Tofu Production from Soybeans or Full-Fat Soyflakes Using Direct and Indirect Heating Processes

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ABSTRACT

We compared processing yield, composition, and quality of tofu from soybeans and from full-fat soyflakes. Tofu was made using a steam-jacketed kettle and a commercial steam-injected cooker. Hydration time was 10 min for flakes and 12h for whole beans. Regardless of cultivar, a higher tofu yield was obtained from the steam-injected cooker system than from the steam-jacketed kettle system. Utilization of flakes required 62-65% less water during soymilk production. Independent of cultivar, tofu produced from full-fat soyflakes was lower in fat (26% d.b.) than whole soybean tofu (40% d.b.).

Key Words: soybean, soyflakes, tofu

INTRODUCTION

SOYMILK IS AN INTERMEDIATE PRODUCT IN THE MANUFACTURE of tofu. It is often used in confections, meat fillers, beverages, and as part of infant formulas for children allergic to dairy milk (Wilson, 1995). There are two typical processing techniques for soymilk: the traditional method where beans are soaked and ground in cold water (Shurtleff and Aoyagi, 1979; Johnson and Wilson, 1984); and the hot-grind method where beans are soaked in cold water but ground in hot water. The hot grind process produces soymilk with less beany flavor (Wilkens et al., 1967), but with a lower % yield of solids and soymilk (Johnson and Snyder, 1978).

Ways to reduce soaking time for whole soybeans have been sought by soymilk and tofu manufacturers (Wilson et al., 1992). Dehulling beans and lowering the moisture decreases the bulk weight of the beans 9 to 11%, which would lower export cost. Full-fat soyflakes are produced by dehulling, flaking, and drying to 7-8% moisture. These flakes are traditionally used for the production of soybean oil, defatted flakes (white flakes), grits and flours (Witte 1995). Defatted flakes were found to produce tofu with lower yield and poorer texture than whole soybeans (Tsai et al., 1981).

Our objective was to compare the production and quality of tofu from whole soybeans with that from full-fat soyflakes.

MATERIALS & METHODS

Materials

Mixed cultivar XLRB, and "identity preserved organically grown" Vinton-81 and Corsoy whole soybeans and dehulled full-fat flakes (produced by "Patent #4895730, issued Jan. 23, 1990") were obtained during commercial soyflake production (Mycal Corporation of America, Jefferson, IA). The beans and their respective flakes were heat sealed in commercial polyethylene-paper-laminated flexible 20 kg bags and stored at 4°C until processed.

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Experimental design

Bags of whole soybeans or flakes were used to make a 5° Brix soymilk. The soymilk was coagulated and pressed to make U.S. firm style tofu. The study was divided into two parts. In the first part, XLRB whole beans and flakes were used to make soymilk and tofu with a steam-jacketed kettle and hydraulic-press (Indirect heating process). A complete randomized design (Kvanli, 1998) was used for each processing day which involved coagulating and pressing in duplicate 8-L batches of soymilk into tofu from beans and flakes. The second part was also a complete randomized design. It involved making soymilk and tofu by a Direct heating process using a pilot scale steam-injected soymilk and tofu machine (Takai Tofu & Soymilk Equipment Co. 1-1 Inari, Nonoichi, Ishikawa-ken 921, Japan) incorporating XLRB whole beans and flakes. Each processing day involved coagulating two 40-L batches of soymilk into tofu from beans and flakes. Identity preserved beans (Vinton-81 and Corsoy) and their respective flakes were used to study ease and quality of tofu production by the Direct heating process.

Compositions of raw materials, final product (tofu), and by-product (okara) were evaluated. Instrumental and sensory evaluation of tofu was used to describe quality and acceptability. Utilization of water was determined with an on-line flow meter. Percentage of water used in flake compared with bean processing, including cleanup of bean soaking tank and grinder, was calculated on an "as is" and "per kg raw soybean or soyflakes" basis as follows:

$$\% \text{ water saved} = (1-X/Y)\ 100$$

where X is the difference between soaking, grinding, additional water and cleanup of the soak tank/grinder of the flakes and Y is the soaking, grinding, additional water and cleanup of the soak tank/grinder for the beans.

Soymilk volume and °Brix were determined in order to achieve optimum coagulation for tofu (Johnson and Wilson, 1984). Amounts of tofu and of insoluble solids (okara) were weighed to determine product yields as follows:

$$\text{product yield} = x/y*100$$

where x was the product weight ("as is" basis), and y is the weight of raw material ("as is" basis).

Tofu production by indirect heating

From whole soybeans. The method standardized by Johnson (1984), and used by Rahardjo et al.(1994), was applied with some modification. Whole soybeans (0.90 kg) were soaked for 12h, drained, washed, and ground twice with 6L of cold tap water (15°C) in a Vibroreactor (Cherry Burrell, Clinton, IA). The resulting slurry was heated in a steam-jacketed kettle (Lee Metal Product Co., Inc., Philipsburg, PA) to 95°C, stirred constantly, and held at 95°C for 7 min to ensure maximum trypsin inhibitor destruction and inactivation of lipoxygenase (Wilkens et al., 1967). A 14 cm-dia propeller attached to an electric stirrer (Fisher Scientific, IL) was used to stir the cooking slurry at medium speed (360 rpm). The hot slurry was filtered through a nylon

100-mesh filter sack (Kawanishi Shoko Co. LTD, Los Angeles, CA). Okara left in the nylon filter sack was pressed using a hydraulic-press (Day Equipment Corp., Goshen, IN). The resulting soymilk was adjusted to 5°Brix and reheated to 85°C. Calcium sulfate dihydrate coagulant (0.019N) (Allied Custom Gypsum, Lindsay, OK) was suspended in a small amount of water, poured into the hot soymilk, and stirred vigorously. Coagulating soymilk was allowed to set for 2 min, cut, gently stirred, and allowed to set another 5 min. Coagulum and whey were poured into a stainless steel press box lined with a single layer of cheese cloth, to form tofu. A pressure of 0.02 kg/cm^2 was used to press the coagulum and whey for 15 min over a 400-cm^2 area. Tofu was removed from the press box, chilled for 10 min in cold water (10–15^{o}C), and stored in a sealed plastic container with water at 4°C. From full-fat soyflakes. Flakes (1.25 kg) were added to 8.125L of water and hydrated by stirring for 10 min at room temperature in the steam-jacketed kettle. Steam was applied and the soyflake slurry cooked, pressed, and coagulated following the same procedure as with whole beans.

Tofu production by direct heating

From whole soybeans.Soymilk and tofu were prepared using the Takai Automated Soymilk and Tofu System. The machine used a paddle mixer for hydrating and mixing the raw ingredients, a steam cooker for direct injection of high pressure culinary steam 2.81 kg/cm^2 into the slurry, and a roller extractor for removal of insoluble solids. This method was standardized by Wilson (1995), used by Ho et al.(1997), and modified as follows:

Whole beans (3 kg) were soaked for 12 h and washed. Water (40L @ 15°C) was used to grind the beans by passing it twice through a pilot scale wet grinder (Bean Machine, Model Corenco M8A, Bodega, CA) with a 0.500 mm screen. The resulting slurry was pumped into the paddle mixer and mixed for 5 min. After blending, the soy slurry was poured into the cooker, heated to 95°C, and held for 7 min before extraction. The hot slurry was pumped subsequently into a 120-mesh, horizontally rotating, cylindrical screen, where most of the soymilk was separated by gravity. The remaining insoluble solids were roller pressed over a 100-mesh screen drum. The soymilk was collected in a coagulation vessel and cooled to 85^{o}C and 0.019N calcium sulfate dihydrate (suspended in a small amount of water) was stirred into the hot soymilk. The system was pre-set to produce a 5±0.1 °Brix soymilk and the °Brix was verified for each batch. The coagulating batch was held for 2 min and the curds were re-stirred gently to ensure complete dispersion of coagulant through the remaining soymilk. The batch was held another 5 min and ladled onto a cheese cloth-lined press box. The tofu was pressed incrementally by an air press (Model AD-DB 141-02, Toyooki Kogyo Co. Ltd., Japan) for 2, 4, and 6 kg/cm^2 of pressure. Pressure was held for 5 min at each increment and applied over a 2125-cm^2 area. Tofu was removed from the press box, weighed, cut into ~500g rectangular blocks, chilled for 10 min in cold water (10-15°C), and stored in a sealed plastic container with water at 4°C.

From full-fat soyflakes. Soyflakes (4.03 kg) were added to 40L of cold tap water (15^{o}C) and mixed with a paddle mixer for 10 min. A preliminary study determined that 10 min was optimum to hydrate and disperse the soyflakes in water (data not shown). From the paddle mixer, the raw slurry was poured into the steam cooker. Then the procedure followed was as described in making tofu from whole beans using the Direct heating process.

Proximate analysis. Moisture was determined using method 925.10.(AOAC, 1990). Crude protein analysis was performed using the Kjeldahl methods 955.04(c) and 954.01 (AOAC, 1990), with Copper (II) Selenite dehydrate as catalyst (for environmental reasons). Percentage oil was determined with a Goldfisch extractor, using method 30-25 (AACC, 1983).

Sensory evaluation of tofu

Refrigerated tofu blocks were cut into 2-cm cubes and steamed in a vegetable steamer over an electric range for 2 min before serving (Johnson, 1984). Samples were served on paper plates coded with random 3-digit numbers. Panelists received one cube from each batch of tofu, a total of 4 cubes per sensory day (2 from soyflakes and 2 from whole soybeans).

A 60-member untrained panel consisting of multinational students, faculty, and staff of the Dept. of Food Science & Human Nutrition at Iowa State Univ. evaluated the preference of the tofu from each processing treatment. Samples were evaluated on unstructured 15-cm line scale score cards for texture preference, flavor preference and overall preference (Meilgaard et al., 1991). The panelists were also asked to comment on color, flavor, and texture of the tofu. Samples were served in individual booths under white fluorescent lights. Unsalted crackers and water at room temperature were provided to cleanse the palate between samples.

Instrumental evaluation of tofu

Texture profile analysis (TPA). Texture differences among tofus were evaluated by a Universal Testing Machine (model 1122, Instron Corp., Canton, MA) equipped with a 57-mm dia compression head (Bourne, 1978). Samples were cut in 2-cm cubes and compressed to 20% of their original height (80% compression) twice. The cross head and chart speeds were 100 mm/min. A 50-kg load cell was used, and a minimum of 3 observations were made with a 5-kg full-scale setting.

Hunter color evaluation. Samples from each batch of soymilk and tofu were evaluated for color using a 5100 Lab Scan (Hunter Lab, Fairfax, VA). The instrument was standardized using black and white tiles wrapped in a layer of Saran Wrap® with specular component included, F illuminant, 10^o standard observer, and 10-mm port size. The samples were sliced smoothly to fit petri-dishes (5-cm dia) and were covered by a single layer of Saran Wrap. Readings were collected from 3 areas on each sample surface. Results were expressed as L, a, and b values.

Statistical analysis

Treatments were repeated on 3 days. Tofus were analyzed in triplicate for composition and quality. Data were analyzed using the General Linear Model procedure (GLM), and differences among treatment means were evaluated by Least Significant Differences (LSD). Significance of differences was defined at P 0.05 (*Statistical Analysis Systems, version 6.03* (SAS Institute, Inc., 1985).

RESULTS & DISCUSSION

Compositional analyses of raw products

Soyflakes were lower ($P<0.05$) in moisture and higher in oil than their whole bean counterparts (Table 1). Wolf and Cowan (1975) reported that the hull consisted of 8% of the total bean composition. The hulls, however, contain 1% fat; so removal of hulls during flaking resulted in flakes with a higher concentration of fat than that in whole beans. Proximate compositions of XLRB, organic Vinton-81 and Corsoy raw beans and flakes were compared (Table 1). Generally soyflakes were 34% drier, 28% higher in fat, and 16% higher in protein than whole soybeans.

Tofu yield by processing method and cultivar

Yields of tofu from whole beans were not different from those of flakes with the XLRB cultivar in Indirect heating (Table 2). Using identical coagulation temperature and stirring conditions, production of tofu by Direct heating, however, resulted in a 12% higher yield for whole-bean tofu than for flake tofu (Table 2). Curds from coagulated whole bean soymilk were larger than those from coagulated soymilk from flakes. The larger curds trapped more whey, which resulted in higher yields for whole bean tofu. The yield differences between Indirect and Direct heating process, when using a mixed cultivar (XLRB), could be due to the size of the soymilk batch (8L Indirect heating vs 30L Direct heating) or to the pressing methods (Indirect

Table 1—Raw product composition by cultivar

Cultivar	Type	Moisture %	Oil % (db)[a]	Protein % (db)[a]
XLRB	Beans	10.01*	17.26*	35.46
XLRB	Flakes	6.43*	25.00*	37.70
Vinton-81	Beans	10.88*	12.62*	40.42*
Vinton-81	Flakes	6.25*	19.69*	42.83*
Corsoy	Beans	9.70*	17.61*	34.96*
Corsoy	Flakes	7.32*	21.10*	51.72*

[a]Dry basis.
*Significantly different (P<0.05) within a column and cultivar.

Table 2—Tofu yields by cultivar

Bean cultivar	Heating process	Soybeans (% yeild)	Soyflakes (%yield)
XLRB	Indirect	174	174
XLRB	Direct	276*	242*
Vinton-81	Direct	224	233
Corsoy	Direct	264	248

*Significantly different (P<0.05) within a row.

Table 3—Tofu and okara composition by processing method

Cultivar	Type	Product	Heating process	% Moisture	% Fat (db)[a]	% Protein (db)[a]
			A			
XLRB	Beans	Tofu	Indirect	74.14*	39.98*	42.76*
XLRB	Flakes	Tofu	Indirect	76.00*	23.93*	47.16*
XLRB	Beans	Okara	Indirect	82.97*	14.81*	18.32*
XLRB	Flakes	Okara	Indirect	70.12*	33.35*	23.94*
			B			
XLRB	Beans	Tofu	Direct	84.93	28.48*	49.06
XLRB	Flakes	Tofu	Direct	83.66	18.64	48.30
XLRB	Beans	Okara	Direct	78.34	5.71*	20.09
XLRB	Flakes	Okara	Direct	77.73	11.69*	19.99
Vinton-81	Beans	Tofu	Direct	79.79	22.74*	56.10
Vinton-81	Flakes	Tofu	Direct	79.31	15.28*	55.38
Vinton-81	Beans	Okara	Direct	79.74	6.09*	18.50*
Vinton-81	Flakes	Okara	Direct	78.69	8.14*	21.38*
Corsoy	Beans	Tofu	Direct	85.70	29.78*	52.45
Corsoy	Flakes	Tofu	Direct	84.54	17.55*	51.18
Corsoy	Beans	Okara	Direct	79.59	6.58	19.63
Corsoy	Flakes	Okara	Direct	77.83	8.93	19.64

[a]Dry basis.
*Significantly different (P<0.05) within a type and method.

Table 4—Sensory evaluation of tofu from direct or indirect heating processes

Cultivar	Type	Heating	Flavor preference[a]	Texture preference[b]
XLRB	Beans	Indirect	7.41	8.26*
	Flakes	Indirect	7.40	7.29*
	Beans	Direct	6.60	5.96*
	Flakes	Direct	7.23	7.05*

[a]Flavor preference: disliked = 0.00, liked = 15.00.
[b]Texture preference: disliked = 0.00, liked = 15.00.
*Significantly different (P<0.05) within the method.

Table 5—Texture profile analyses of tofu

Cultivar	Type	Heating process	Cohesive-ness	Fractur-ability (kg)	Gummi-ness	Hardness (kg)
XLRB	Beans	Indirect	0.33	1.74*	1.26	3.96
	Flakes	Indirect	0.32	1.37	1.23	3.68
	Beans	Direct	0.29	0.55*	0.49	1.64*
	Flakes	Direct	0.29	0.78	0.69	2.20

*Significantly different (P< 0.05) within the method.

heating 0.02 kg /cm^2 applied for 5 and 10 min, vs Direct heating 2 to 4 to 6 kg /cm^2 applied incrementally at 5-min intervals). Identity preserved beans such as organically grown Vinton-81 and Corsoy did not show a yield difference between bean and flake tofus under Direct heating. This indicated that identity-preserved beans in both forms (beans and flakes) would retain their whey similarly during the tofu pressing stage (Table 2). Direct heating process produced a 28% higher yield than Indirect heating when using mixed cultivar XLRB. Overall, the use of soyflakes in place of whole beans produced 8% less okara (Table 2) and 15% more tofu.

Indirect heating process

Compositional evaluation of tofu and okara. Soyflakes tofu contained 2% more moisture, 9% more protein, and 40% less fat than whole bean tofu (d.b.) (Table 3A). Soyflake okara was drier, had 23.5% more protein, and had 43.0% more oil than whole bean okara. The difference in fat contents could be due to the absence of hulls in the flakes. During pressing of the hot slurry (90-95°C), the hulls may act as a filtering aid by providing channels for the fat from the cells to be released into the soymilk. The absence of the hull (in flakes) may cause caking of the insoluble matter, leaving very few channels for the fat to escape.

Sensory and instrumental properties of tofu. Panelists preferred the whole bean tofu over the flake tofu (Table 4A). Based on comments, panelists did not observe color or beany flavor differences between whole bean and flake tofu so preference could be related to texture. They commented that the flake tofu was softer than whole bean tofu, which was consistent with the higher flake tofu moisture (Table 3A). The TPA showed that flake tofu was 21% more fracturable than whole bean tofu (Table 5). Although Hunter Color Lab Scan (Table 6) showed that whole bean tofu was lighter and less red than its counterpart soyflake tofu, this difference was too slight to be detected visually.

Direct heating process

Compositional evaluation of tofu and okara. Tofus from XLRB soyflakes contained 35% less fat than tofus from whole beans (Table 3B). No significant differences in protein or moisture existed between bean and flake tofus. These results supported the findings for the Indirect heating process, which incorporated the kettle and hydraulic-press system. The flake okara composition (Table 3B) contained >50% more fat than the corresponding bean okara when the XLRB cultivar was used. Although the pressing of okara in Direct heating process was done by drum-roller extraction there were no differences in okara moisture and protein. This could be attributed to the more efficient extraction method in the Direct heating process. The tofu from soyflakes (Table 3A & B) under both methods contained 35-40% less fat (d.b.) than that from whole beans.

Proximate compositions of tofus from XLRB, Vinton-81, Corsoy raw beans, and their respective flakes were compared (Table 3B). Tofus from Vinton-81 and Corsoy flakes had 33% and 26% less fat respectively than their whole bean counterparts.

Sensory and instrumental properties of tofu

Under each method, no differences in flavor preference scores were found between bean and soyflake tofus (Table 4). Panelists preferred the texture of flake tofu under Direct heating which they commented was firmer than the whole bean tofu. This was in contrast to the Indirect heating process, where the panelists preferred the firmer bean tofu over the flake tofu. The TPA results showed that flake tofu under the Direct heating process had higher hardness, fracturability, and brittleness than whole bean tofus (Table 5). Textural preference may be related more closely to firmness than to the raw material (beans or flakes).

Table 6— Evaluation of tofu color

Cultivar	Type	Heating process	L[a]	a[b]	b[c]
XLRB	Beans	Indirect	81.26*	0.38*	10.75
	Flakes	Indirect	77.35*	0.87*	11.53
	Beans	Direct	80.38	1.52	12.79
	Flakes	Direct	81.93	0.88	11.85*

[a]L (0.00 = dark black, 100.00 = white).
[b]a (+ = red, - = green).
[c]b (+ = yellow, - = blue).
*Significantly different (P<0.05) within the method.

Table 7—Water usage during tofu process

Heating process	Water usage (L)	Actual bean to tofu	Actual flake to tofu	Per kg of beans to tofu	Per kg of flakes to tofu
Indirect	Soaking	2.7	8.125	3.00	6.50
Indirect	Grinding	6.0	0.0	6.67	0.00
Indirect	Addn water	2.0	0.0	2.22	0.00
Indirect	Cleanup soak tanks/grinder	5.0	0.0	5.00	0.00
Total		15.7	8.125	16.89	6.50
Water saving using indirect heating		**48%**		**62%**	
Direct	Soaking	10.0	40.0	3.33	7.44
Direct	Grinding	40.0	0.0	13.30	0.00
Direct	Addn water	1.1	1.1	0.37	0.27
Direct	Cleanup soak tanks/grinder	5.0	0.0	5.00	0.00
Total		56.1	41.1	22.0	7.71
Water saving using Direct heating		**27%**		**65%**	

Evaluation of color using the Hunter Lab Scan showed no differences in degree of lightness ("L" value) or redness ("a" value) between bean and flake tofus (Table 6). There was a 7% difference in yellowness ("b" value), however, that was too slight to differentiate visually.

Water usage for tofu production

Producing flake tofu by the Indirect heating process required 48% less water ("as-is" basis) or 62% less water/kg raw ingredient than producing tofu from whole beans (Table 7). Similarly the Direct heating process used 27% less water ("as-is" basis) or 65% less water/ kg of raw ingredient. The water usage for cleanup of the processing room was identical for both processes and was not included. The major differences were that processing with soyflakes did not require disposal of the soaking tank water and clean up of the soaking tank and grinder.

CONCLUSION

MANUFACTURING SOYMILK AND TOFU FROM SOYFLAKES WAS faster than manufacturing from whole soybeans, (10 min hydration vs. 12 h for whole beans). The omission of prolonged hydration and grinding in flake tofu production decreased water usage.

Tofus produced from soyflakes by either Direct or Indirect heating methods were lower in fat than those from whole soybeans, regardless of bean cultivar. Okara from soyflakes produced by Direct or Indirect heating methods were higher in fat than those from whole soybeans. Panelists did not differentiate color, flavor, or flavor preference between tofus made with either method from whole soybeans or flakes. Regardless of method or raw material, panelists preferred firmer textured tofu. Thus soyflakes are a viable alternative to whole beans for production of soymilk and tofu.

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