edamame* when it is sold in the pod and *mukimame* when it is sold as individual beans. Green vegetable soybeans contain about 13% protein (the same amount as tofu) and are naturally high in calcium. They work very well in stir-fry dishes and can also be blended into dips and other preparations. They are becoming increasingly easy to find in the United States, as some American food processors are now packaging them for the domestic market.

Soy Sprouts

Soy sprouts are the fresh, crisp sprouts of germinated soybeans. They are a traditional food of Korea and may be eaten raw or in prepared food dishes. They are usually harvested after having grown for 5 to 7 days. They contain vitamin C and are high in protein and fiber. Soy sprouts are slightly larger than ordinary bean sprouts, which are prepared from mung bean seeds. Soy sprouts are available in some specialty food stores.

Full-Fat Soy Flour

Full-fat soy flour is made from whole or dehulled soybeans, which are ground into fine flour. Because it is made from the whole soybean, the composition of full-fat flour is identical to that of the natural soybean, with a protein content between 35 and 40% and a fat level between 15 and 20%. It is extremely nutritious and high in fiber and contains all of the vitamins, minerals, and phytochemicals of soybeans. Full-fat soy flour is available either as raw, enzyme-active flour or as toasted flour. The raw form is great for baking, as the active enzyme, lipoxygenase, helps to bleach wheat flour and produce a whiter bread loaf with improved moisture retention and shelf