Practical Handbook of Soybean Processing and Utilization

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Chapter 22

Soy Foods

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Introduction

From 2800 B.C. to the present, soybeans have been cultivated in China (1). Ancient texts give detailed information on varieties, cultivation practices, and harvest and preservation procedures. The utilization of soybeans, alone or in combination with other cereals, is well documented. The origin of soybeans is believed to be within the boundaries of modern China. However, some authorities believe that the point of origin is elsewhere within East or Southeast Asia.

Due to their ease of production, long-term storage characteristics and exceptional protein content, soybeans have been highly prized as a nutritional food source. Consequently, soybeans were introduced into Korea and Japan, gaining widespread acceptance throughout those cultures. Soybeans are traditionally consumed in nonfermented and fermented forms (Tables 22.1, 22.2). The nonfermented forms include soymilk, yuba, tofu, and toasted soy protein powders. The fermented forms include miso, natto, soy sauce (shoyu), and tempeh. While the names of these soy foods vary

TABLE 22.1 Nonfermented Soy Food Products and Common Names by Country (2,3)

Product	Nation of origin			
	Japan	China	Korea	Other
Fresh soybeans	Edaname	Mao-dou	Put kong	
Soybean sprouts	Daizu no moyashi	Huang-dou-ya	Kong na moal	
Soy milk	Tonyu	Dou-jiang	Kong kook	
Soy milk film	Yuba	Dou-fu-pi	Doo Yoo	Fu chok (Indonesia) Fu chok (Malaysia)
Soybean curd (fresh)	Tofu	Dou-fu	Doo bu	Tahu (Indonesia) Tau-foo (Malaysia) Tokua (Philippines)
Frozen-dried	Kori tofu	Dong-dou-fu		
Deep fried	Aburage Nama-age Atsu-age Gan-modoki Use-age Kara-age			
Toasted soy flour	Kinako	Dou-fen	Kang ka rau	Bubuk kadele (Indonesia)

from country to country within Asia, this chapter always uses the Japanese terms.

These foods play important roles in the diet and culture of the people in Asia. Despite significant changes in the variety of foods consumed over the years, it is estimated that nearly 10% of the Japanese population's protein intake is from these basic soy foods (2). A heavy dietary reliance on rice, which is low in protein, the essential amino acid lysine, and lipid, has led to universal use of soybean and fish products as alternative protein sources throughout Asia (5). Supplemental soybean use, in particular, has made a significant improvement in the nutritional well-being of the population. The relative protein contents of various soy foods are listed in Table 22.3.

Soybeans are relatively high in lysine but low in methionine. Together, these protein sources—corn and soybeans—compose what is known as nutritionally complete "complementary protein." The amino acid balance for soy protein is comparable to animal sources based upon human requirements.

Changes in food consumption and nutritional intake by Japanese and other Asian consumers are evidence of a general "Westernization" of their dietary patterns. The correlation of this trend with increased heart disease and related disorders, hitherto inconspicuous in Japan, has been widely reported. The Japanese government has recently taken action to develop a guideline for citizens to be more aware of dietary health issues (5).

The per capita production and consumption of soybeans in several Asian countries have tended to remain constant or increase (Table 22.4) (3). In recent years, increases in utilization in Indonesia, Malaysia, Philippines, Thailand, Japan, and Korea have resulted from increased consumption of some soy foods (soymilk and tofu). Historically, production of Japanese soybeans decreased until ten years ago; then production gradually increased to 200,000 metric tons (MT) per year, because of Japanese governmental policy designed to encourage farmers to grow soybeans as an alterna-

TABLE 22.2 Fermented Soy Food Products and Common Name by Country (2,3)

Product	Nation of origin			
	Japan	China	Korea	Other
Whole soybeans	Natto			Tempeh (Indonesia and Malaysia)
	Hamanatto			
Soy paste	Miso	Jiang	Doen jan	Tauco (Indonesia and Malaysis)
				Tao si (Philippines)
Soy sauce	Shoyu	Jiang-you	Kang jang	Kecap (Indonesia and Malaysia)
				Tayo (Philippines)
Soy curd		Sou-fu		
Soy pulp				Tempeh gembus
				Oncom ampas tahu (Indonesia)

tive to rice cultivation. This policy resulted from increasing annual rice surpluses.

Present Japanese soybean production constitutes 20% of total national demand for soyfoods. Soybeans from the United States and China are imported into Japan at well over 4,000,000 MT per year, with 80% of the raw tonnage (mainly U.S. soybeans) being processed for oil extraction. Of this, 80% of the soybean meal is used as feed, the remaining 20% being used for human foods (nonfermented and fermented soy foods), amino acid mixtures, and new protein foods such as textured soybean protein. This compares with about 2% in the United States.

Soybean Chemical Composition

Soybeans are a rich source of protein (30 to 40%) and oil (20%) (Table 22.3). They contain 9 to 12% total sugars, of which 4 to 5% is sucrose, 1 to 2% is raffinose, and

TABLE 22.3 Chemical Compositions of Soy Foods (2,3,4,6,7,8,9)

	Moisture	Protein[a]	Fat	Carbohydrate Soluble	Fiber	Ash
	(percent)					
Nonfermented						
Soybean[b]	12.5	35.3	19.0	23.7	4.5	5.0
Soymilk	94.0	3.0	1.0	1.0	0	0.3
Tofu						
Momen	86.8	6.8	5.0	0.8	0	0.6
Kinugoshi	89.4	5.0	3.3	—	—	0.6
Packed	90.0	4.5	3.2	—	—	0.6
Aburage	44.0	18.6	33.1	2.8	0.1	1.4
Kori	10.4	53.4	26.4	7.0	0.2	2.6
Yuba	8.1	50.2	33.4	5.3	0.2	2.8
Soybean sprouts	88.3	5.4	2.2	2.6	0.8	0.7
Kinako	5.0	35.5	23.4	26.4	4.6	5.1
Fermented						
Tempeh	64	18	4	1	—	1.0
Natto	59	17	10	12	2.0	3.0
Miso[c]	45.7	13.1	5.5	19.1	2.0	14.6
Hamanatto	36	26	12	14	3.0	12.0
Soy sauce[d]	72	7	0.5	2	0	18.0
Soy paste	50	14	5	16	2.0	5.0
Ko chu jang	48	9	4	19	4.0	20
Fermented soy curd	60	17	14	0.1	—	9.0
Fermented soy pulp						
Tempeh gembus	81	5	2	11	—	1.0
Oncom ampas tahu	84	4	2	8	—	2.0

Note: Given as % approximate chemical composition as is basis.
[a]Protein = N x 5.71
[b]Obtained in Japan
[c]Dark yellow
[d]Regular; nonspecialty

3.5 to 4.5% is stachyose (see Chapter 2). While all of the sugars are fermentable by microorganisms, raffinose and stachyose (oligosaccharides) are not digestible by humans and other monogastric animals (e.g., pigs and poultry). These sugars produce intestinal gas and discomfort in humans and a loss of feed efficiency in livestock operations. The removal of the oligosaccharides with an increase in sucrose (or other simple sugars) would not only eliminate the oligosaccharide problem, but improve soybeans as an industrial fermentation feedstock. Typically, Chinese and some Japanese soybeans are higher than U.S. soybeans in carbohydrate content, which may make them more desirable for fermented soy food products than U.S. soybeans (15,16). However, care must be taken when interpreting "sugar" levels of Japanese soybeans in the literature and Japanese government reports, because the sugar referred to is a figure obtained by acid hydrolysis, not the free sugar present in the soybean or its total carbohydrate content (3).

Soybeans also contain less than 1% starch, 5% ash, and 4.5% crude fiber (2,14) (Table 22.3). Over half of the crude fiber in soybeans contributes to the physiologically important dietary fiber that is necessary for proper human nutrition. In recent years, the importance of dietary fiber in the diet has received considerable attention in the United States. While the role of fiber in reducing the incidence of colon cancer and heart disease is not well understood, the potential health benefits of increasing fiber in the diet should not be overlooked. Soybean hulls contain about 87% crude fiber, consisting of cellulose, hemicellulose, lignin, and uronic acids.

Linoleic acid comprises 50% of the available fatty acid and is believed to be conducive to decreasing the content of blood cholesterol (see Chapter 23). New varieties containing different amounts of saturated and unsaturated fatty acids have been developed, as noted in Chapter 2. Soybeans also contain vitamins B_1, B_2, B_6, and E (17,18). Additionally, trypsin inhibitors, goitrogenic substances, isoflavones, saponins, and hemagglutinins are present in small or trace amounts.

Certain phytochemicals in fruits, vegetables, and grains may possess cancer-preventive properties that inhibit tumor initiation, prevent oxidative damage, and affect steroid hormones or prostaglandin metabolism to block tumor promotion. Isoflavones are one class of these compounds that are found in soybeans in high amounts. The major soybean isoflavones, genistein and daidzein, have been identified for a considerable period of time. Because these compounds appear to act as anticarcinogens by exerting a biological antioxidant effect, their contents and

TABLE 22.4 Per Capita Annual Consumption of Soybeans (kg) in Selected Asian Countries (3,10,11,12,13)

Country	1968	1978	1988	1994
China	6.7	5.9	4.8	4.4
Indonesia	3.4	5.9	7.8	10.5
Japan	6.3	6.8	7.1	7.4
Korea	7.9	9.5	9.0	9.1[a]
Malaysia	1.8	1.9	3.5	4.7
Philippines	0.0	0.2	0.3	0.4
Thailand	0.4	1.0	2.0	1.8

[a]Additional 5.1 kg in North Korea.

bioavailabilities in foods have been a topic of recent interest. Isoflavone (potential cancer-preventive properties) profiles of traditional soybeans and soy foods showed that soy foods contained 6 to 20% of the isoflavone of soybeans (Wang, H.-J. and P.A. Murphy. *J. Agric. Food Chem.*, in press).

In spite of the fact that soybeans are excellent nutritional staples, they are not consumed raw, because of their hard texture and undesirable flavor. Undaunted by these attributes, the people of Japan and other Asian countries have developed a variety of sophisticated processed soy foods. These products and their culinary presentation have done a great deal to enhance the table aesthetics, palatability, and nutritive value of soy protein.

Traditional soybean foods are classified into two groups: non-fermented foods, including regular, deep-fried, frozen-dried, roasted tofu, soybean protein film (yuba), and soybean sprouts; and fermented soybean foods, such as miso, soy sauce (shoyu), and fermented whole soybeans (natto).

Unfermented Soy Foods

Soymilk

Soymilk is a very popular beverage with the Chinese, though considerably less so for the Japanese consumer. However, soymilk production is very important to Japanese tofu producers, because it is the intermediate product in the manufacture of tofu. Since 1978, Japanese soymilk consumption has increased. To some extent, this is the result of effective marketing campaigns that have advertised soymilk as having physiological benefits, particularly as a healthful pick-me-up "energy drink" for stressed workers and business persons (5).

Many Japanese, like their Western counterparts, find the flavor and odor of soymilk undesirable. This flavor and odor are formed by the oxidation of specific unsaturated fatty acids by lipoxygenase enzymes during the grinding of the seed. Understanding how off-flavors and undesirable flavors interact with soy proteins and similar seed constituents may lead to improved processing systems. Breeding programs at Purdue University (West Lafayette, IN), Iowa State University (Ames, IA), and the Japanese Ministry of Agriculture, Forestry, and Fisheries (Tsukuba, Japan) have developed lipoxygenase-null varieties. Davies (19) reported that the flavor of soymilk was improved by using lipoxygenase-2-null soybeans. Additionally, odor formation may be circumvented by heat inactivation of the enzyme before the beans are ground (although this significantly lowers yields) or by masking the flavor with additives (20).

Soymilk is traditionally made by soaking soybeans in water (1:10) overnight, then grinding the beans in a mill with additional water being added during the grinding step (Fig. 22.1). The resulting slurry is boiled and stirred for 15 to 30 min. This heating step improves the nutritional value of the milk, by inactivating trypsin inhibitors, and improves the flavor, by inactivating lipoxygenase and volatilizing some of the off-flavor compounds that appear during grinding. Heating also increases the shelf life of the milk by reducing its microbial load (critical control point).

The heated slurry is then filtered through a cloth or nylon bag to separate the undispersible fiber residue, *okara*, from the soymilk.

A more recent innovation utilizes MicroSoy® flakes instead of whole soybeans (Nichii Company of America, Jefferson, IA). Soy flakes are dispensed into a paddle mixer (3.5 kg MicroSoy flakes to 40 L of potable water for a 5% solids soymilk), rehydrated and blended at room temperature for 10 min. The resulting slurry can be steam-injected into a cooker and cooked by direct culinary steam or indirect steam injection with continuous agitation. The temperature of the slurry is held for 7 min at 95°C (203°F) and subcooked for 40 s before extraction in a "Takai Automated Soymilk Plant" machine (Takai Tofu and Soymilk Equipment Co., Ishikawa-ken 921, Japan). The cooked slurry is sieved through a 120-mesh roller screen to extract the milk. The insoluble materials are expelled onto a 100-mesh roller drum and roller press to further extract milk before expelling the solid okara. The soymilk at 90°C (194°F) is collected in a coagulation tub, where it is allowed to cool to 85°C (185°F) prior to tofu manufacture or bottling and refrigeration. The resulting soymilk from either whole soybeans or flakes may have flavors added to mask the beany flavor. It may also be homogenized, pasteurized, and sterilized before being bottled, aseptically packaged, or retorted.

Typically, high-protein, clear- or yellow-hilum (see Chapter 2), large-seed soybeans are preferred for soymilk production. Two hundred grams of soybean will yield about 1 L of soymilk (2). The chemical composition of soymilk is given in Table 22.3. Soymilk can be made more shelf-stable by spray-drying or roller-drying it into a dry powder (as is done with cow's milk in the United States). Spray-dried soymilk is often used in confections, meat fillers, and beverages.

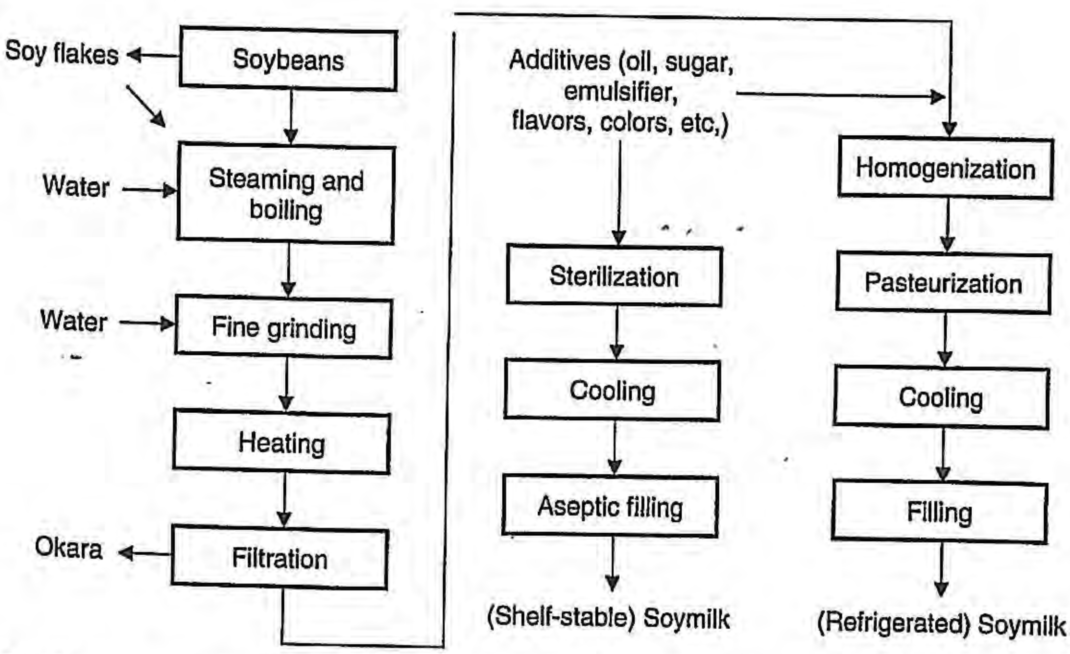

Fig. 22.1. Steps in refrigerated and shelf-stable soymilk production. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes,* MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

Fig. 22.2. JAS Seal of Approval. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes,* MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

Soymilk is certified by labeling, which includes the Japanese Agricultural Specifications (JAS) Seal of Approval (5) (Fig. 22.2).

Japanese Agricultural Specifications classify soymilk into four groups: regular soymilk, reconstituted soymilk, soft drinks, and soy protein beverages. Although soymilk has a similar composition to cow's milk, the oil-to-protein ratio is lower. For this reason, reconstituted soymilk is supplemented with oil. In addition, soymilk may be supplemented with sugar to enhance its palatability in soft drinks. These soymilk beverages often contain fruit juice, cocoa, sugar, flavors (artificial or natural), stabilizers, and other ingredients to enhance customer acceptance by masking soy flavors.

Tofu (bean curd) has been produced in Japan for over 2,000 years. It was introduced from China along with the agronomic introduction of soybeans (1). Then as now, the production of tofu was largely a small-scale enterprise consuming less than 60 kg of soybeans per day. The shelf life of tofu can be quite variable ranging from 1 to 5 d for fresh tofu; 1 to 3 wk for pasteurized tofu; and six months to two years for tofu processed aseptically. The initial microbial load and storage temperature largely govern the shelf life (22,23,24). Some products (e.g., silken tofu) are more difficult to transport due to temperature abuse and physical damage.

Large-scale factories consume 2 to 3 MT of soybeans per day (Fig. 22.3). These large manufacturers have developed integrated production and marketing systems. From the factory to the supermarket showcase, superior product quality is ensured by sophisticated, timely distribution using refrigerated transport and display systems. Likewise, some supermarket chains are now producing their own tofu "in-house" where it is kept in refrigerated display cases. Aseptically packaged tofu is gaining in popularity. This product has greater utility with respect to preservation, storage and transportation. Consequently, its production scale is much larger, exceeding 6 MT of soybeans per day. However, much of this tofu is for the Japanese export market due to legislation protecting the small tofu producers (3).

The official Japanese sanitary guidelines for soy milk and tofus, first published in 1959, remain relatively unchanged (1):

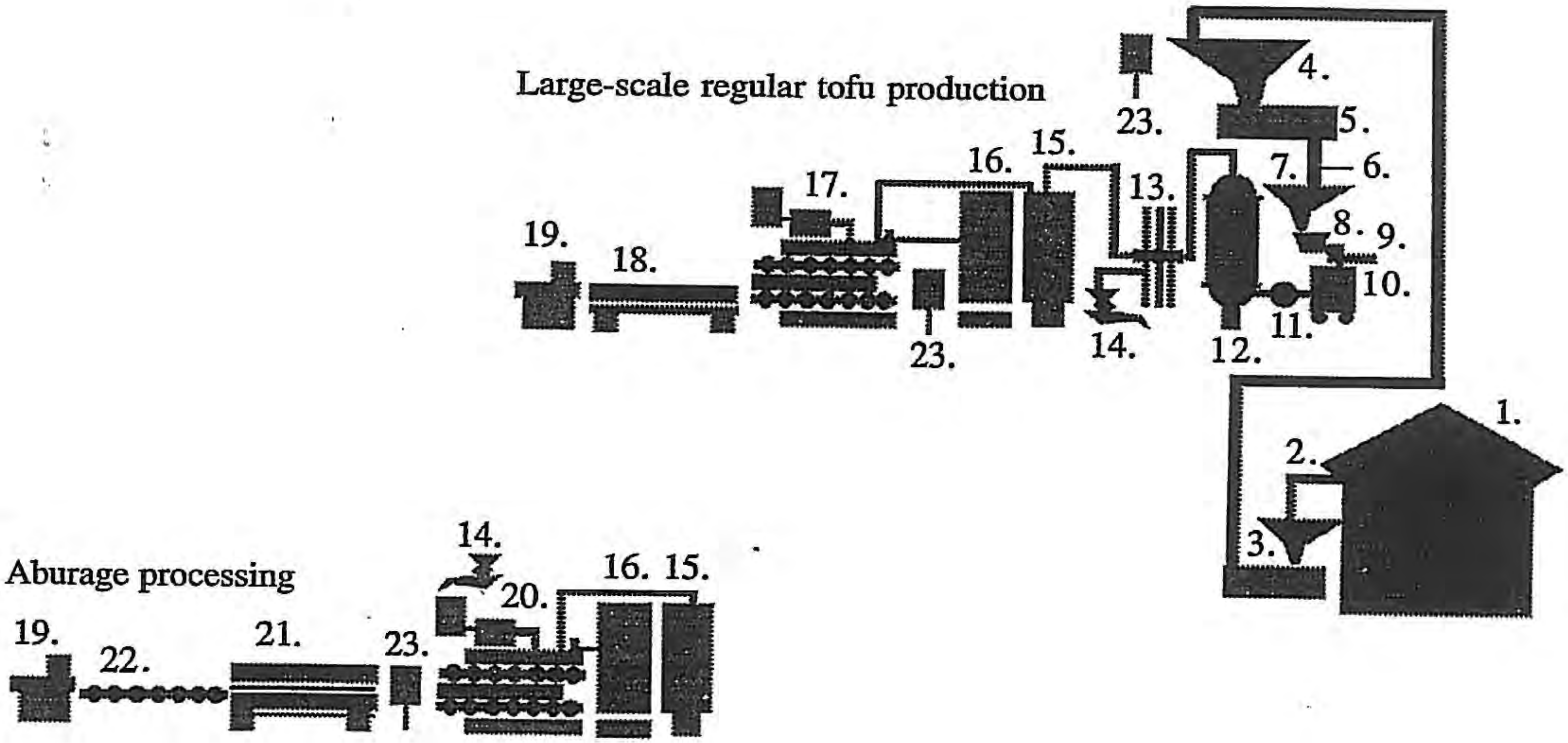

Fig. 22.3. Large-scale manufacturing operation for tofu production: (1) soybean pit (storage) with air conveyor, (2) cyclone, (3) storage and weight measure, (4) divider and storage, (5) soybean tank, (6) washer and conveyor, (7) hopper, (8) grinder, (9) antifoam measure dispenser, (10) slurry tank, (11) pump, (12) cooker, (13) filter, (14) rotary feeder (residue discharge), (15) soymilk storage, (16) coagulant storage, (17) coagulation vessel, tofu molder, and press, (18) tofu cutter and tofu cooler, (19) tofu packer, (20) coagulation vessel, tofu molder, press, and cutter, (21) deep fryer, (22) conveyor for packed products, and (23) control station. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes*, MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

Standards of manufacturing of bean curd: .

1. Soybean as ingredient shall be of good quality and shall not contain foreign substances.
2. Soybean as ingredient shall be sufficiently washed in water.
3. Soybean juice and soybean milk shall be sterilized by the method of heating at the boiling state for 2 minutes or by a method having the same or superior effect.
4. Soaking of the bean curd shall be performed while continually changing the water.
5. Wrapped bean curd (meaning bean curd prepared by adding a coagulating agent to soybean milk, filling the milk in a package, then heating to coagulate) shall be sterilized by the method of heating at 90°C (194°F) for 40 minutes or by a method having the same or superior effect.
6. Tools used for manufacturing bean curd shall be sufficiently washed and sterilized.
7. Water used for manufacturing bean curd shall be potable water.

Standards of storage of bean curd:

1. Bean curd shall be stored refrigerated or in a sufficiently washed and sterilized water tank with continually changed potable cold water. However, this does not apply to bean curd for itinerant sale and bean curd ordinarily intended for immediate sale after molding and without soaking.
2. Bean curd for itinerant sale shall be sufficiently washed and kept cool using sterilized tools."

Tofu

Momen (Cotton) Tofu. The traditional production process for momen tofu, the most popular kind of tofu in Japan, is shown in Fig. 22.4. After soybeans are soaked in water for 8 to 12 hr (25), they are ground with water into a slurry using a stonemill or stainless steel centrifugal grinder. Alternately, MicroSoy Flakes (Nichii Company of America, Jefferson, IA) could be used, as noted in the soymilk section of this chapter.

Water and an antifoaming agent are added to the slurry before it is heated. After heating for 5 to 10 min to reduce the beany flavor and antinutritional factors, the slurry is filtered to remove any insoluble soybean solids. This filtration is accomplished by hand, air, hydraulic, or mechanical pressing. The residue (okara) remains in a cotton or nylon cloth filter bag. Traditionally, the okara is often used as animal feed or landfill (buried). Currently, however, some okara is being processed for use in new (proprietary) dietary and medicinal products.

Control of the percent solids and temperature of the soymilk, amount of coagulant, and the stirring of the coagulating soymilk are critical quality control points, because they influence the texture and yield of the tofu. Firm tofu can be produced by using a lower-solids soymilk (5 to 8%), higher coagulation temperature (90 to 95°C, 194 to 203°F), and vigorous mixing during the coagulation step. A softer, larger-yielding tofu can be produced with a high-solids soymilk (10 to 13%), coagulated at a lower temperature (70 to 80°C, 158 to 176°F), with a minimum of stirring (only enough to thoroughly disperse the coagulant in the soymilk). The amount and type of coagulant are also critical. Lack of sufficient coagulant will fail to coagulate the soymilk, but too much coagulant can produce low yields of small, hard curds with uneven texture and bitter (magnesium chloride) or chalky (calcium sulfate) taste (26). It is recommended that the solids content of the hot soymilk be measured and standardized before adding the coagulant (27). The correct amount of coagulant can be determined by plotting the amount of coagulant added to a known solids "hot" soymilk against the transparency of the resulting whey after curd formation (Figs. 22.5 and 22.6). The correct amount of coagulant is determined by the point where the whey transparency plot (line) becomes parallel with the x-axis. A similar plot can be made using yield of tofu, firmness of tofu, or dry tofu solids. The optimum amount of coagulant is also influenced by the solids content of the soymilk; the more concentrated the soymilk, the more coagulant required (26).

Calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), not to be confused with anhydrous calcium sulfate or calcium sulfate monohydrate, at a rate of about 2% to 3% of the

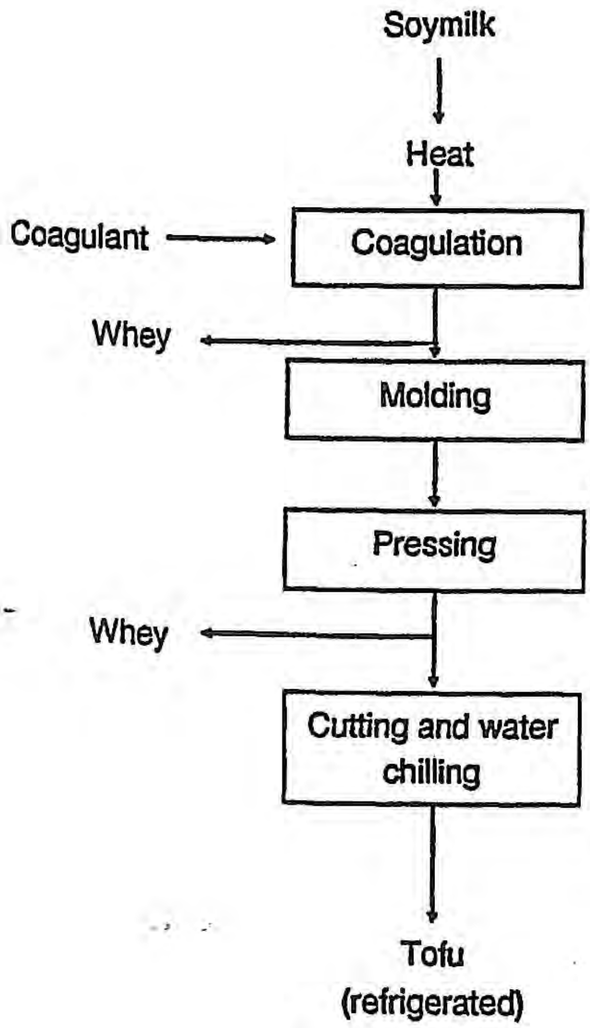

Fig. 22.4. Steps in momen (cotton or regular) tofu production. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes*, MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

soybeans used for the batch (0.013 to 0.023 N), is mixed with water and added to 70° to 90°C (158 to 194°F) soymilk, depending on the desired firmness of the tofu (26,28,29,30). Calcium sulfate, produced as a byproduct of the soda industry, is the most extensively used coagulant, although products derived from powdered gypsum and seawater are also available. A concentrated solution of magnesium chloride ($MgCl_2$), called *nigari*, has been commonly used for over 100 years. Recently, its use has been widely replaced by calcium sulfate and glucono-delta-lactone (GDL). Both of these coagulants are GRAS (generally recognized as safe) and contribute to the public's dietary calcium intake. However, nigari's perceived superior contribution to tofu texture and flavor has been a reason for its continued use by some processors.

The coagulant causes the soymilk to gel. Breakage of the gel into curds facilitates separation of the whey from the curds. After whey removal, the curds are transferred to a perforated press-box, covered with a cloth, pressed, and shaped. Unfortunately, bamboo mats instead of perforated metal plates are often used by small processors to help distribute the press weight, potentially increasing the microbial load of the tofu by the end of the production day. The press-boxes are made from aluminum or stainless steel. For sanitary reasons, wooden press-boxes are not advisable; however, some small operations still use them. Pressing is accomplished with hydraulic, air, or manual (ratchet) presses. From a microbiological quality standpoint (critical control point), the tofu temperature should not fall below 60°C (140°F) during the pressing step.

After the pressing weight is removed, the tofu is cut, then taken out of the press-box within a refrigerated water bath. Great care is taken not to damage the fragile blocks. Soaking is continued to cool the blocks and to remove excess coagulant. The tofu is held within these water baths until packaged or is refrigerated at 0 to 10°C (32 to 50°F) prior to packaging and shipment. Tofu is either packed in plastic containers or sold "in bulk," as unpackaged blocks, directly to consumers. To extend the shelf life of finished packaged tofu, the package can be submerged in water and pasteurized in the package. This process is used in California to ship tofu to the midwestern United States. Typically, 10 kg of soybeans will yield 40 to 50 kg of soft momen tofu or 15 to 30 kg of firm momen tofu.

There is considerable interest in reducing the amount of soaking time for whole soybeans. This would result in more economical processing: less water and energy consumption, lower labor costs, less okara production, more uniform tofu, and a faster response time when filling orders. Three approaches are used or are under consideration (3):

1. Dehulling the beans prior to soaking them (or grinding the dehulled beans with water)
2. Flaking the dehulled beans prior to grinding or soaking them
3. Making soy flour from the beans prior to a combined heating and soaking step

The first strategy was observed in use in Japan in 1989. The second strategy, the use of flakes, was proposed in 1989 by one manufacturer (Nichii Company, Japan), who has subsequently built processing facilities of this type in both Japan and the United States (31). Due to the extremely high cost of industrial land in Japan, there is

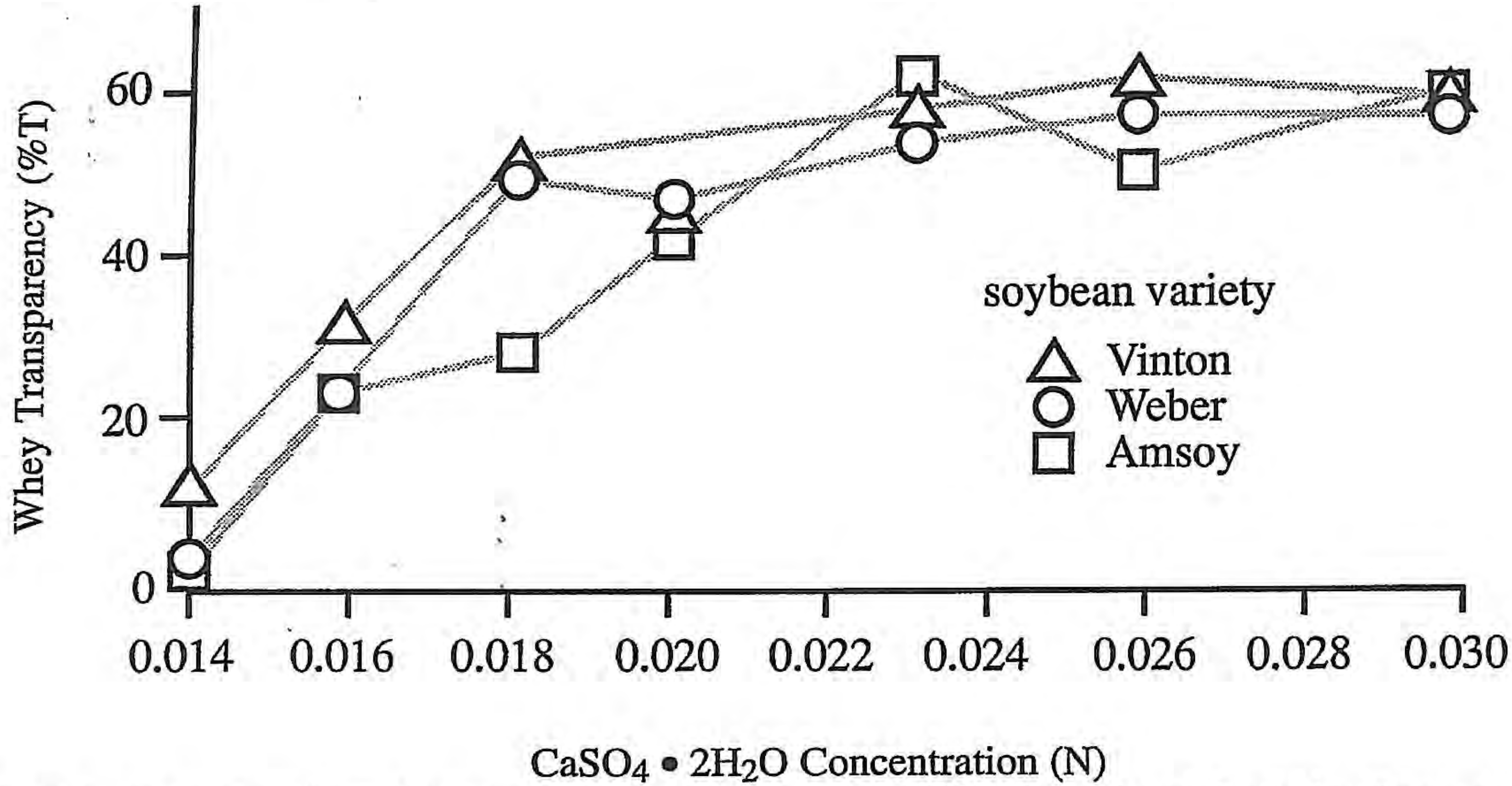

Fig. 22.5. Percent transmittance of whey versus coagulant concentration for soymilks at 6% solids made from Weber, Vinton, and Amsoy soybeans. A concentration of 0.023 N was selected as the optimum coagulant concentration. *Source:* Johnson, L.D., Influence of Soybean Variety and Method of Processing on Tofu Manufacturing, Quality, and Consumer Acceptability. M.S. Thesis, Iowa State University, Ames, IA, 1984, p. 128.

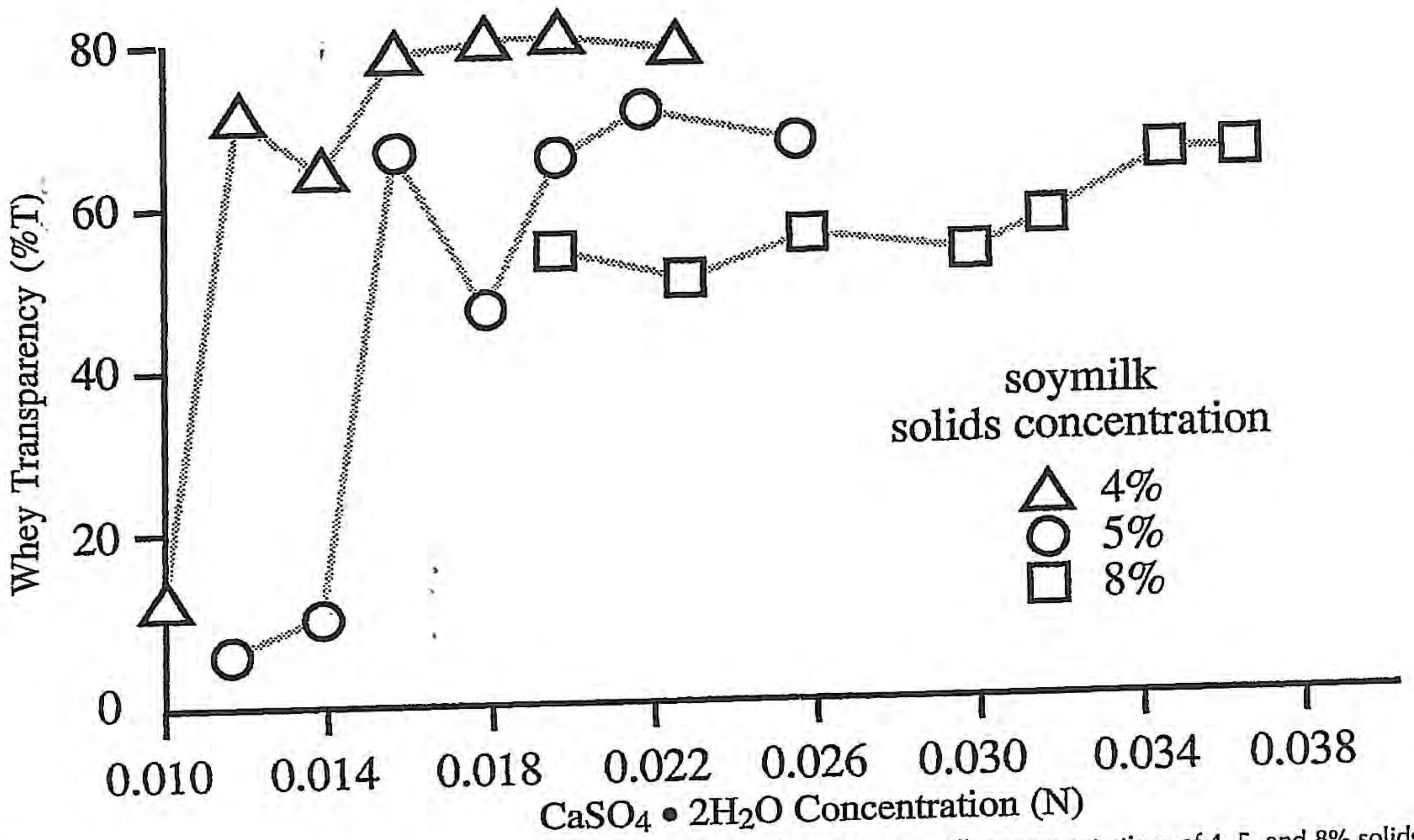

Fig. 22.6. Percent transmittance of whey versus coagulant concentration for Amsoy soymilk at concentrations of 4, 5, and 8% solids. Concentrations of 0.018N, 0.19N, and 0.035N, respectively, were selected as the optimum coagulant concentrations. *Source:* Johnson, L.D., Influence of Soybean Variety and Method of Processing on Tofu Manufacturing, Quality, and Consumer Acceptability. M.S. Thesis, Iowa State University, Ames, IA, 1984, p. 128.

considerable interest in locating soybean-processing plants outside the country. We have found that flaking of soybeans for soymilk and tofu manufacture generates a 20 to 40% cost savings, because of reduced water and electrical usage during the tofu-manufacturing process, and significantly shorter processing (soaking) times (15 min versus 12 h). Tofus produced from flakes were lower in fat than those produced from whole beans. Flake production in the United States is cost-effective for some Japanese producers. The third strategy in the foregoing list is "steam infusion cooking" (32), a technique that has been commercially adopted in parts of the United States and has been test-marketed in Japan.

Kinugoshi (Silken) Tofu. The name "silken" is often misconstrued as referring to the use of a silk cloth instead of a cotton cloth for filtering soymilk. It actually refers to the fine, delicate texture of the tofu. Kinugoshi has a much more homogenous, delicate texture, is softer and has a smoother mouth feel than "regular" momen tofu. This is due to the use of GDL, developed expressly for kinugoshi and packed tofu. GDL coagulates the soymilk slowly due to the slow release of gluconic acid.

Kinugoshi tofu is unique in that it is produced by coagulating whole soymilk without separation and removal of the supernatant (whey) (Fig. 22.7). This results in a tofu with higher nutrient content, softer texture, and lower antinutritional factors; however, whey inclusion usually compromises flavor. More concentrated soymilk is used for kinugoshi (12 to 13% solids) than for momen tofu (5 to 10% solids).

Kinogoshi tofu can also be produced by the rapid mixing of a calcium sulfate suspension (0.5 to 0.6% of the soymilk by volume) and soymilk at about 70°C (158°F). This processing is done within either heated or unheated coagulation vessels. After the milk has coagulated in the vessel, it is carefully removed and irrigated with running water within a holding tank.

Packed Tofu. Packed tofu differs from the others previously discussed in that it is processed within its sealed retail container. It is manufactured by pouring cooked soymilk into a plastic rectangular container or plastic-lined fiberboard box with a coagulant (often a mixed coagulant such as a mixture of calcium sulfate and GDL) (Fig. 22.8).

The container is then heat-sealed with a plastic sheet, or the mixture is sealed within a similar commercial plastic packaging system, then heated in water at 90 to 95°C (194 to 203°F) for 40 to 50 min. The whole soymilk coagulates in the container. Again, whey is incorporated into the product, as it is with kinugoshi tofu. Packed tofu is more sanitary than other types, because all pathogenic bacteria are killed during heating. Additionally, the product is protected from contamination during manufacture, storage, and distribution. Packed tofu is more shelf-stable and easier to transport than either momen or kinugoshi tofu. For these reasons, large continuous-production operations are possible. This product is increasing in popularity with supermarket chains and other large retailers.

Aseptically Packaged Tofu. Aseptically packaged tofus are essentially the packed tofu products mentioned in the previous section, except that all ingredients are commercially sterilized prior to formulation and packaging (Fig. 22.9).

These products were specifically developed and manufactured with an emphasis on their marketing as an export product. However, unanticipated consumer enthusiasm has resulted in advantageous openings into domestic tofu markets. To protect traditional tofu manufacturers (a well-organized small-business lobby) from this threat, production of aseptically packaged tofu for domestic markets has been strictly limited by government regulation to 1% of total tofu sales (3).

Production begins with the heat sterilization of soymilk at 135°C (275°F) for several seconds using a plate heat exchanger. The sterilized soymilk is then mixed with a sterile-filtered GDL solution, packaged within a plastic container, and sealed. All preparation is done under carefully controlled conditions within a "clean room." The packages are then heated in hot-water baths to coagulate the tofu. The resulting product has a shelf life of 6 mo to 2 yr at ambient temperatures.

Deep-Fried Tofu. There are three main types of deep-fried tofu: *namage* (single-fried tofu), *aburage*, and *gan-modoki* (double-fried tofus). Deep-fried tofu also has a longer shelf life and is more transportable than conventionally packed, fresh momen tofu. Additionally, it can be made on a relatively large scale using continuous fryers.

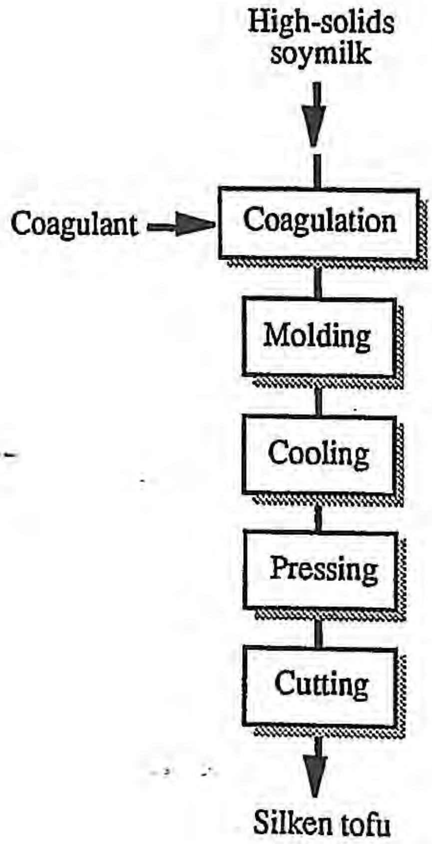

Fig. 22.7. Steps in kinugoshi (silken) tofu production. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes*, MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

Namage is a fresh, single-fried tofu that is prepared by deep-frying cut pieces of pressed tofu. While the inside texture is nearly the same as the original tofu, the surface is lightly browned and firm.

Aburage is made swollen and porous by an initial first frying in low-temperature oil (110 to 120°C, 230 to 248°F) (Fig. 22.3). This texture is then fixed by removing additional water by a second frying in high-temperature oil (180 to 200°C, 356 to 392°F). The best tofu of this type is obtained when the tofu expands to three times its original size. This swelling can be negatively influenced by improper heating conditions during the initial stages of soymilk and tofu production. Careful control of heat regimes during these and subsequent stages of production ensure minimal protein denaturation and maximum retention of air bubbles within the product.

Gan-modoki is another kind of double-fried tofu. It is made from dehydrated minced tofu and is a mixture of tofu, Chinese yams, finely chopped carrots, kelp, hemp seeds, sesame seeds, and other ingredients. It is usually molded into a ball, deep-fried, and sold hot to the customer. This product has a more porous texture than aburage.

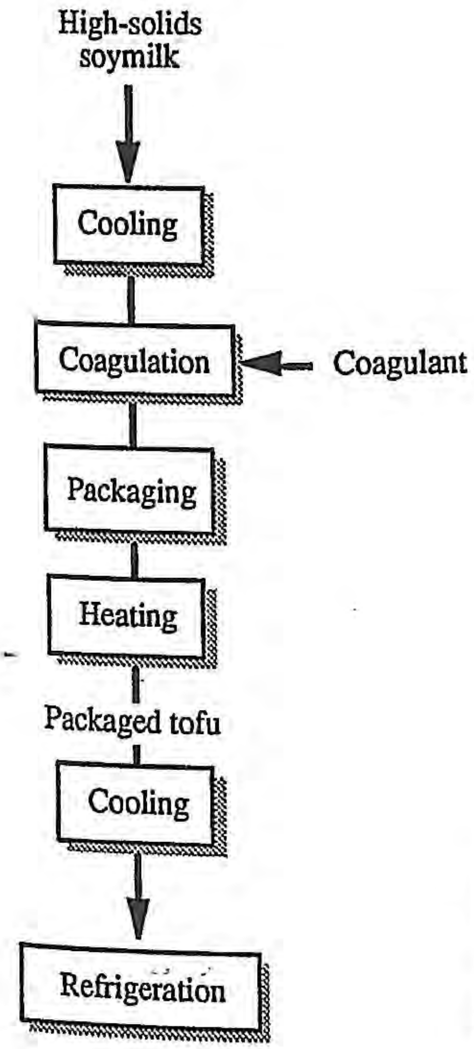

Fig. 22.8. Steps in packaged tofu production. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes*, MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

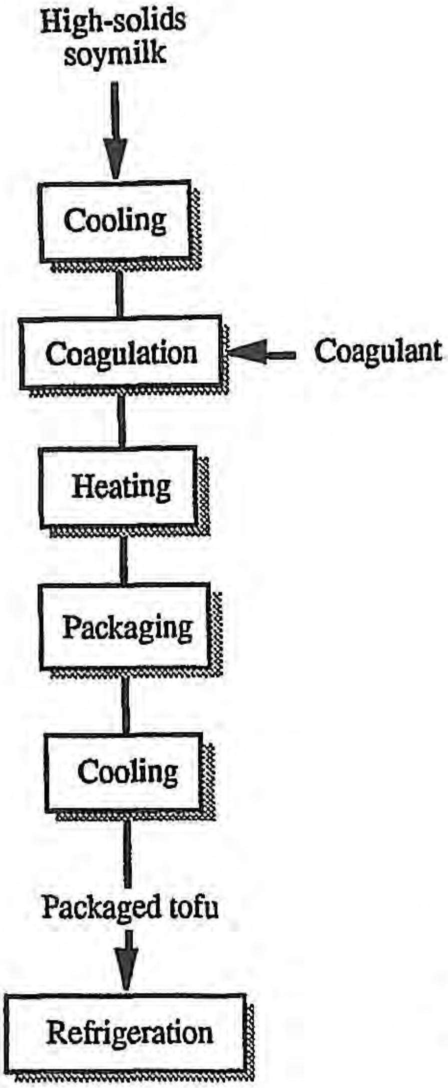

Fig. 22.9. Steps in aseptically packaged tofu production. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes*, MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

Kori Tofu (Dried-Frozen Tofu). Kori tofu is a frozen, dehydrated tofu. The dehydration process does not detrimentally affect the nutritional value or digestibility of the material. Upon rehydration, its texture is very different from the original tofu.

The production process for kori tofu begins when hard and sandy-textured tofu is made from soymilk coagulated with calcium chloride. The whey is removed, and the mixture is blended to break down the curds. This releases more whey, which is again removed. The curds are then transferred to wooden boxes for pressing (Figs. 22.10 and 22.11).

The resulting tofu is very firm. This is cut into pieces of 60 × 72 × 25 cm (24 × 28 × 10 in) or similar size. They are then forced-air frozen on metal trays at –10°C (14°F). After freezing they are stored for three weeks at –1 to –2°C (30 to 28°F).

Once thawed, the aged tofu, now very spongy, is easy to dehydrate. This is usually accomplished by mechanical compression, followed by hot-air drying until the product reaches 17 to 18% moisture. Care is taken during the drydown to ensure against cracking of the blocks. Final drying is accomplished in the open air.

Historically, kori tofu was produced during the winter season as a result of the natural freezing of stored tofu. Some tofu in the northeastern part of Japan is still preserved as kori tofu following historical preparation methods. Almost all commercially dehydrated products are made using large-scale freezing units. Kori tofu's long shelf life and its transportation, and storage characteristics make it an attractive product for large-scale manufacturers. Several production facilities currently use over 10 MT of soybeans per day, and the products from three of these companies hold more than a 70% share of the Japanese market (3).

Older Japanese consumers prefer kori tofu, which swells to a large size yet remains soft when cooked, and they appreciate the taste of the product. Younger consumers do not relish the taste and usually purchase other tofus. In the past, to enhance desirable textural characteristics, the dried product was exposed to ammo-

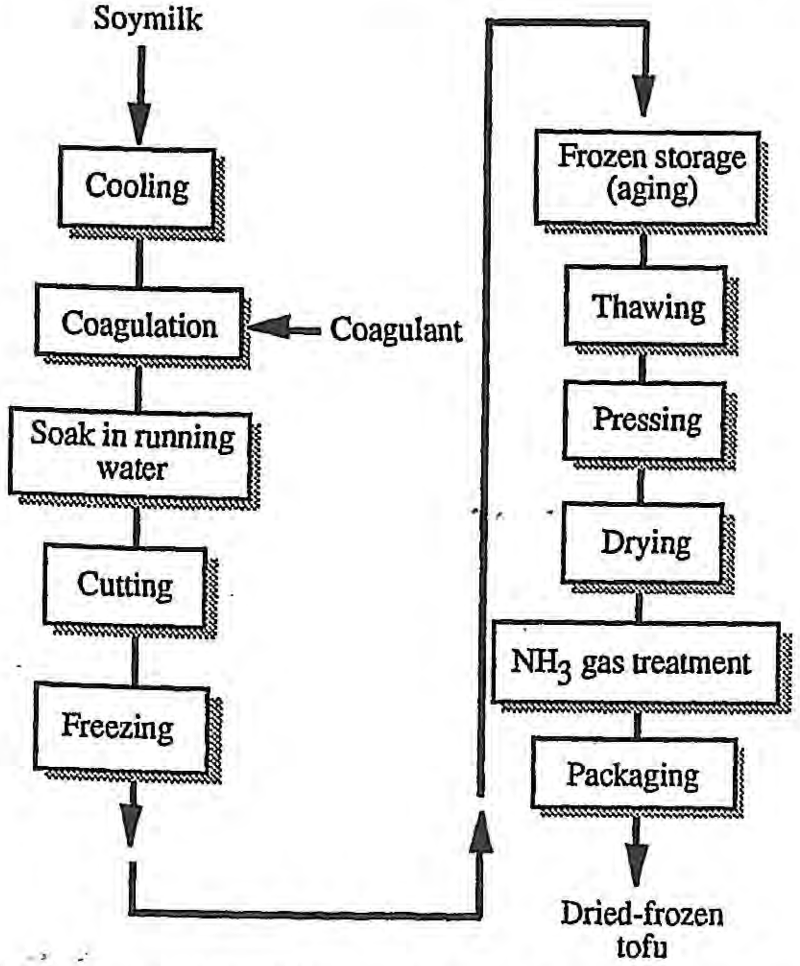

Fig. 22.10. Steps in kori (dried-frozen) tofu production. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes,* MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

nia gas. Fortunately, soaking in *kansui* (a solution of sodium or potassium carbonate or potassium phosphate) has replaced the practice of ammonia exposure. Ammonia use is undesirable, particularly with respect to worker safety. In addition, it was known to impart an unacceptable brown color and a characteristic off-odor to the stored product (5).

The yield of kori tofu is about 4.5 to 5.0 kg from 10 kg soybeans, with each dried piece of kori tofu weighing about 20 g. Kori tofu, with 53% protein and 26% fat (Table 22.3), is considered to be highly nutritious and desirable by consumers. It is more commonly used in western Japan.

Other Nonfermented Soy Foods

Yuba (Soybean Protein Film). Some consumers use fresh film for cooking, whereas others prefer dried yuba. This is packaged in sheet form, in small rolls, or in pieces of various shapes and sizes.

To prepare yuba, soymilk of the same solids content as that used for tofu is heated in a flat pan until it nears the boiling point. A protein film then forms on the surface of the milk and is then removed with a bamboo stick (or a sanitary stainless

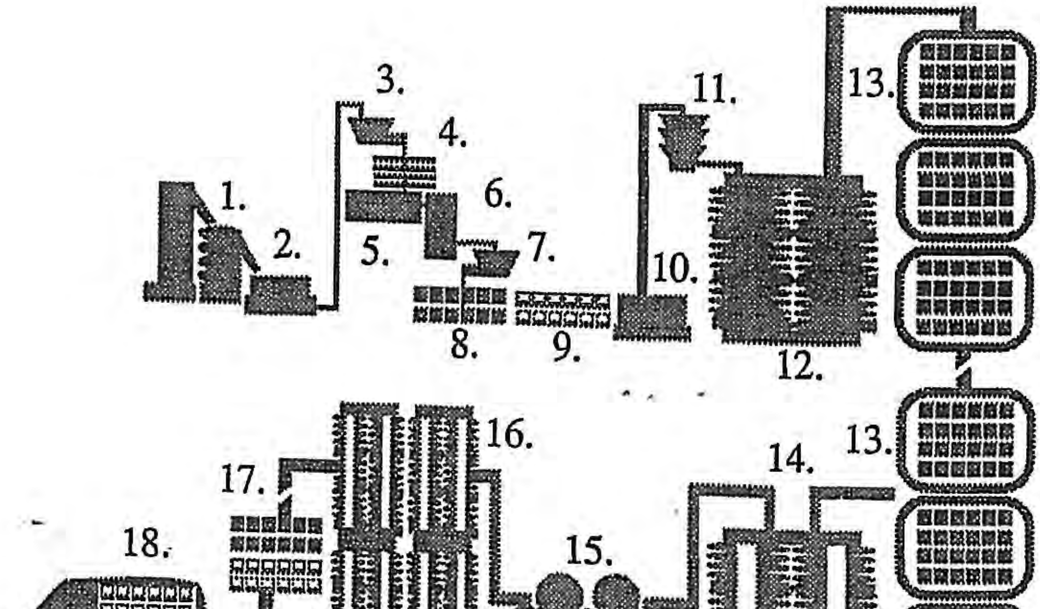

Fig. 22.11. Process for large-scale kori tofu (dried-frozen tofu) production: (1) soaking tank, (2) grinder, (3) cooker, (4) filter, (5) soy milk, (6) coagulation tank, (7) grinder, (8) molding box, (9) dehydration, (10) soaking, (11) cutter, (12) freezing equipment, (13) frozen storage, (14) continuous thawing, (15) press dehydration, (16) drier, (17) trimming, and (18) packaging. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes,* MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

steel rod), and carefully dried at ambient temperature. After the first film is lifted, continued heating produces successive films, each of which is in turn removed. As the films are removed, the solids content of the soymilk is gradually reduced to the point where it is impossible to form another film.

Yuba is rich in protein and oil; however, it is an expensive product because of its labor-intensive production. Yuba is primarily a local food in western Japan, although it is increasing in national and international popularity (especially Korea). The product is gaining widespread exposure as an ingredient in vegetarian dishes.

Kinako (Roasted Whole Soybean Flour). To make kinako, whole soybeans are roasted in a pan or rotating roaster, dehulled, cracked to grits, then ground to a fine powder with an impact grinder. The powder is then roasted until it has a desirable toasted flavor. Great care is taken not to exceed 220°C (428°F) within 30 s. This constitutes overheating and is deleterious to the protein, forming a bitter taste and lowering its nutritive value.

The hull is usually excluded from the product, although in some cases it is included to increase the fiber content. The digestibility of kinako is lower than that of tofu. It is often mixed with sugar and salt and is used to coat baked mochi. It is also used as a cake base. Green kinako is made from domestic soybeans, which have green hulls and cotyledons.

Fresh (Edamame) and canned soybeans. Soybeans that are green, soft, and large can be harvested when they are about 80% mature and prepared as fresh beans or peas. They can also be canned using the appropriate times and temperatures for low-acid foods.

Texturized Soy Protein–Based Foods. Texturized soy protein products, made by texturizing whole soybeans with single- and twin-screw extruders (see Chapter 8), are also manufactured and marketed in Japan. They are similar to extruded foods in the West and are primarily marketed as meat analogs, but only to specialty markets (hospital food services, individuals on restricted diets, some canned foods, etc.) (3). Consumers generally prefer "fresh" products to those that are reconstituted or extended. A related product, called "emulsion curd," is a tofu made from soybean protein isolate, soybean oil, and water. When these materials are mixed at a specific ratio, a stable curd resembling tofu is formed; this is then frozen or dried. The curd recovers much of its original shape and texture when rehydrated or thawed, unlike the traditional dried or frozen tofu. For this reason, it often replaces traditional tofu as an ingredient in dried or frozen foods.

Fermented Soy Foods

Fermented soy foods usually contain salt and the byproducts from a desirable fermentation. Both inhibit or slow the spoilage of these products and allow them to have a relatively long shelf life compared with fresh soy products such as traditionally prepared momen tofu (33).

Miso

Miso is made by mixing cooked soybeans with *koji* (starter culture, often fermented rice), and salt water. This material is then fermented for several months (Fig. 22.12). There are several miso products, which differ in the type of koji used for the fermentation (34). Rice koji is used to make rice miso, barley koji to make barley miso, and soybean koji to make soybean miso. A high ratio of rice or barley to soybeans results in a more lightly colored and sweeter miso. In conjunction with the ratio of rice or barley to soybeans, the hydrolysis of starch to maltose and glucose is essential to miso production. The fermentation period for high-wheat or -barley miso is usually shorter than for miso with greater soybean content. "Soybean miso" has the longest fermentation period, taking from 1 to 2 yr to produce an acceptable flavor.

The salt content of miso is usually about 10% or more by weight. Recent research has succeeded in depressing the salt content by adding alcohol or extra yeast to suppress undesirable "wild" fermentations.

To make miso, washed soybeans are soaked in water, then autoclaved (1.5 to 2.0 h at 0.5 atm) until softened (Fig. 22.12). In large plants, continuous soybean cookers are used. The cooked soybeans are cooled to 35 to 40°C (95 to 104°F), then mixed with koji and salt. The type of koji starter and whether rice or barley is used are important components in the biochemical process responsible for the flavor characteristics of the final product (Fig. 22.13). This mixture is then agitated in a semisolid state with water or previously drained cooking liquid. The resulting material is packed within fermentation casks, tightly covered with a thin plate or wax sheet, top-weighted, and allowed to ferment.

In the past, miso was produced by a seasonal, natural fermentation, which ran through the summer months. Temperature-controlled fermentation has made it possible to ripen miso within three months. The lactic acid bacterium *Pediococcus halophilus* and the yeast *Saccharomyces rouxii* are often added to the mash to accelerate the ripening process. The yield from 100 kg of soybeans and 100 kg of rice is about 300 to 400 kg of miso.

For other "specialty misos" the ingredients and fermentation vary. For white miso, rice is the dominant raw material, and the water in which the soybeans soak is removed. This procedure prevents the product from browning during fermentation, so that it retains the desired "white" color. Of some 600,000 MT of soybeans used for miso in Japan, 70% was for regular miso and 30% was used for white miso (34).

Soybean miso is made exclusively from soybeans. Cooked soybeans are ground, molded into balls, then covered with powdered koji starter and incubated in a koji room to promote the growth of *Aspergillus oryzae*. After four days, soybean koji germination is complete. The mash is then mixed with water and salt, and ripened in casks. This miso is aged for one year. The interrelationships between the various ingredients that produce the unique sensory properties of miso (color, texture, flavor, taste, aroma) are complex (see Fig. 22.13). A key factor in the quality of the final product is the enzymatic action of the microorganisms and how they influence the composition of the substrate (rice, barley, soybeans, rice and barley, rice and soybeans, barley and soybeans).

A spicy red "hot" soy paste (*ko chu jang*) is made in Korea by mixing a cooked soybean *koki* with cooked rice and red pepper in brine. The mass is allowed to ferment and ripen for several months (2).

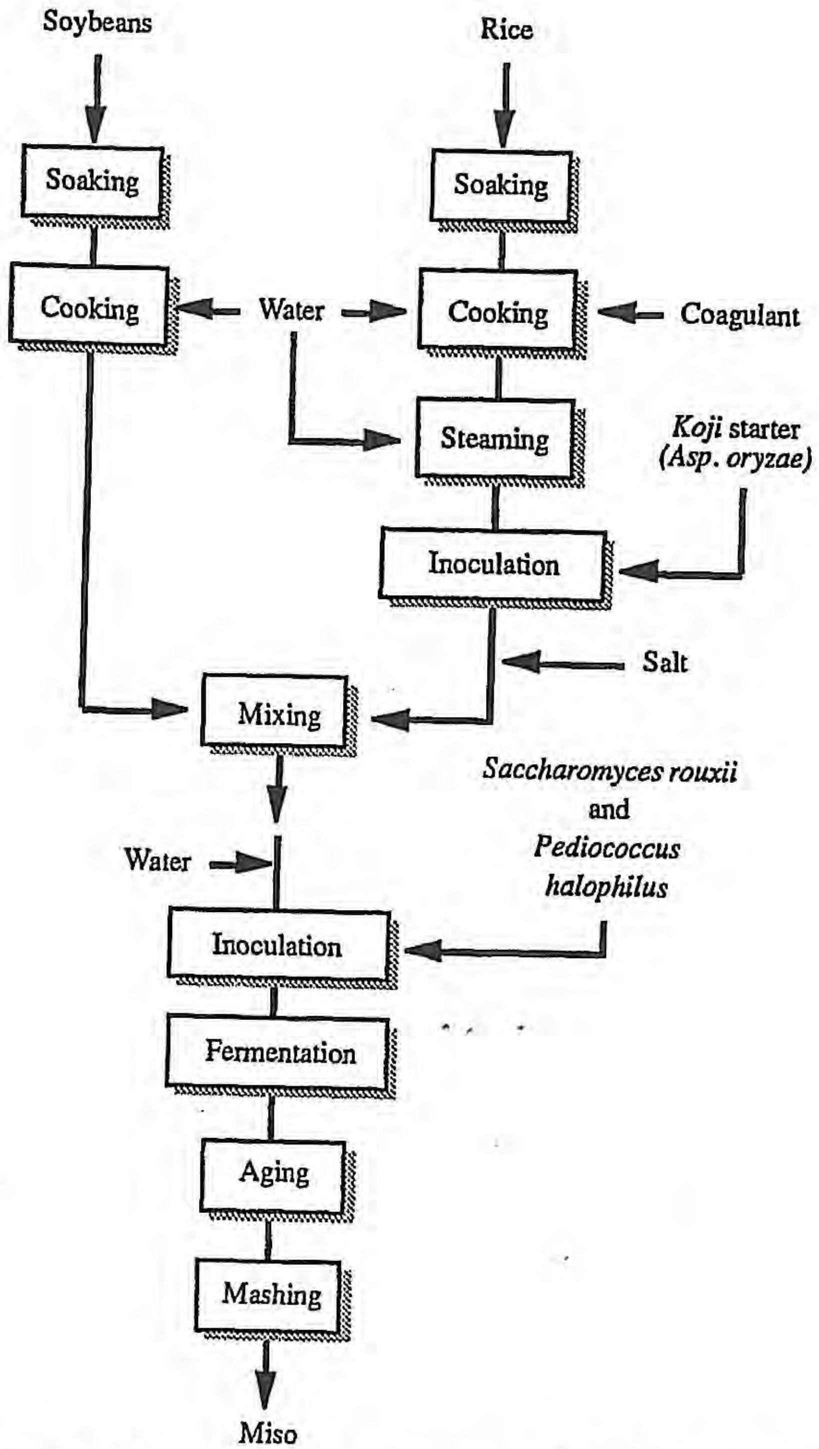

Fig. 22.12. Steps in miso production. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes*, MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

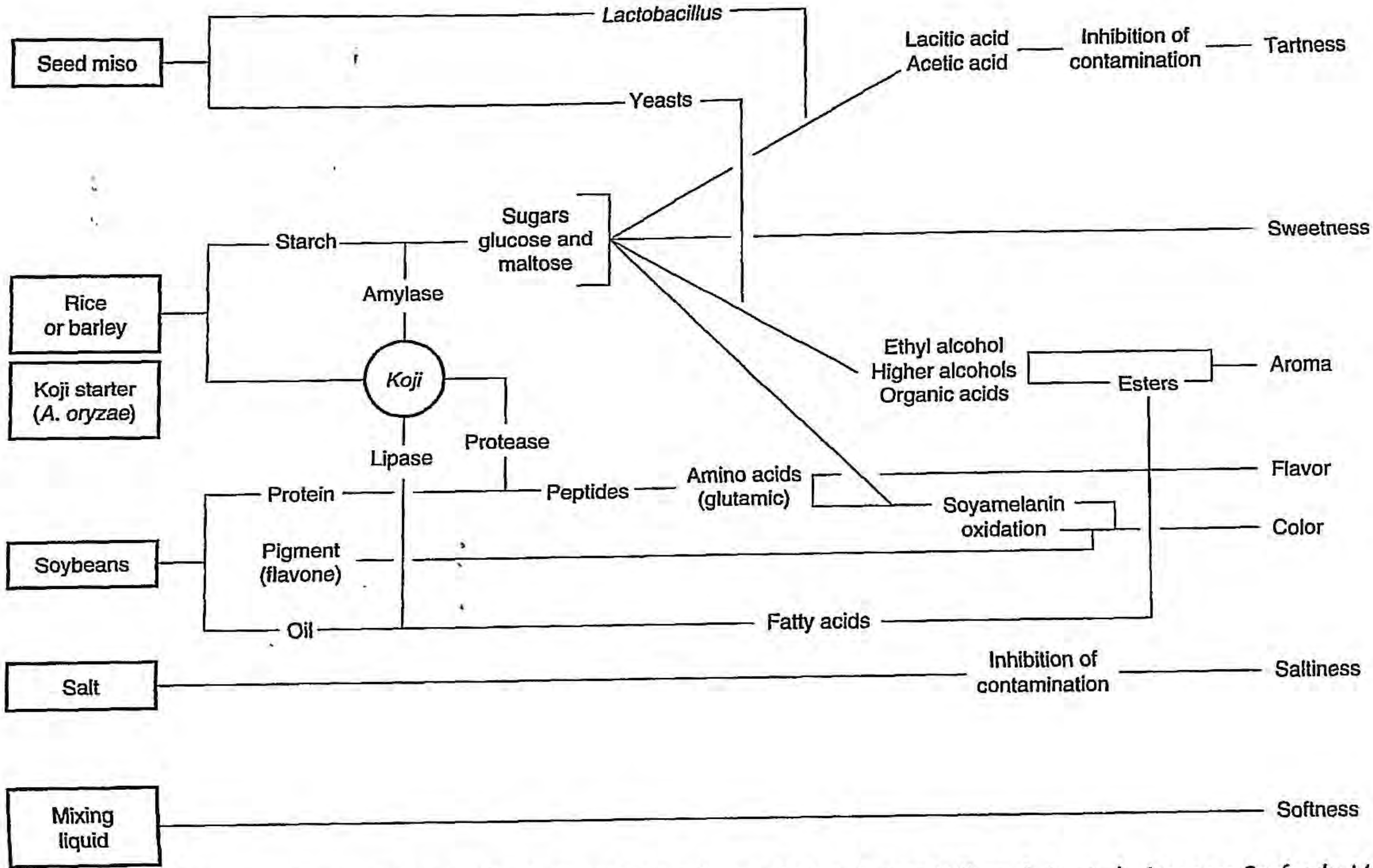

Fig. 22.13. The interactive factors producing the characteristic attributes of miso. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes*, MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

The introduction of supermarkets throughout Japan has stimulated the development of innovative packaging strategies. Previously, difficulties were encountered when some plastic packaging swelled and ruptured from carbon dioxide produced by the product once it was sealed in the container. This was especially a problem in supermarket shelf displays. Heating of the miso and incorporation of ethyl alcohol have largely solved these problems. The average Japanese citizen consumes around 20 g of miso a day, often in the form of hot miso soup served with vegetables (leafy vegetables, daikon radish, onions, etc.), seaweeds, or tofu. "Instant" miso is made by drying miso in a vacuum drum drier. Ingredients, such as lyophilized (freeze-dried) vegetables and deep-fried tofu, are often added to complete the product for marketing as a fast-food convenience item. Production drying technology influences the ultimate quality of the finished product.

Shoyu (Soy Sauce)

Soy sauce manufacturing was modernized much earlier than that of other soy foods. Soon after World War II (1945), the introduction of labor-saving machinery and mass production techniques spurred both profitability and growth in the industry. Defatted soybeans, the meal byproduct of soybean oil extraction, were already used prior to World War II as the raw material for soy sauce. When whole soybeans are used, soybean oil separates and collects on the surface of the sauce. For this reason defatted soybeans are preferred (4,5).

To make soy sauce, defatted soybean meal (30 to 60 nitrogen solubility index (NSI) (see Chapter 8) is well moistened with water and then cooked in a kettle or continuous cooker. The meal is then cooled to protect the protein from further denaturation. Although the protein is denatured to some extent during the cooking process, overdenatured meal can have an adverse affect on protein hydrolysis during aging and is rigorously avoided. Concurrent with meal preparation, wheat kernels are roasted and then broken into grits. These are then mixed with soy sauce koji starter, spread on top of the steamed soybean meal, and then mixed together. This material is piled on the floor of the koji room at 30 to 35°C (86 to 95°F) to start the growth of *A. oryzæ*. As the organisms grow, they congeal the mixture. The growing clumps of cultured material are continually separated from the remaining mash. This is done to ensure an adequate supply of fresh air to the growing culture.

Forty-eight hours are necessary for the preparation of soy sauce koji. The koji is greenish-yellow with white spots and has a sharp, volatile flavor. It is then mixed with salt water in a fermentation cask or tank. The material, now called *moromi*, is stirred with a paddle or by compressed air at least once a day to supply oxygen, remove carbon dioxide, and homogenize the mixture. Stirring time is reduced as fermentation progresses.

Enzymes from *A. oryzae* hydrolyze starch and protein, producing the characteristic flavor and aroma of soy sauce. The growth of various added or natural microorganisms assists fermentation and ripening. Historically, this aging took about one year. Today, it can take as little as six months because of technical processing improvements (e.g., continuous-agitation fermenters). Some brands employ accelerated ripening at 40°C (109°F). In these cases the ripened moromi is filtered to remove insoluble material, then heated (pasteurized) for 30 min at 60 to 70°C (140 to 158°F). To produce 50 kg of soy sauce, 10 kg soybeans (corresponding to 3 kg defatted soybean meal) are used.

Soy sauce quality determinations (or the nitrogen utility value) are based on the product's nitrogen content. Standard soy sauce contains 1.5% nitrogen and has a salt content of about 18%. Within the past few years, low-salt soy sauce has entered the market, reflecting the interest in reducing salt intake exhibited by the majority of Japanese and American consumers.

The nitrogen content of soy sauce (nitrogen utility) results from the fermentation conversion of proteins to amino acids. This value is influenced by the temperature and duration at which the soybean meal is steamed and, to a lesser extent, the strain or strains of fermentation microorganisms. Formerly, the nitrogen utility value of most products was 55 to 65%, but production improvements (e.g., fermentation temperature control technology) has raised this to 90% (2,3). Another method for increasing nitrogen utility is to heat the soybeans in the presence of hydrochloric acid to partially hydrolyze the protein in the meal. The acid is then neutralized with caustic soda, and the material is supplemented with salt and wheat bran koji and allowed to ripen at 30°C (86°F) for several months. This process raises the nitrogen utility value to 90%; however, the resulting product has an odor and flavor that differ from those of traditional soy sauce. Soy sauces produced by each production method are currently available as brand name products in both the United States and the Pacific Rim.

Annually in Japan, roughly 1.25 million MT of soy sauce are produced. This processing consumes from 170,000 to 180,000 MT of defatted soybeans and wheat. Five firms account for 50% of total production. Each Japanese citizen consumes a daily average of about 30 g of soy sauce.

Natto

Natto is a cooked whole soybean product fermented with *Bacillus natto*. There are similar products in the Indonesian and Thai markets, but not in China. Originally natto was developed using *B. natto* grown in rice straw. Preparation involved wrapping steamed or cooked whole soybeans within bundles of these prepared rice straws, then incubating them, allowing the *B. natto* in the straw to grow into the soybeans. Today, natto is made using pure-cultured *B. natto*.

Modern production is relatively straightforward. Soybeans are soaked in water overnight, then cooked to soften them. The cooled mash is inoculated with a commercial *B. natto* culture (a liquid suspension or starchlike powder), then mixed in a rotary cask. Fresh packets are then prepared by wrapping 50 to 100 g of mash with a thin piece of perforated polyethylene film or by placing the mixture in shallow polystyrene or wood trays. These are stacked in the fermentation room at 30 to 40°C (86 to 104°F) for 24 hr or until the soybeans are fully covered by a white, sticky glutamic acid polymer. The product is then transferred to a cold room for storage or transported to market.

Within the last few years a number of large-scale natto production plants have been established. Their existence is the direct result of solid-state temperature and humidity control systems that have facilitated automated production techniques. Additionally, the development of active-enzyme treatments to decompose starch and protein has reduced soaking and cooking times, accelerating the breakdown of the cooked soybeans and softening product texture. These additives are believed to have the additional benefit of aiding the digestion of the soy food within the human intestine.

Small soybeans are often preferred for natto production. It is perceived that small beans absorb water more easily, shortening the steaming time. Additionally, the larger surface-to-volume ratio of small beans may be a factor in establishing the proper degree of *B. natto* colonization and growth. Smaller beans are also easier to eat. Hardness problems, frequently related to small bean size in the United States (35; Kim, C.J., L.A. Wilson, and K.H. Hsu, *Cereal Chem.*, in press), have not been reported to be a problem in Japan. In 1984 roughly 1000 natto production plants used 150 kg of soybeans per day. The larger plants used from 2 to 3 MT daily. The total use of soybeans for natto production in Japan is from 70,000 to 80,000 MT annually.

Tempeh

Tempeh is a fermented whole soybean product that originated in Indonesia but is now equally popular in Malaysia. Tempeh is made by soaking soybeans overnight, then boiling them with the hulls (Malaysian) or without the hulls (Indonesian) for 30 min. The excess water is drained off, and the beans are placed on a tray for inoculation with a piece of tempeh or *Rhizopus oligosporus* (2,36). The beans are then allowed to ferment at room temperature for 1 to 2 d or at 30 to 32°C (86 to 90°F) for 20 h (Fig. 22.14). During fermentation, white mold mycelium covers the beans and binds them together into a solid sheet. The tempeh sheet is then cut into smaller pieces and, since it is a perishable product, sold that day. If it is to be stored for future use, it is usually blanched, sun-dried, or frozen. Tempeh is usually cooked before it is eaten. Preparation usually involves frying, deep-fat frying, or baking the product. It is also added to soups and fast foods and is used as a meat replacement in main dishes (37).

Sou-Fu

Fermented tofu (soy curd) is made in China by inoculating small cubes of pasteurized firm tofu (less than 70% moisture) with *Actinomycor elegans*. Other molds, such as *Mucor* and *Rhizopus*, can also be used. Depending upon the mold used, fermentation lasts from 3 to 7 days at 20°C (68°F). After fermentation, the cubes are placed in a 12% salt and rice wine brine for several months. The finished product is packaged with the brine and sterilized prior to marketing. The product has a mild flavor, a salty taste, and a creamy cheese texture (38).

Japanese Agricultural Standards

The Japanese Agricultural Standards (JAS) were enacted in 1951 to improve the quality of processed foods, simplify the Japanese trading system, promote uniform labeling, and to make it easier for the consumer to select high-quality processed foods (21,39). Unlike the U.S. Food and Drug Administration Standards of Identity, these standards are optional. The JAS quality standards define the food product, specify the application range, and define quality judgment criteria. The standards also set labeling formats, such as volume or weight, and similar criteria. These standards are applied to all products before they are shipped.

In 1988 the JAS covered over 70 items of processed foods including shoyu, kori tofu, vegetable proteins and their products, and refined soybean oil. These foods are therefore allowed to carry the JAS seal on their labels. Foods processed outside of Japan can be labeled with this seal if the company producing this product has petitioned for certification and received permission from the Japanese Government.

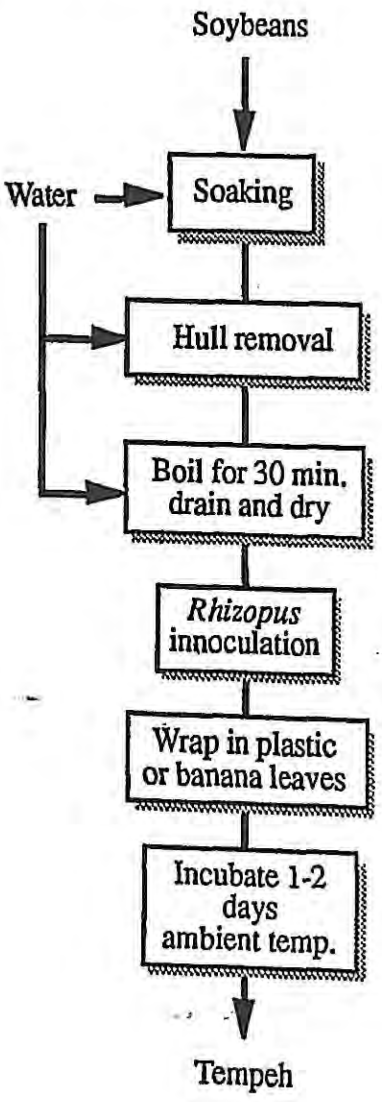

Fig. 22.14. Steps in tempeh production. *Source:* Wilson, L.A., et al., *Japanese Soyfoods: Markets and Processes*, MATRIC, Iowa State University, Ames, IA, 1992. Reprinted with permission of MATRIC.

Identity Preservation and Transportation

There are three main avenues by which U.S. soybeans are exported to Asia for food use. Traditionally, when importers purchase soybeans, they are sized, cleaned, and bagged on arrival. The importer then sells the beans directly to large tofu manufacturers or through various distributors to the smaller tofu shops and other soy food producers. The importation of mixed-variety Indiana, Ohio, and Michigan (IOM) beans is an example of this system.

Soybeans for crushing (resulting in oil and meal) constitute the second route through the distribution system. These soybeans are not specifically grown for the soy foods market and are generally composed of mixed varieties of U.S. No. 2 soybeans. The beans are often imported directly to the crushing company, where they are sorted by size and cleaned. They are then bagged, put into containers for sale to soy food processors, or crushed for oil and meal. Alternatively, the company may sell the beans to other primary or secondary distributors (15). Some of the crushers also extrude meal to produce soy-based meat analogs.

More recently, Japanese companies have contracted with specific U.S. seed companies or directly with American farmers to supply specialty "identity-preserved" soybeans for the production of specific soy foods in Japan. These purchases were initially related to tofu production; however, specialty purchasing of beans for miso and natto production is increasing in frequency (31).

Specialty soybeans are typically cleaned and bagged at the farm or seed company and then loaded into 18 MT (6601 bu) containers. These are then shipped by rail to U.S. west coast seaports, where they are loaded onto container ships bound for Japan. Container shipping maintains segregation (identity) of the individual lots, unlike the mixed cultivar U.S. No. 2 and IOM soybeans routinely bulk-shipped by freighter. The quality of container-shipped beans is usually much higher, since they are not a mixed lot that requires regrading and the multiple handling steps that directly expose the grain to physical degradation.

U.S. farmers, seed companies, and co-ops interested in directly marketing their soybeans to Japan may do so by contacting a local exporter, a Japanese trading company, or a Japanese soy food processor (15).

Soybean Quality Characteristics

While plant breeders, seed companies, brokers, and soy food manufacturers are all interested in identifying measurable soybean characteristics that can be used to characterize the end product quality of soy foods, very little published research is currently available. Likewise, computerized retrospective literature searches yield few references (Shurtleff, W., personal communication). The majority of reports concern the influence of particular varieties or soybean processing methods on the resulting soymilk and tofu rather than on identifying specific, measurable characteristics (40). Worldwide, most soybean producers and soy food processors recognize that in order to make quality tofu, high-quality soybeans are a must; however, actually identifying the "favorable characteristics" of desirable soybeans is not an easy task.

Quality characteristics of soybean-based foods, such as tofu and soymilk, have been defined subjectively (color, flavor, texture, etc.) by approximate analysis and texturally by using instrumentation. However, the relationships of these end-product quality factors to composition of the soybean are largely unknown.

Many variables contribute to soybean quality, including soybean variety, soybean environment (field and storage), phytic acid (phosphorus content), bean water uptake, composition of the protein fraction (glycinin, β-conglycinin, and their subunits), removal of the insoluble solids (okara), soymilk solids concentration, coagulation temperature, type of coagulant used, curd breakage, whey removal, pressing time and force, and plant and personnel sanitation.

Overview

Research at Iowa State University and the body of published articles on soy food quality suggests that the environment under which the beans are grown and the variety of soybean are the greatest initial influences on tofu quality (3). Neither the total amount of soybean protein or its NSI correlated with the yield or the textural qualities of tofu made from those soybeans. Glycinin appears to play a more significant role in forming the texture (elasticity, chewiness, brittleness) of tofu than does β-conglycinin.

The length of soybean storage, even under closely controlled refrigeration, significantly influences the textural properties of the resulting tofus (3). After 15 months of storage, all correlations between glycinin or β-conglycinin and the textural properties of the tofus were lost.

High-temperature and -relative humidity storage conditions of soybeans also caused significant decreases in the quality of soybeans and significant changes in textural and appearance characteristics of tofus. The effects were very variety-dependent, allowing no overall prediction indicator of tofu quality. For example, the NSI of Vinton 81 soybeans was significantly correlated with fracturability and cohesiveness, whereas the NSI of Pioneer 9202 soybeans was correlated only with cohesiveness, and no correlations were found for all other stored varieties between NSI and textural characteristics (40,41). The significant change in extractable lipid content suggests that its role in tofu quality may be more important than previously realized.

The percentage protein of soybean varieties should not be used as the sole criterion for the breeding or purchasing of soybeans for tofu manufacture. However, low β-conglycinin levels in the soybeans may increase tofu yield. Some U.S. soybeans compare favorably in composition, tofu yield, and tofu sensory properties to Japanese soybean varieties.

Judging Quality

The following recommendations apply to soybeans intended for soy foods (3,15).

Tofu. For tofu, the Japanese currently prefer soybeans with a clear to light-colored hilum and large seed size (>180 g/1000 beans, 6.5 to 7.0 mm). (However, some beans with black hila have been observed blended into some lots.) Ideal soybeans should be cream-colored, without cracks in the seed coat or seed, and firm to the touch. While the seed coat should be intact, it should be thin enough to be easily removed (usually self-exclusive properties). The protein content of the beans should be >40% (moisture-free basis). Some processors specify a high NSI or protein dispersibility index (PDI) in the belief that a high value will mean a larger yield of soymilk, a larger yield of tofu, or less degradation from overheating during shipment. Of these perceptions, the second is relatively unlikely, while the first and last may have some validity.

There is also a commonly held belief that soybean color, size, and protein level indicate whether a high-yielding, white to cream-colored tofu with acceptable texture will be produced. However, processors have acknowledged that these characteristics have proven less than reliable for identifying desirable bean varieties. Recent sensory and analytical evaluations of U.S. and Japanese varieties confirm that many U.S. varieties (Vinton 81 is the current standard variety) should be as acceptable as Japanese varieties for use in high-value soy foods.

Often, varieties that pass these screening specifications fail to produce desirable tofus. For that reason, each processor has developed specific processing parameters for different commonly used soybeans (e.g., Enrei, Vinton 81, IOM). Some companies are now setting specifications for not only color, protein, and NSI but also peroxide value (PV) and thiobarbituric acid (TBA) tests (measure of oil oxidation) or acid value, or free fatty acid (FFA) level (enzymatic activity releasing fatty acids). If the beans do not perform under these conditions, they are deemed unreliable and are rejected. Plant breeders, processors, trading company representatives, educators, government agencies all desire an objective testing system that would identify desirable imported beans prior to purchase. Likewise, such a test could be used by processors' quality control departments to monitor supply integrity during transit and storage. Production departments could then use these test results to set the optimal processing parameters for individual varieties.

Miso. Miso processors prefer somewhat different soybeans than do tofu producers. They prefer soybeans with a white to yellow hilum and cotyledon, although brown, black, and purple are acceptable as long as they are large in size (200 to 250 g/1000 beans), preferably with intact thin hulls. These beans should have high total sugar contents, with sugars of relatively high fermentable or hydrolyzable value. Protein contents should be of average value; oil content is seldom considered.

Natto. In the production of natto, round, small(~170 g/1000 beans)-sized (5 mm diameter, although one prefecture prefers 8 to 10 mm diameter) soybeans are preferred. The seedcoat and hilum should be white to a light cream color. It is said that "the brighter the light yellow, the better the taste." The 100,000 MT of soybeans used by producers yields roughly 200,000 MT of natto per year. Approximately 60% of the beans used for natto production are of Chinese origin, while the remaining 15% are Japanese, and 26% are from U.S. sources). Producers commonly experience two problems with U.S. soybeans. They are typically larger in size than is desired and have insufficient "sugar" content. The price of soybeans for natto is five times the cost of normal soybeans (e.g., 2000 to 3000 ¥/60 kg for tofu vs. 15,000 ¥/60 kg for natto). It is possible that a marketing opportunity may exist with respect to the production of specialty small, "high-sugar" soybeans.

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