Yield and Amino Acid Composition of Fractions Obtained During Tofu Production

H. L. WANG and J. F. CAVINS[1]

ABSTRACT

Five fractions are derived during processing of soybeans into tofu: soak water, water-insoluble residue, soymilk, tofu, and whey. Soak water and whey accounted for 14% of bean solids, 4.7% of bean protein, and a small amount of oil; the residue accounted for 30, 20, and 11%, and soymilk accounted for 63, 79, and 82%, respectively. Almost all of the soymilk oil and 90% of soymilk protein are converted into tofu. Consequently, 52% of solids, 71% of protein, and 82% of the oil in the soybeans were recovered in the tofu fraction. Amino acid composition varied considerably among the fractions, indicating the biological values of these fractions may differ. The residue that contained 27% protein had an essential amino acid to total amino acid ratio similar to that of tofu and soymilk and an oil content of only about 8%.

Cereal Chem. 66(5):359–361

Whole soybeans have been processed into a great number of palatable foods for centuries in the Orient (Wang et al 1979a). The most common practice is the hot-water extraction of wet-ground beans to yield a milk-like product known as soymilk. Soymilk is consumed as a beverage, but more often it is converted to curd or tofu by the addition of a calcium or magnesium salt. Tofu has a bland taste and is one of the traditional soybean foods that is gaining attention and general acceptance in the West.

Soybeans are valued for their high protein content, and when properly processed, the protein is of good quality. It is well established (Smith and Circle 1972, Wolf and Cowan 1975, Wilcke et al 1979) that processing procedures, such as physical and chemical treatments and fractionation, can greatly affect the nutritional quality, chemical composition, and functionality of the protein product. The variations of nitrogen in the fractions may be influenced more by the mechanics of fractionation than by changes in the original level of protein in the soybeans. However, much of the research has been conducted with defatted soymeal or with procedures that are quite different from those practiced in the tofu industry (Shurtleff and Aoyagi 1979). Rackis et al (1961) reported the amino acid composition of acid-precipitated protein, residue, and whey prepared from defatted soymeal without heat treatment. Hackler et al (1963, 1967a,b) compared the nutritional value and amino acid composition of acid-precipitated curd, heat-treated (100°C, 1 hr) soymilk, residue, and whey prepared from dehulled beans. The raw material, the heat treatment, and the coagulant used in these studies may be different from that used in the tofu industry due to the scale of the process.

This study was undertaken to evaluate the relative distribution and recovery of soybean solids, protein, and oil in fractions obtained from whole soybeans by a tofu processing procedure similar to the commonly used commercial procedure. The amino acid composition of each fraction was also evaluated.

MATERIALS AND METHODS

Preparation of Tofu on a Laboratory Scale

Three commercial soybean varieties, Vinton, Baird B31000, and Beeson 80, were used. Vinton and Beeson are varieties favored by many tofu producers.

Tofu was prepared by the method of Wang and Hesseltine (1982): 100-g portions of soybeans (as is basis) were washed, immersed in 300 ml of distilled water for 16 hr at room temperature (24–25°C), drained, and rinsed with distilled water. The combined liquid from soaking and rinsing was designated as soak water. The soaked beans were homogenized for 2 min in a Brinkmann homogenizer with the addition of enough water to give a ratio of dry beans to water, including that absorbed during soaking, of 1:10. The resulting slurry was brought to a boil and kept at boiling for 15 min. The hot slurry was then filtered through four-layered cheesecloth to separate the soymilk (water soluble) from the residue consisting of hulls and other insoluble materials. After the milk was cooled to about 70°C, it was poured into a calcium sulfate ($CaSO_4 \cdot 2H_2O$) suspension (10% volume of the milk) containing an amount of the salt, so that the final concentration of salt in the milk was 0.02*M*. After settling for 10 min, the curds were transferred to a cheesecloth-lined wooden box and pressed by placing weight (10 g/cm^2) on the top for 1 hr to separate whey from curd (tofu).

The processing of whole soybeans into tofu results in five fractions known as soak water, residue, soymilk, tofu, and whey. These fractions were collected and either freeze-dried or used directly for analyses.

Tofu preparation was carried out twice with each soybean sample.

Analytical Methods

The moisture content of each fraction was determined by drying a portion of freshly collected fraction to constant weight at 110°C. Micro-Kjeldahl analysis (AOAC 1975) was used to determine the crude protein (N × 6.25), and hexane extraction (5-hr butt tube, AOAC 1975) was used for oil content.

Amino Acid Analyses

Defatted freeze-dried samples were hydrolyzed for 24 hr by refluxing in 6*N* hydrochloric acid, evaporated to dryness, and dissolved in citrate buffer at pH 2.2. A portion of the hydrolysate with norleucine as internal standard was analyzed for amino acids with a Beckman model 330 liquid chromatography system employing ninhydrin detection. Data were computed by automatic data processing.

RESULTS AND DISCUSSION

Composition and Solids Recovery of Soybean Fractions

Data in Table I compare the composition of each fraction collected from tofu processing with that of the original beans. The percentages of total solids, protein, and oil recovered in each fraction are presented in Table II. All values represent averages of duplicate analysis on two different tofu preparations of each soybean sample.

Soak water and whey are dilute solutions and are considered as waste, although they have traditionally been used in animal feed. About 13.5–14.8% of total bean solids and 5.4–6.6% protein were lost from the original soybeans in these two fractions (Table II). Hackler et al (1963) reported losses of 16% solids and 9%

[1]Northern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, 1815 N. University Street, Peoria, IL 61604.

The mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.

protein in the whey fraction. Whey is derived during the coagulation of protein from soymilk; therefore, the coagulation conditions could affect the amount of solids and protein lost in the whey. Depending on the soybean variety and soaking conditions used, soaking alone has been reported to result in as much as 10% loss of solids, and the loss of solids as well as the ratio of protein to total solid is increased as soaking time and temperature are increased (Lo et al 1968, Wang et al 1979b).

The by-product residue contained an average of 83.0% water, 4.6% protein, and 1.3% oil. On a dry weight basis, it contained 27.1% protein and 7.6% oil. The residue accounted for 29.6% (27.6–30.6), 20.2% (17.8–22.3), and 11.4% (11.1–12.0) of original bean solids, protein, and oil, respectively. These values may vary with the extraction procedures and the method used to separate the solubles from the insolubles as well as with the soybean varieties. Among the three varieties tested, Vinton had the lowest percentage of unextracted protein. Smith et al (1960) reported 29% of the original bean solids recovered in the residue, but the protein recovered in the residue varied from 12.3 to 18.4%, with an average of 16.8% (seven varieties). Hackler et al (1963) found 23.5% of bean solids and 13.5% of bean protein in the residue fraction (one soybean sample).

The composition of milk is greatly affected by the amount of water used to extract the beans (Johnson and Snyder 1978). The milk we prepared contained 3.4% (3.1–3.5) protein and 1.7% (1.5–1.8) oil. The total solids recovered in the soymilk averaged 62.5% ranging from 60.4 to 64.7%. The respective amounts of extracted protein and oil were 78.8% (75.5–83.0) and 82.3% (78.7–84.6) of that in the beans. Hackler et al (1963) observed a 65% solids recovery and 83.0% protein recovery in the soymilk. In the present study, the soybean slurries were heat-treated before filtration. Heat treatment facilitates filtration; however, it almost certainly reduced protein solubility. Because of the low percentage of protein recovered in the residue prepared from Vinton beans, it is not surprising to find a high percentage of protein recovered in the milk fraction; this is a desirable characteristic of bean varieties for soymilk and tofu processing. These figures may vary with extraction and separation procedures as well as with bean variety.

Tofu is a highly hydrated product. As shown in Table I, tofu made in this study had a composition of 85.9% (84.9–87.3) water, 7.6% (6.5–8.8) protein, and 4.4% (4.1–4.6) oil and an average of 53.9% protein and 31.2% oil on a dry weight basis. The protein content varies with the protein content of the bean, but it is also affected by water content. The water content of tofu can vary significantly with the type and quality of coagulant used, coagulation conditions, and the method used to separate the whey (Wang and Hesseltine 1982). In agreement with previous findings (Smith et al 1960, Wang et al 1983), soybean varieties with high protein content (dry weight basis) yield tofu with high protein. Among the three varieties tested, tofu made from Vinton beans had the highest protein content: 58.3% (on dry basis) versus 53.5% from Baird beans and 51.2% from Beeson beans. The high percentage of extractable protein from Vinton beans apparently contributes to the high protein content of the resultant tofu. It is also known that protein extractability slowly decreases as the beans age (Smith and Circle 1972), so the storage time and conditions of the beans probably also affect the protein content of tofu.

Tofu yield averaged 52.2% (51.2–53.7) of solids in the original beans in this study. The protein and oil recovered in tofu amounted to 71.1% (68.5–75.8) and 82.4% (79.5–84.4) of that in the original beans, respectively. Smith et al (1960) reported an average of 46.1% solids and 62.7% protein. Hackler et al (1963) found 49% solids and 74% protein.

Tofu and whey fractions are prepared from soymilk. Results in Table II show that about 90.2% of the protein and almost all of the oil in soymilk were recovered in tofu, indicating an efficient coagulation procedure. As indicated in Table I, the residue has an average of 83.0% water. Perhaps the filtration procedure used in this process could be improved to separate more solubles from the residue and thus increase the yield of soymilk and tofu.

Amino Acid Composition of Soybeans and Soybean Fractions

The amino acid composition of soybeans and soybean fractions is given in Table III. The data were calculated to 100% nitrogen recovery and expressed in grams of amino acid per 16 g of nitrogen recovered. Fractions were identified as the major source of variations; therefore, data derived from three soybean samples were pooled. Thus, the values in Table III represent averages of six measurements, two for each soybean sample.

Results in Table III show that the residue, soymilk, and tofu were most limited in sulfur amino acids, whereas the whey protein was richer in these amino acids and may reflect the presence of a high percentage of trypsin inhibitor protein. The whey protein, however, is higher in lysine and lower in some of the other essential amino acids such as phenylalanine, isoleucine, leucine, and valine. Consequently, whey protein contained the lowest ratio of essential amino acids to total amino acids (E/T) among the fractions. Furthermore, only 83.5% of total nitrogen was recovered as amino acids nitrogen, indicating the presence of nonprotein nitrogen.

The residue, soymilk, and tofu had similar E/T ratios. The threonine and valine contents of the residue were somewhat higher than those found in soymilk and tofu. On the other hand, tofu had a higher phenylalanine but somewhat lower methionine

TABLE I
Composition (%) of Soybeans and Soybean Fractions Obtained During Tofu Preparation from Three Varieties of Soybeans

	Vinton			Baird			Beeson		
Fractions	**Moisture**	**Protein**	**Oil**	**Moisture**	**Protein**	**Oil**	**Moisture**	**Protein**	**Oil**
Whole soybeans	11.4	36.1	15.4	10.2	33.6	17.5	7.5	37.1	19.6
Soak water	99.0	0.1	nd[a]	98.8	0.1	nd	97.9	0.1	nd
Residue	82.9	4.5	1.2	82.7	4.8	1.3	83.5	4.4	1.3
Soymilk	93.4	3.5	1.5	93.3	3.1	1.7	93.2	3.5	1.8
Tofu	84.9	8.8	4.5	87.3	6.5	4.1	85.6	7.7	4.6
Whey	97.9	0.4	0.01	97.8	0.4	0.01	98.1	0.3	0.01

[a]Not detected.

TABLE II
Percentage of Total Solids, Protein, and Oil Recovered in Fractions Obtained During Tofu Preparation from Three Varieties of Soybeans[a]

	Vinton			Baird			Beeson		
Fractions	**Solids**	**Protein**	**Oil**	**Solids**	**Protein**	**Oil**	**Solids**	**Protein**	**Oil**
Soak water	3.6	0.9	trace	4.0	0.9	trace	5.1	1.9	trace
Residue	27.6	17.8	11.2	30.5	22.3	11.1	30.6	20.6	12.0
Milk	64.7	83.0	83.5	62.4	77.8	84.6	60.4	75.5	78.7
Tofu	53.7	75.8	83.2	51.2	69.1	84.4	51.4	68.5	79.5
Whey	11.2	5.7	trace	9.7	4.5	trace	8.4	4.0	trace

[a]Based on original soybeans.

TABLE III
Average Amino Acid Composition (g/16 g N) of Fractions from Three Soybean Varieties

Amino Acid	Soybeans	Soak Water	Residue	Soymilk	Tofu	Whey	LSD[a]
Aspartic acid	12.61	14.94	11.63	11.91	11.70	12.48	0.41
Threonine	4.11	4.53	4.42	4.01	4.00	4.52	0.15
Serine	5.74	5.13	5.47	5.19	5.32	4.15	0.16
Glutamic acid	19.76	17.68	17.71	19.61	19.26	23.62	0.57
Proline	5.53	5.28	5.66	5.33	5.47	4.14	0.25
Glycine	4.46	4.73	4.61	4.16	4.14	4.87	0.14
Alanine	4.49	4.61	4.36	4.14	4.11	4.42	0.22
Valine	3.73	4.92	5.28	4.88	4.99	2.65	0.24
Cystine	0.78	0.87	trace	0.03	trace	2.40	0.30
Methionine	1.34	1.72	1.67	1.59	1.43	2.61	0.16
Isoleucine	3.46	4.69	4.50	4.66	4.85	2.92	0.20
Leucine	7.90	6.90	8.31	7.94	8.32	3.89	0.20
Tyrosine	3.90	4.13	3.74	3.91	3.99	3.39	0.21
Phenylalanine	4.85	4.59	5.20	5.15	5.41	2.52	0.18
Lysine	6.19	5.45	6.36	6.08	6.14	8.56	0.40
Histidine	2.60	2.35	3.07	2.64	2.64	3.21	0.15
Arginine	8.64	7.27	8.61	8.65	8.52	9.69	0.65
E/T[b]	0.36	0.38	0.39	0.38	0.39	0.33	...

[a]Least significant difference ($P = 0.05$).
[b]Ratio of essential amino acids to total amino acids.

content than did the residue and soymilk. Because the sulfur amino acids are limiting in soybean protein, the differences in the amounts of sulfur amino acids may have a greater effect on the quality of the protein than do the differences in other essential amino acids.

The soak water protein had an unusually high aspartic acid content, and its threonine content was also higher than in other fractions except the residue. The lysine content of soak water was lower than other fractions. But like the whey fraction, the soak water also had a low nitrogen recovery as amino acids (84.8%), indicating the presence of nonprotein nitrogen.

Hackler et al (1963) studied the nutritional value of soybean fractions through a feeding study and reported that the residue was nutritionally superior to the other fractions. Although the residue obtained from our process has an E/T ratio comparable to that of soymilk and tofu, other factors such as the balance of essential amino acids and release of amino acids during digestion may affect the nutritional value. This by-product of tofu processing, which accounts for one-third of the original solids, could be a valuable food source. The American tofu industry uses the residue to make a fermented food known as tempeh and continues to develop other new food products. Whey has already been demonstrated to be a suitable fermentation substrate for xanthan gum (Kanda 1977) and vitamin B_{12} (Yongsmith and Apriaktivongse 1983). Soak water appears to be a good nitrogen source and perhaps could also serve as mineral source for growth of microorganisms. Similar to the use of corn steep liquor, soybean whey and soak water have the potential to become a widely used substrate in the fermentation industry. The use of soymilk and tofu as food has already been accepted in the West.

LITERATURE CITED

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. 1975. Official Methods of Analysis, 12th ed. The Association: Washington, DC.

HACKLER, L. R., HAND, D. B., STEINKRAUS, K. H., and VAN BUREN, J. P. 1963. A comparison of the nutritional value of protein from several soybean fractions. J. Nutr. 80:205.

HACKLER, L. R., and STILLINGS, B. R. 1967a. Amino acid composition of heat-processed soymilk and its correlation with nutritive value. Cereal Chem. 44:70.

HACKLER, L. R., STILLINGS, B. R., and POLIMENI, R. J. 1967b. Correlation of amino acid indexes with nutritional quality of several soybean fractions. Cereal Chem. 44:638.

JOHNSON, K. W., and SNYDER, H. E. 1978. Soymilk: A comparison of processing methods on yields and composition. J. Food Sci. 43:349.

KANDA, H. 1977. Xanthan gum. Jpn. Kokai 10:492.

LO, W. Y. L., STEINKRAUS, K. H., HAND, D. B., HACKLER, L. R., and WILKENS, W. F. 1968. Soaking soybeans before extraction as it affects chemical composition and yield of milk. Food Technol. 22:1188.

RACKIS, J. J., ANDERSON, R. L., SASAME, H. A., SMITH, A. K., and VanETTEN, C. H. 1961. Amino acids in soybean hulls and oil meal fractions. J. Agric. Food Chem. 9:409.

SHURTLEFF, W., and AOYAGI, A. 1979. Tofu and soymilk production. In: The Book of Tofu. Vol. 1. New-Age Foods: Lafayette, CA.

SMITH, A. K., and CIRCLE, S. J., eds. 1972. Soybeans: Chemistry and technology. Avi: Westport, CT.

SMITH, A. K., WATANABE, T., and NASH, A. M. 1960. Tofu from Japanese and United States Soybeans. Food Technol. 14:332.

WANG, H. L., and HESSELTINE, C. W. 1982. Coagulation conditions in tofu processing. Proc. Biochem. 17:7.

WANG, H. L., MUSTAKAS, G. C., WOLF, W. J., WANG, L. C., HESSELTINE, C. W., and BAGLEY, E. B. 1979a. Soybeans as Human Food—Unprocessed and Simply Processed. U.S. Dep. Agric. Util. Res. Rep. 5. U.S. Government Printint Office: Washington, DC.

WANG, H. L., SWAIN, E. W., HESSELTINE, C. W., and HEATH, H. D. 1979b. Hydration of whole soybeans affects solids losses and cooking quality. J. Food Sci. 44:1510.

WANG, H. L., SWAIN, E. W., KWOLEK, W. F., and FEHR, W. R. 1983. Effect of soybean varieties on the yield and quality of tofu. Cereal Chem. 60:245.

WILCKE, H. W., HOPKINS, D. T. and WAGGLE, D. H., eds. 1979. Soy Protein and Human Nutrition. Academic Press: New York.

WOLF, W. J., and COWAN, J. C. 1975. Soybeans as a Food Source. CRC Press: Cleveland, OH.

YONGSMITH, B., and APIRAKTIVONGSE, P. 1983. Vitamin B_{12} production from 'soybean curd whey with *Propionibacterium freudenreichii*. J. Ferment. Technol. 61:105.

[Received July 20, 1988. Accepted April 4, 1989.]