may have formed a complex with proteins in corn, causing it to be insoluble in solvents used for extraction.

ACKNOWLEDGMENT

L. M. Elam, J. Greer and M. S. Milburn prepared samples and made analyses.

REFERENCES

1. Wilson, D.M., W.W. McMillian and N.W. Widstrom, JAOCS 56:798 (1979).
2. Shotwell, O.L., W.F. Kwolek and C.W. Hesseltine, Ibid. 58: 980A (1981).
3. Shotwell, O.L., G.A. Bennett, W.F. Kwolek and C.W. Hesseltine, J. Assoc. Off. Anal. Chem. 66:204 (1983).
4. Official Methods of Analysis of the Assoc. Off. Anal. Chem., 13th Ed., AOAC, Washington, DC, 1980, Sec. 26.049, 26.026-26.031.
5. Methods of American Association of Cereal Chemists, 1972 Rev. to AACC Approved Methods 45-05:1-9, AACC, Minneapolis, MN.
6. Mycotoxin Separate from Chapter 26, Official Methods of Analysis of the Assoc. Off. Anal. Chem., 13th Ed., AOAC, Washington, DC, 1980, Sec. 26.A01-26.A07.
7. Thean, J.E., D.R. Lorenz, D.M. Wilson, K. Rodgers and R.C. Gueldner, J. Assoc. Off. Anal. Chem. 63:631 (1980).
8. Shannon, G.M., O.L. Shotwell and W.F. Kwolek, Method for Determining Aflatoxin B_1 in Mixed Feeds, Ibid. 66:224 (1983).
9. Pohland, A.E., M.E. Cushmac and P.J. Andrellas, Ibid. 51:907 (1968).
10. Pons, W.A., Jr., A.L. Cucullu, L.S. Lee, H.J. Janssen and L.A. Goldblatt, JAOCS 49:124 (1972).

[Received September 19, 1983]

Tofu and Tempeh as Potential Protein Sources in the Western Diet[1]

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ABSTRACT

In recent years, a growing interest in foods of plant origin, especially plant protein foods, has become evident. A large number of low-technology, Oriental soybean foods have appeared on the American market outside the Oriental community. The most popular one is tofu. Tempeh, another soybean protein food, also has attracted a lot of attention. Tempeh has not yet been accepted to the extent that tofu has, but it is becoming a hamburger-alternative for vegetarians, now numbering 10-15 million in the United States. According to information published by the Soyfoods Center of California, the number of tofu producers in North America rose from 50 in 1975 to 182 in 1983, and annual production has increased from 13,250 tons in 1979 to 27,500 tons in 1983. The annual tempeh production was estimated at 500 tons in 1982. Changes in the perceptions of soybean foods as they pertain to health and social status seem to be the determining factors behind the momentous expansion of Oriental soybean foods. Therefore, the growth trend is expected to be continuing for some time into the future. Tofu is made by curdling the protein with a calcium or magnesium salt from a water extract of whole soybeans. It is a highly hydrated, gelatinous product with a soft, smooth texture and a bland taste. Therefore, tofu can be easily incorporated with other foodstuffs and used in nearly every culinary context, from salad to dessert and from breakfast foods to burgers. Tempeh is made by fermenting boiled soybeans with *Rhizopus oligosporus*. After 20-24 hr at 30 C, the beans are covered with white mycelium that binds the beans together to form a firm cake. It can be seasoned, and cooked by frying, roasting or baking – just like meat.

INTRODUCTION

In recent years, a growing interest in foods of plant origin, especially plant protein foods, has become evident. A large number of low-technology soybean foods that have been an important protein source in the far eastern countries for centuries have appeared on the American market outside the Oriental community. The most popular ones are tofu, or bean curd, and tempeh. These products are basic protein foods that are prepared by traditional methods. Westerners know very little of these products and their processing technology.

[1] Presented at the symposium on Potential New Protein Sources 75th AOCS Meeting, Chicago, 1983.

TRADITIONAL SOYBEAN FOODS

Traditional soybean foods may be categorized as either nonfermented or fermented. Fresh green soybeans, soybean sprouts, soybean milk, protein-lipid film, soybean curd and soybean flouer are the principal nonfermented ones (1) (Table I). Of these, soybean curd, or tofu, is the most widely consumed. Despite the fact that to make tofu and protein-lipid film one first must make soybean milk, consumption of traditional soybean milk was popular only among the Chinese. Today, it is not unusual to find soybean sprouts and soybean milk in health food stores in the United States, and tofu has become a regular item in many supermarkets around the country.

Of the great number of fermented soybean foods consumed in the Far East, only a few have been studied in the West; these are described in Table II (1). Some of these products are used primarily as flavoring agents that also add some protein or amino acid to generally bland and low-protein diets. Others, such as tempeh and natto, are served as staples. Because of its universally acceptable flavor, texture and high protein, tempeh has been the hamburger alterntive for vegetarians in the United States since the early 1970's.

TRENDS IN MARKET GROWTH FOR TOFU AND TEMPEH

According to industry statistics gathered by Shurtleff and Aoyagi (2) of The Soyfoods Center in California, tofu has been made commercially by Asian immigrants in the United States since 1904. By 1975, there were more than 50 tofu producers, all of whom were Asian-Americans. Tofu was then an ethnic food, available mostly in Chinatown and other ethnic food stores, or at supermarkets in California and Hawaii where large Oriental populations live. Publication of "The Book of Tofu" by William Shurtleff in 1975, undoubtedly set in motion the Western tofu market (Table III). About 70 tofu shops, mostly run by Caucasian-Americans, were opened in the 3 years after the publication, and the number has continued to grow. Annual production has increased from 13,250 tons in 1979 to 27,500 tons in 1983. The retail value of tofu was estimated at $50 million

TABLE I

Oriental Nonfermented Soybean Foods (1)

Foods	Local names	Description	Uses
Fresh green soybeans	Mao-tou, edamame	Picked before mature, plump, firm, bright green	Steamed or boiled in the pods and shelled or shelled before cooking, served as fresh green vegetable
Soybean sprouts	Huang-tou-ya, daizu no moyashi	Bright yellow beans with 3–5 cm sprouts	Steamed or boiled, served as vegetable or in salad (parboiled)
Soybean milk	Tou-chaing	Water extract of soybeans, resembling dairy milk	Boiled, served as breakfast drink
Protein-lipid film	Tou-fu-pi, yuba	Cream-yellow film formed over the surface of simmering soybean milk, moist and firm or dried and brittle in the form of sticks, sheets, or flakes	Cooked and used as meat
Soybean curd	Tofu, tou-fu, tubu, tahoo, touhu, tau-foo, dou-fu, dan-fu	White or pale yellow curd cubes precipitated from soybean milk with a calcium or magnesium salt or vinegar, soft to firm	Served as main dish with or without further cooking
Soybean flour	Tou-fen, kinako	Ground roasted dry beans, nutty flavor	Used as filling or coating for pastries

TABLE II

Oriental Fermented Soybean Foods (1)

Foods	Local names	Organisms used	Substrate	Nature of product
Soy sauce	Chaing-yu, shoyu, toyo, kanjang, ketjap, see-ieu	*Aspergillus, Pediococcus, Torulopsis* and *Saccharomyces*	Whole soybeans or defatted soy products, wheat	Dark reddish brown liquid, salty taste suggesting the quality of meat extract, a flavoring agent
Miso	Chiang, doenjang, soybean paste	*Aspergillus, Pediococcus, Saccharomyces, Torulopsis* and *Streptococcus*	Whole soybeans, rice or barley	Paste, smooth or chunky, light yellow to dark reddish brown, salty and strongly flavored resembling soy sauce, a flavoring agent
Hamanatto	Tou-shih, tao-si, tao-tjo	*Aspergillus, Streptococcus* and *Pediococcus*	Whole soybeans, wheat flour	Nearly black soft beans, salty flavor resembling soy sauce, a condiment
Sufu	Fu-ru, fu-ju, tou-fu-ju, bean cake, Chinese cheese	*Actinomucor, Mucor*	Soybean curd (tofu)	Cream cheese-type cubes, salty, a condiment, served with or without further cooking
Tempeh	Tempe kedelee	*Rhizopus*	Whole soybeans	Cooked soft beans bound together by mycelia as cake, a clean fresh and yeasty odor. Cooked and served as main dish or snack
Natto		*Bacillus natto*	Whole soybeans	Cooked beans bound together by and covered with viscous, sticky polymers produced by the bacteria, ammonium odor, musty flavor, served with or without further cooking as main dish or snack

TABLE III

Tofu Industry in the United States (2)

	Year					
	1975	1979	1980	1981	1982	1983
No. of producers	50	120	145	159	173	182
Annual production (tons)	NA[a]	13,250	16,875	21,100	24,300	27,500

[a]NA = Not available.

in 1981. In 1976, the Soyfoods Association of North America was founded by producers to promote research, production, marketing and consumption of soybean foods. The Association sponsors an annual conference that provides both instruction and overviews on producing and marketing of soybean foods. It also publishes an informative quarterly trade journal that links together suppliers, producers and scientific investigators.

Shurtleff and Aoyagi (2) collected weekly production data between April and July, 1982, from 30 tofu manufacturers who produce about 83% of total U.S. tofu; they found that the largest company operated by Asian-Americans produced 141,000 lb of tofu weekly, whereas the largest one operated by non-Oriental Americans produced 36,000 lb. Of the 30 companies surveyed, 7 were established between 1904–1945 and produced 49% of the tofu; 8 established between 1946–1975 produced 19%; and the remaining 15, established between 1976–1981, produced 32%. So the majority of the tofu probably still is made and consumed by Asian-Americans; however, the growth clearly is generated by the non-Oriental consumers.

The nation's largest tofu producer is the Hinode Company of Los Angeles, with the sale of 3.85 million dollars in 1981 (3) compared with 1 million dollars in 1969. To meet the expanding market from neighborhood Asian outlets to mainstream supermarkets, Hinode brought in a non-Asian marketing director in 1980 and now is investing a million dollars in facilities and marketing. Their tofu is sold coast to coast. Supermarkets account for 85% of their business and natural food stores for the remaining 15%.

Cookbooks have been instrumental in popularizing tofu; they describe the use of tofu in nearly every culinary context from salad to dessert, breakfast foods to dinner entrees and burgers to gourmet meals. National publications also have lent a hand in getting people acquainted with tofu.

Tempeh has been produced and consumed as a staple in vegetarian communes around the United States since 1974, and a small, family-owned company began to produce tempeh commercially in 1975. Since then, a steady growth has occurred in the tempeh market. Now, more than 50 tempeh manufacturers are in the United States. As surveyed in May, 1982, by Shurtleff and Aoyagi (2), the largest one produced about 5,000 lb of tempeh weekly. Annual production is estimated at about 500 tons, which has a retail value of $1.78 million. Unlike tofu, tempeh is mainly produced and consumed by non-Orientals.

As of late 1981, Shurtleff estimated that almost 37,000 tons of soybeans per year are used for making traditional soybean foods in the U.S.

TOFU

Tofu is made by precipitation of the proteins with a calcium or magnesium salt from a hot-water extracted, protein-oil emulsion of whole soybeans. It is usually sold in the form of a wet cake with a cream-white color, smooth fine texture and bland taste. Tofu is a highly hydrated, gelatinous product and, depending on the water content, tofu with different charactetistics can be produced. In the Orient, the typical type has an approximate composition of 85% water, 7.5% protein and 4.3% oil. This type of tofu has a soft, puddinglike texture but is firm enough to retain its shape after slicing. Tofu with a water content as high as 87–90% and a smooth, fragile texture is especially popular in Japan. On the other hand, many types of hard tofu products, with a water content as low as 50–60%, are enjoyed by the Chinese. These hard tofu products, known as tofu kan, have a chewy, meatlike texture and a special aroma and taste because they are flavored with tea, sugar, spices, or soy sauce, and then surface dried over a slow open fire. Tofu found in U.S. markets contains 75–80% water. According to U.S. tofu producers, Western consumers prefer tofu with a firm, chewy texture.

Traditionally, 3 main steps are involved in making tofu: preparation of soybean milk, coagulation of protein and formation of tofu cubes in a mold (Fig. 1). Dry soybeans are washed and soaked inwater overnight or until the beans are fully hydrated. The soaked beans are drained, rinsed and ground with water. The slurry is brought to a boil and kept at boiling for 15 min. The boiled slurry then

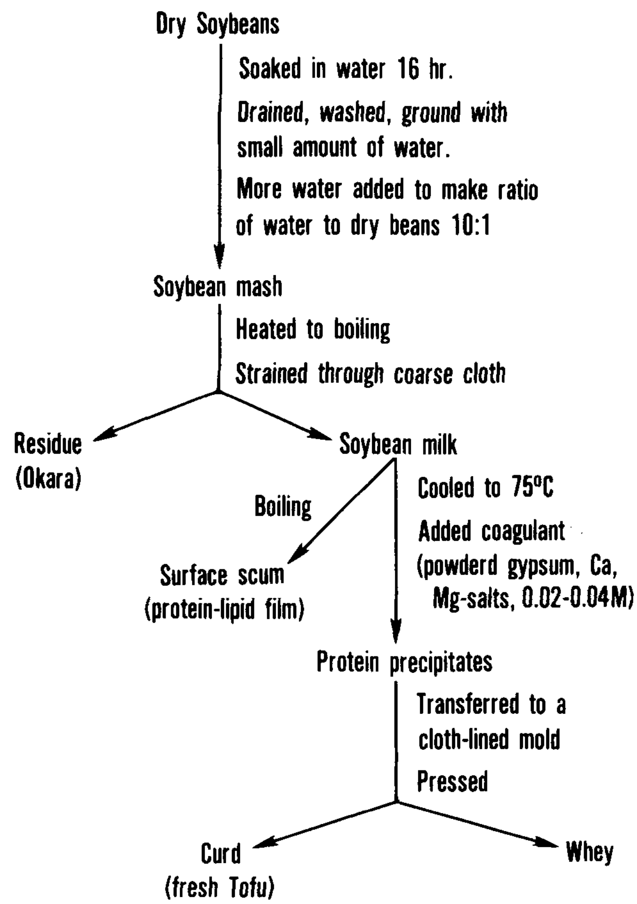

FIG. 1. Flow diagram for the preparation of tofu (1).

is filtered through cheesecloth, yielding a milklike product known as soybean milk. When bittern or nigari (the bitter liquid that remains after salt is crystallized from sea water), gypsum, magnesium, calcium salts or vinegar is added to the milk, a curd forms. This curd is pressed to remove excess whey, forming a highly hydrated curd or tofu. Thus, the tofu process is a very simple one; however, the making of a high-quality and reproducible product is sometimes a problem. Many factors, from the dry beans to pressing the curd, could affect the yield and the quality of the resulting tofu. Several studies have been made on tofu processing in recent years in an attempt to understand the process and to establish its optimum conditions. Following are some of the findings.

In addition to proper storage conditions, washing the soybeans is an effective way to reduce surface microbial contamination. The presence of heat-resistant, spore-forming bacteria observed on soybeans (4) suggest that bacterial contamination could occur. This could shorten the shelflife of such foods as tofu and tempeh, which are made from whole soybeans and have a short processing and cooking time. Therefore, the beans should be cleaned before processing by washing or spraying with water or by air expiration.

The purpose of soaking the beans is to facilitate grinding and, perhaps, to remove some undesirable factors such as the gas-forming oligosaccharides. But, soaking could also leach out protein and other solids, depending on temperature and time (5) (Table IV). Although complete hydration is reached at different times depending on the temperature, the amount of solids leached out during the time required to reach complete hydration at different temperatures is about 4.5%. But at lower temperatures (20-25 C), the rate of solids losses beyond the saturation point is much slower than at high temperatures (30-37 C). Thus, the soaking time becomes more critical at a higher temperature. To keep soaking losses at a minimum, to avoid extended soaking and to save energy for cooling and heating, hydration of soybeans at an ambient temperature, around 20-22 C for 16-18 hr, is most suitable. Under these conditions, 20-40% of oligosaccharides can be leached out.

TABLE IV

Soybean Solids and Proteins in Soybean Soak as Affected by Soaking Conditions (5)

Soaking time (hr)	Soaking temp. (°C) 20	25	30	37
	Total solids g/100 g soybeans			
2	0.70	0.70	0.95	1.25
6	1.75	2.10	3.10	4.40
12	3.00	4.40	5.60	7.35
18	4.65	5.00	6.25	9,45
24	5.00	5.20	7.35	10.40
	Lowry's protein g/100 g soybeans			
2	0.05	0.06	0.10	0.15
6	0.15	0.24	0.38	0.61
12	0.35	0.62	0.79	1.10
18	0.52	0.71	0.99	1.50
24	0.56	0.75	1.22	1.67
	Lowry's protein g/100 g solids in soak			
2	7.10	8.6	10.5	12.0
6	8.6	11.4	12.3	13.9
12	11.7	14.1	14.1	15.0
18	11.2	14.2	15.8	15.9
24	11.2	14.4	16.6	16.1

By experience, the Orientals have found the most suitable ratio of water to dry beans to be 8:1 to 10:1. Watanabe et al. (6) reported a significant reduction in the amount of protein and total solids extracted when the amount of water used is reduced to less than 6.5 times that of dry beans. Increasing the amount of water above 10:1 increases the amount of solids and protein extracted. However, excess water would result in a soybean milk with a protein concentration too low to obtain proper curd formation. Therefore, the ratio of water to dry beans, including that absorbed during soaking, is preferred at 10:1.

Grinding or blending the soaked beans in water facilitates the extraction and also the production of protein and lipid emulsion. Hot grinding (7) or heating the soaked beans before grinding (8) to prevent the formation of off-flavors from lipoxygenase have been suggested and practiced at some of the Western tofu production plants.

The heat treatment is essential, not only for protein denaturation to attain proper curd formation (9), but also to improve nutritional value and reduce off-flavor. Tofu often is consumed without further cooking; therefore, sufficient heat treatment is necessary to destroy the anti-nutritional factors and to obtain the maximum nutritional value of the soybean milk. In vitro digestibility (Fig. 2) and amino acid composition (10) indicate that the maximum nutritive value of soybean milk can be ensured by boiling for 10-15 min, but excessive heat may adversely affect the nutritive value. Watanabe et al. (6) reported that boiling the soybean slurry for more than 20 min not only reduces the total solids recovery, and thus reduces the tofu yield, but also affects the tofu texture. Therefore, the slurry should be boiled for 15 min.

The coagulation step is the most significant in terms of yield and texture of tofu, but it is the least understood. In the Orient, the making of tofu has been considered an art, and even today, the relationship between the ion binding to the soybean protein and the coagulation phenomenon are still not completely understood.

Data in Figure 3 (10) show that both ionic concentraation and type of coagulant afffect the gross weight and moisture content of the final product, as well as total solids and nitrogen recoveries. Except when calcium sulfate is used, gross weight, moisture content of tofu, and total

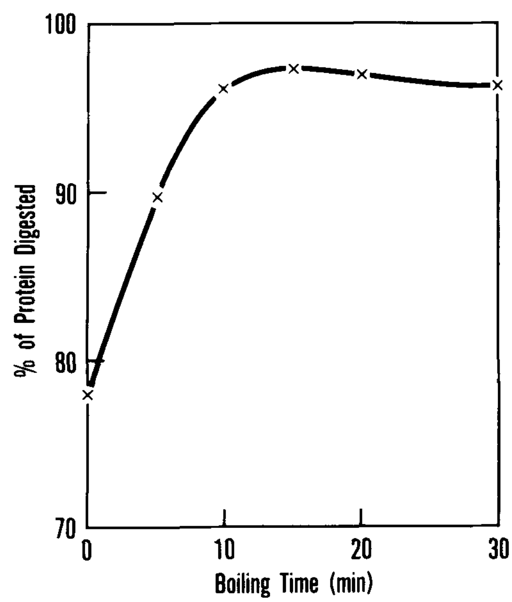

FIG. 2. In vitro digestibility of soybean milk as affected by the duration of boiling (10).

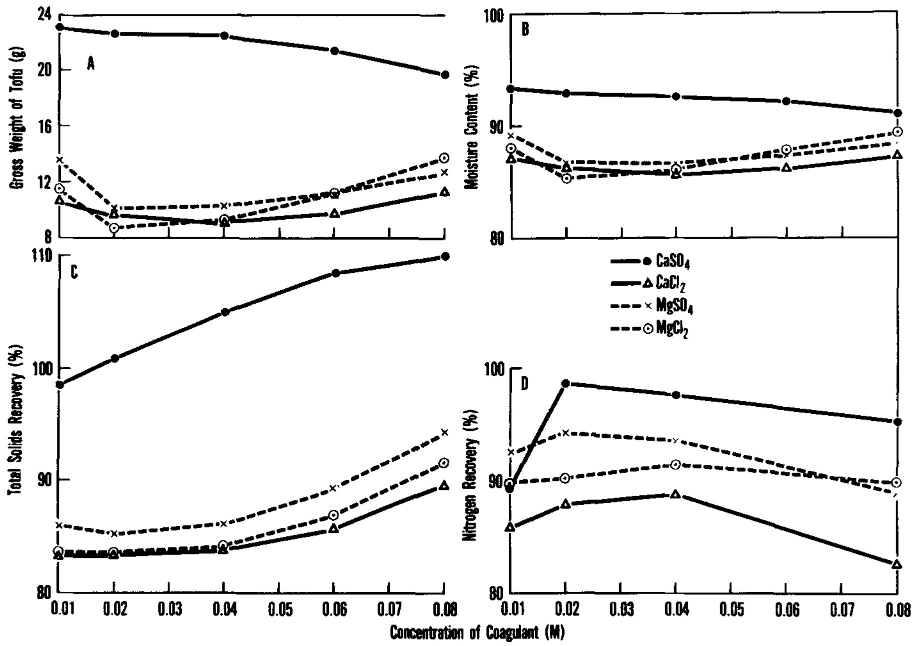

FIG. 3. Relationship of concentration and type of coagulant to the yield of tofu (10).

solids recovery decrease as the salt concentration increases from 0.01 to 0.02 M, remain about the same between 0.02 and 0.04 M, and then steadily increase at higher concentrations. No curd is noted when the concentration of coagulant is higher than 0.1 M and lower than 0.008 M. On the other hand, the percentage of nitrogen recovery increases as the concentration of salt increases, remains the same at 0.02-0.04 M, and then decreases at higher concentrations. In studying the binding of unfractionated soybean proteins with calcium ion, Appurao and Rao (11) observed that, at higher concentrations of calcium ion, the extent of precipitation decreases and the protein becomes soluble again, which also explains our results of decreasing nitrogen recoverty at higher salt concentrations.

Because of the limited solubility of calcium sulfate, the acutal ionic concentration at each level may be uncertain and the concentration gradient is less than that indicated. This limited solubility could partly account for the smaller variation noted in tofu made with calcium sulfate compared with that made with the other three salts. This study shows that salt concentrations between 0.02 to 0.04 M have the least effect on the 4 quantities investigated, and also result in the highest nitrogen recovery. Therefore, the use of salt at a level between 0.02 to 0.04 M is more likely to yield a reproducible product with high nitrogen recovery. For the same reason, calcium sulfate seems to be preferred.

The texture characteristics of the curds also are influenced by the concentration and type of coagulant (Fig. 4). When the concentration of the coagulant is increased from 0.01 to 0.02 M, significant increases in hardness, brittleness, cohesiveness and elasticity are noted. No significant effect is observed at concentrations between 0.02 to 0.04 M, but above that range these measurements of the curds decreased steadily. These data again indicate that the use of salt at a level between 0.02 to 0.04 M is more likely to yield reproducible firm products. Tsai et al. (12) made a study on yield and characteristics of tofu using various coagulants at concentrations ranging from 0.01 to 0.08 M. They found that, based on coagulability and texture, coagulant concentrations between 0.025 to 0.03 M were the more suitable for making Chinese-style tofu.

Calcium chloride and magnesium chloride resulted in curds with much greater hardness and brittleness than did calcium sulfate and magnesium sulfate, suggesting that anions have a greater effect than cations on these two parameters. Aoki (13) has investigaged the effect of salts on the gelation of soybean protein and found that anions have a stronger effect on water-holding capacity than do cations. In our study (14), we found the hardness of tofu increases as its water content decreases.

The temperature of soybean milk when adding coagulant and the mode of mixing greatly affect the yield and texture of the resulting tofu. As the temperature increases, the gross weight and moisture content of the curd decrease, whereas its hardness increases (10). Increased mixing decreases tofu volume and increases hardness (10, 15).

Thus, many factors come into play during the process, and each factor affects the final product. By knowing the effects exhibited by varying each factor, one can choose and establish a set of conditions to reproduce the desired type of tofu.

The chemical composition of soybeans has been reported to affect tofu texture. Saio et al. (16) found that gel made from 11S protein isolated from defatted meal was much harder than that made from 7S protein, and they also noted increasing tofu hardness as the amount of phytic acid added to soybean milk increased. Since the ratio of 7S to 11S protein and the phytic acid content of the beans may vary with the variety, Saio and her coworkers speculated that soybean variety could have an effect on tofu texture. Recently, Skurray et al. (17) compared 15 varieties and found no significant correlation between the ratio of 7S to 11S protein or phosphorus content and quality of tofu, but they did find that the quality of tofu was greatly affected by the amount of calcium ion added. Perhaps such chemical variations may not be great enough to have a significant effect when compared with the processing variables. Japanese soybean varieties have been suggested (6) to be better suited for tofu than U.S. soybeans. We (14) have, therefore, studied varietal effects with 5 U.S. and 5 Japanese soybean varieties grown under the same environmental conditions; we found that the composition and color of tofu are

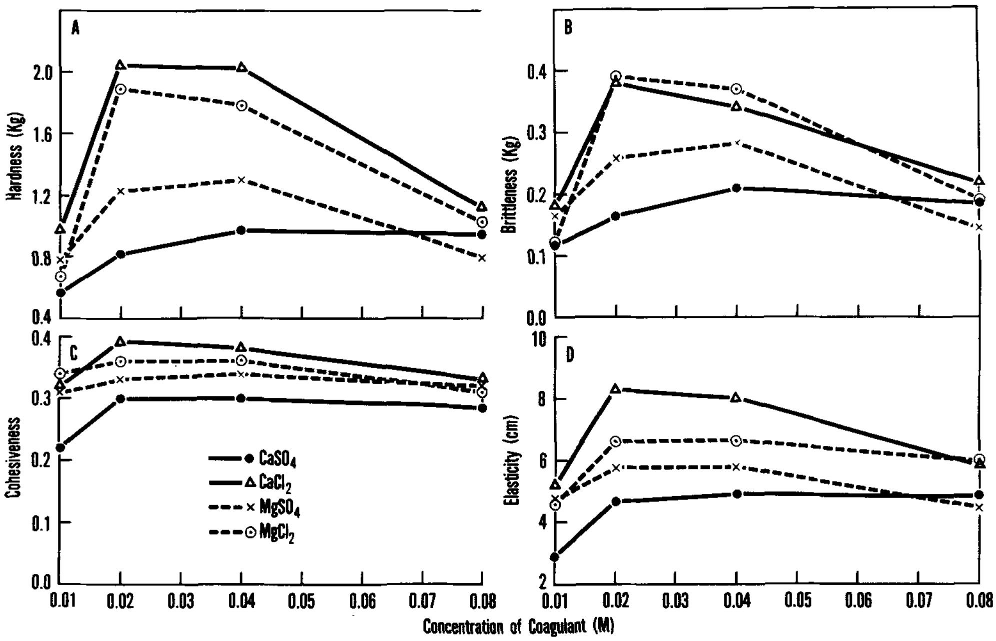

FIG. 4. Relationship of concentration and type of coagulant to the texture characteristics of tofu (10).
texture characteristics of tofu (10).

TABLE V

Ratio of Protein to Oil Content of Tofu and Soy Milk as Affected by Protein Content of Soybeans (14)

Soybean variety	Soybean protein (%)	Protein/oil Tofu	Protein/oil Milk
Wase-Kogane	45.2	2.07	2.49
Vinton	45.1	2.01	2.50
Toyosuzu	44.1	1.87	2.13
Coles	43.2	1.78	2.11
Yuuzuru	42.3	1.89	2.30
Tokachi-Nagaha	41.8	1.88	2.12
Weber	40.9	1.57	1.75
Hodgson	40.9	1.67	1.90
Corsoy	40.8	1.69	1.95
Kitamusume	40.8	1.57	1.86

affected by soybean variety but that yield and texture are not significantly affected. Tofu made from a variety with a high protein content has a higher protein/oil ratio than tofu made from a variety with less protein (Table V). Varieties with a high protein content are preferred; varieties with a dark hilum are not desirable.

TEMPEH

Tempeh is made by fermenting dehulled and briefly boiled soybeans with a *Rhizopus* mold. Unlike most other soybean fermentations, which usually involve long brining and aging, tempeh fermentation is short and simple.

Traditionally, soaked, hand-dehulled and boiled beans are inoculated with small pieces of tempeh from a previous fermentation. The inoculated beans are wrapped in banana leaves and left at room temperature for 1–2 days. At the end of the fermentation time the beans are bound together by mycelium, forming a firm, cakelike product.

Studies carried out at our Center identified *Rhizopus oligosporus* as the major organism responsible for tempeh fermentation (18), and these studies resulted in the development of a pure culture fermentation as shown in Figure 5. To save time and labor, mechanically dehulled, full-fat grits replace whole soybeans. A tempeh starter containing

Dehulled full-fat soybean grits
↓ ← **Tap water**
Soaked 30 min. at 25 C
↓
Drained
↓ ← **Tap water**
Cooked (30 min.)
↓
Drained and cooled
↓
Inoculated ← **Spore suspension of *Rhizopus oligosporus* Saito NRRL 2710**
↓
Tightly packed in petri dishes
↓
Incubated 31 C for 20-24 hr
↓
Tempeh cake

FIG. 5. Flow diagram for tempeh fermentation (1).

spores of *Rhizopus oligosporus* NRRL 2710 was developed at our Center (19) and now is available commercially. We found petri dishes to be the most convenient laboratory container for tempeh fermentation. Some commercial producers now are using petri dishes for tempeh patties. Shallow aluminum foil or metal trays with perforated bottoms and perforated plastic film covers may be used to replace banana leaves. Perforated plastic bags and tubing also have been used successfully. Like many other molds, *R. oligosporus* requires air to grow, but it does not require as much aeration as many other molds. In fact, too much aeration will cause spore formation and also may dry up the beans, resulting in poor mold growth. Therefore, properly perforating the containers and properly packing the beans for fermentation are important.

Tempeh has a short shelf life. Steaming for a few minutes to kill the mold and to inactivate the enzymes and then freezing will extend the shelf life.

Tempehlike products can also be made (20) by fermenting whole cereal grains such as wheat, oats, barley, rice or mixtures of cereals and soybeans with *R. oligosporus*. Tempeh made from a mixture of wheat and soybeans has been shown (21-22) to have a better protein value than that made from soybeans alone, because of the complimentary effect of mixed proteins and the increased use of lysine in wheat by fermentation. Wheat tempeh and a mixed wheat-soybean tempeh are commercially available in the U.S.

Traditionally, tempeh is sliced and deep-fried, but it can be cooked by roasting, baking or sauteing just like meat. In the West, tempeh burgers and chips are popular.

REFERENCES

1. Wang, H.L., in Handbook of Processing and Ulitization of Agriculture, Vol. II, Part 2, *Plant Products*, edited by I.A. Wolff, CRC Press, Inc., Boca Raton, Florida, 1983, p. 91.
2. Shurtleff, W., and A. Aoyagi, Soyfood Industry Directory and Databook, The Soyfoods Center, Lafayette, California, 1983.
3. Leviton, R., Soyfoods 8:33 (1983).
4. Swain, E.W., H.L. Wang and C.W. Hesseltine, unpublished data.
5. Wang. H.L., E.W. Swain, C.W. Hesseltine and H.D. Heath, J. Food Sci. 44:1510 (1979).
6. Watanabe, T., C. Fukamachi, O. Nakayama, Y. Teramachi, K. Abe, S. Suruga and S. Mivanage, The Report of Food Research Institute, Ministry of Agriculture and Forestry, Japan, 14B (1960) (in Japanese).
7. Wilkens, W.F., L.R. Mattick and D.B. Hand, Food Technol. 21:1630 (1967).
8. Nelson, A.I., M.P. Steinberg and L.S. Wei, J. Food Sci. 41:57 (1976).
9. Fukushima, D., in Chemical Deterioration of Proteins, edited by J.R. Whitaker and Masao Fugimaki, ACS Symp. Ser. 123, Washington, D.C., 1980, p. 211.
10. Wang, H.L., and C.W. Hesseltine, Process Biochem. 17:7 (1982).
11. Appurao, A.G., and M.S. Narasingo Rao, Cereal Chem. 52:21 (1975).
12. Tsai, S.J., C.Y. Lan, C.S. Kao and S.C. Chen, J. Food Sci. 46:1734 (1981).
13. Aoki, H., Nippon Hogei Kagaku Kaishi 39:277 (1965) (in Japanese).
14. Wang, H.L., E.W. Swain, W.F. Kwolek and W.R. Fehr, Cereal Chem. 60:185 (1983).
15. Saio, K., Cereal Foods World 24:342 (1979).
16. Saio, K., M. Kamiya and T. Watanabe, Agric. Biol. Chem. 33:1301 (1969).
17. Skurray, G., J. Cunich and O. Carter, Food Chem. 6:89 (1980).
18. Hesseltine, C.W., M. Smith, B. Bradle and Ko Swan Djien, Dev. Ind. Microbiol. 4:275 (1963).
19. Wang, H.L., E.W. Swain and C.W. Hesseltine, J. Food Sci. 40:168 (1975).
20. Hesseltine, C.W., M. Smith and H.L. Wang, Dev. Ind. Microbiol. 8:179 (1967).
21. Wang, H.L., D.I. Ruttle and C.W. Hesseltine, J. Nutr. 96:109 (1968).
22. Wang, H.L. and C.W. Hesseltine, in Microbial Technology, edited by H.J. Peppler and D. Perlman, Vol. II, 1979, p. 96.

[Received June 16, 1983]

Automated AOM Test for Fat Stability[1]

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ABSTRACT

A home-built version of the automated AOM test was used with Canola, corn, sunflower, olive and Crisco® oils, shortening and lard. The endpoint was found by measuring the conductivity of a solution of the exit gas from the reaction tube. Coefficients of variability of the samples ranged from 1.1% to 8.3%. The endpoint of the test was ca. 100 PV for Canola oil, ca. 200 PV for corn oil and 35 PV for lard. The aqueous solutions of the volatiles of three oils were used to determine the TBA value. Canola, sunflower and olive oil had TBA values ranging from 6-60 μg malonaldehyde/g at the end point. No apparent relationship was found between the TBA values of the volatiles' solutions and the PV's of the oils.

INTRODUCTION

The stability of fats is usually measured by the active oxygen method (AOM) described in the AOCS official method Cd 12-57 (1). This method suffers from the disadvantage of being time consuming, labor intensive and wasteful. Therefore, attempts have been made to come up with alternative tests and improved versions of the AOM.

Alternative tests have included procedures that involve the direct recording of oxygen absorption of fats. Systems of this type have been described by Marcuse and Remi (2) and Imaeda et al. (3). In addition, there is the well-known Schaal or oven test. These methods have been reviewed by Pardun (4). A good deal of effort has been devoted in recent years to automated versions of the AOM test. The most successful of these is the version based on the observation that in an oxidizing oil, volatile acids are formed at the end of the induction period. Loury (5) has described the mechanism of this reaction. He postulates the transitory presence of a diperoxide; this unstable compound decomposes into two aldehydes and formic acid. Oxidation of the aldehydes can also lead to formic acid. The volatile acids consist mainly of formic acid with small quantities of acetic and propionic acid. The air emerging from the oil in the AOM test can be led into water and the acids titrated potentiometrically or determined conductometrically. A curve obtained by potentiometric titration was published by Hadorn and Zürcher (6), and this curve demonstrated that the volatile acids formed in the AOM test can be used as a basis for automated endpoint detection. During the past few years, several papers have been published dealing with the use of formic acid formation as the basis of a simplified, automated AOM test. A potentiometric titration system was described by Pardun and Kroll (7). In their system, the oil bath of the AOM method was replaced by a metal heating block. This simplification was proposed as early as 1950 by Lips (8) and subsequently by Schroeder and Draper (9). Later versions of the equipment have generally been constructed with heating blocks instead of oil baths. Hadorn and Zürcher (6) used a system involving conductometric measurement of the AOM endpoint. This principle has now been included in a commercial version of the automated AOM test (Metrohm Ltd., CH-9100, Herisau, Switzerland).

[1] Presented at the 73rd AOCS Annual Meeting, Toronto, 1982.