Yield and Quality of Tofu Made from Soybeans and Soy/Peanut Blends

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The yield and quality of tofu made from blends of soybeans and raw peanuts, partially defatted peanut flour, and defatted peanut flour were investigated. Defatted peanut flour appears to be the most compatible with soybeans for tofu making, followed by partially defatted peanut flour and raw peanuts. Raw peanuts could be incorporated at levels of 10% while partially defatted or defatted peanut flour could be incorporated at a level of 20%: higher levels produced tofu with either poor texture or low yield.

SEM images of tofu made from 100% soybeans showed a uniform, continuous, three-dimensional honeycomb-like protein network structure. When 10% of the soybeans was replaced by either raw peanuts; partially defatted peanut flour; or defatted peanut flour, the protein strands that make up the network structure were thicker than those of 100% soybean tofu. When soybeans were replaced with either of the three peanut products at a 30% level, the protein strands of the network structure were either less continuous or appeared perforated.

Tofu is an important part of the food supply in the Orient. It is made by coagulating hot soymilk with a coagulant followed by molding and pressing of the coagulated curds to remove whey. Good quality tofu should be uniform and smooth in appearance, moderately hard and firm in texture in order to resist breakage during handling.

Tofu produced by the traditional Oriental method has a distinct beany flavor that is acceptable to Orientals but is disliked by Western consumers. The flavor profile of conventionally prepared soymilk is complex and is mainly the result of the action of lipoxygenase and possibly other enzymes on the lipids during soaking and wet grinding of the beans prior to heating. Various processes to reduce the beany flavor have been developed which involve the application of heat during grinding of the beans to inactivate the lipoxygenase enzymes (1-4).

As tofu is a blend product, addition of other acceptable protein-rich food materials such as peanuts may improve the taste and enhance consumer acceptability. However, factors such as protein-protein interactions and the compatability of this system have not been studied. The objective of this study was to investigate the effect of adding raw peanuts and peanut flour on the yield, texture and microstructure of tofu.

MATERIALS AND METHODS

Materials. Soybeans of the variety Corsoy (Maple City brand) were purchased from Chatham Beans 66 Ltd. (Chatham, Ontario, Canada). Ontario-grown raw peanuts were purchased from a local supplier. Partially defatted untoasted peanut flour 100 series was supplied by Seabrook Blanching Corp. Albany, Georgia 31701. The peanuts were hydraulically pressed to remove approximately 55% of the oil. Defatted peanut flour was supplied by Dr. S.S. Koseoglu of the Food Protein R&D Center, Texas A&M University. The defatted flour was obtained by hexane extraction of hydraulically pressed peanuts. All materials were kept at 10°C until used.

Statistical analysis. The experiment was a completely random design (5). All analyses were carried out in triplicate, except yield of tofu, whey volume and texture of tofu which were the mean of 6 measurements. Statistical significance of the effect of peanut addition on the yield and quality of tofu was tested using the analysis of variance procedures (ANOVA). Separation of means using the least significant difference (LSD) was carried out when the F-value was significant. Differences between mean values with $p<0.05$ were considered statistically significant. ANOVA and LSD were performed using the ANOVA procedure of the Statistical Analysis System (6).

Preparation of samples for analysis. Soybeans were ground in a Wiley mill to pass through a 20 mesh sieve. Raw peanuts were ground at low speed in a blender. All of the ground samples were then dried in an air oven at 100°C to constant weight. Both the soymilk and tofu samples were freeze-dried by using a Stokes freeze dryer (Pennsalt Chemicals Corp., Philadelphia, PA, U.S.A.), and then ground to a powder using a porcelain mortar and pestle. The samples were further dried in an air oven at 100°C to constant weight. All of the dried samples were stored in air-tight plastic bags in a desiccator.

Preparation of soymilk. A total of 150 g soybeans was soaked overnight (16 hr) in 500 mL of distilled water at 20°C. The soaked beans were drained, rinsed and blended with 375 mL of distilled water in a commercial Waring blender for 2 min at high speed, followed by the addition of 200 mL of boiling water and blending at high speed for another 2 min. The resultant slurry was strained through a small centrifugal juice extractor (Golden Harvest Juicer, model 120215, supplied by Natural Sales Co., P.O. Box 25, Pittsburgh, PA 15230, U.S.A.) lined with filter cloth. The final volume of soymilk was adjusted to 1000 mL with distilled water. When a portion of the soybeans was replaced by raw peanuts, both were soaked together before processing into soymilk. When peanut flour was used to replace part of the soybeans, it was added to the soaked beans before the initial blending process. The volume of the distilled water used for soaking soybeans was reduced proportionally when less than 150 g of soybeans was used.

Preparation of tofu. A total of 300 mL of fresh soymilk was heated to boiling on a hot plate with constant stirring. A suspension of 2.7 g calcium sulfate ($CaSO_4 \cdot 1/2H_2O$) in 7.5 mL of distilled water was prepared. The hot soymilk and coagulant were poured simultaneously into a 500 mL plastic container ensuring mixing without stir-

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ring. The plastic container had a removable lid, and the base was cut off so that it could be used in the inverted position. The curd was left at ambient temperature to coagulate for 15 min before transferring to a perforated plastic container lined with cheesecloth. During transfer, the open ends of both containers faced each other, and transfer without breakage was achieved when the removable lid was lifted. The top of the curd was then covered with cheesecloth and a weight was applied on the top to give a pressure of 15.7 g/cm^2 for 15 min. The weight of freshly formed tofu and the volume of pressed whey were recorded. Tofu yield was expressed as kg tofu per kg of material (dry basis) used.

Moisture determination. Moisture content of the tofu was determined by drying 5 g of freshly prepared tofu at 110°C in an air oven to constant weight (7). Moisture content of the soybeans and raw peanuts were determined by drying in a forced draft air oven at 130° ± 3°C for 3 hr (8,9). The moisture content of the partially defatted and defatted peanut flour was determined by drying in a forced draft oven at 130° ± 3°C for 2 hr (10).

Total solids determination. Total solids of the whey and soymilk were determined according to the A.O.A.C. method (11). About 5 g of the sample in an aluminum dish was heated on a steam bath for 10 to 15 min followed by further heating in an air oven for 3 hr at 98 to 100°C. The sample was then cooled in a desiccator and weighed quickly. The residue was reported as % total solids.

The pH measurement. The pH of the soymilk was measured by using a Fisher Accumet pH meter (model 825 MP) fitted with Fisher universal glass pH electrodes. Commercially prepared buffer solutions of pH 4.00 and 7.00 (Fisher Scientific) were used to standardize the pH meter.

Determination of protein. The total nitrogen contents of the soybeans, raw peanuts, peanut flour, freeze-dried tofu and freeze-dried soymilk were determined by using a Technicon AutoAnalyzer II system. The determination of nitrogen is based on a colorimetric method in which an emerald-green color is formed by the reaction of ammonia, sodium salicylate, sodium nitroprusside and sodium hypochlorite in a buffered alkaline medium at a pH of 12.8 to 13.0 (12). The ammonia-salicylate complex formed was then read at 660 nm. The protein content of the soybeans, freeze-dried tofu and soymilk was obtained by multiplying the total nitrogen by the factor 6.25. The protein content of the raw peanuts and the peanut flour was obtained by multiplying the total nitrogen by the factor 5.46. Nitrogen solubility index (NSI) was determined according to the AOCS method Ba 11-65.

Determination of fat. Fat contents of the soybeans, raw peanuts and peanut flour were determined by extraction with ether (13, 14) using a Tecator extraction unit (RaFaTec). Fat contents of freeze-dried soymilk and tofu were determined by the Roese-Gottlieb ether extraction method (15) using a Mojonnier fat and solid tester, model D (Mojonnier Bros. Co., Chicago, U.S.A.).

Determination of ash. Ash contents of the soybeans, raw peanuts, peanut flour and freeze-dried tofu were determined as the residue remaining after incineration in a Lindberg electric muffle furnace at 600 ± 15°C for 2 hr (16).

Determination of carbohydrates. Carbohydrate contents of the soybeans, raw peanuts, peanut flour and freeze-dried tofu were determined by difference (% carbohydrate = 100 - % protein - % fat - % ash).

Texture of tofu. The texture of the tofu was evaluated by using an Instron Universal Testing Machine (model TM) with a Sensotec load cell (capacity 5 kg) and a Daytronic 9000 strain gauge conditioner-indicator (Daytronic Corp., Miamisburg, OH, U.S.A.). The signal voltage was fed to an A-D Converter linked to an Apple IIe computer. The instrument output was stored on a floppy disk and analyzed using a texture program developed by the Engineering and Statistical Research Centre, Agriculture Canada, Ottawa. Cylindrical samples (20 mm diameter, 20 mm height) were prepared from the tofu with a stainless-steel boring tube and wire cutter. (Samples were compressed by a cylindrical flat plate (39 mm diameter) to 50% deformation using a crosshead speed of 10 mm/min. The hardness was expressed as the peak force (N) obtained during 50% deformation and the firmness (N/mm) was the slope of the stress-deformation curve.

Microstructure of tofu. A scanning electron microscope (Hitachi S-570) fitted with a cryo unit (Emscope SP2000A system) was used to examine the fine structure of tofu. Small pieces of tofu (about 2mm cube) were taken from the center of a tofu sample and mounted on specimen stubs with Tissue-Tek embedding medium (Emscope Laboratories Ltd.). The sample was frozen promptly by plunging into liquid nitrogen slush at -210°C. It was then transferred under vacuum to the preparation chamber of the cryo unit and cryofractured with an installed knife. The ice coating on the sample surface was removed by exposing the sample for 20 min of sublimation at -80°C. The sample was then sputter-coated in the cryo unit with a thin layer of gold/palladium (60:40) to eliminate surface charging. The coated stage sample was transferred directly under vacuum to the cold stage of the scanning electron microscope by a transfer device attached to the cryo unit. Observations were made at 5 to 10 KV and at approximately -180°C.

RESULTS AND DISCUSSION

Chemical compositoin of raw materials. Table 1 compares the chemical composition of the soybeans, raw peanuts, partially defatted peanut flour and defatted peanut flour used in this study. The soybeans contained nearly twice the amount of protein but less than half the amount of fat present in the peanuts. The partially defatted peanut flour contained less protein but more fat than the soybeans. However, the defatted peanut flour contained more protein but less fat than soybeans. The carbohydrates of soybeans consist of sugars, gums and pectins (17). Peanuts contain, on the average, 4% starch with the remainder of the carbohydrates consisting of disaccharides, pentosans and crude fiber (18).

Tofu made from blends of soybeans and raw peanuts. Table 2, which also includes soy-peanut milk, whey and tofu obtained from different blends of soybeans and raw peanuts, gives the properties and chemical composition of soymilk. The total solids contents of the whey and soymilk made from blends of soybeans with 10 and 20% of raw peanuts were not significantly different from the 100% soybean products. This indicates that the solids of the peanuts were extracted into the soymilk. Replacing 20% of the soybeans with peanuts significantly decreased the pH of the soymilk. Therefore, peanuts contain more acidic groups than soybeans.

TABLE 1

Proximate Analyses of Raw Materials Used To Study the Effect of Peanut Addition on the Yield and Quality of Tofu[a]

	Soybean[b]	Peanut[c]	Peanut flour[d]	Peanut flour[e]
Moisture (%)	13.27	6.74	5.80	8.50
Protein (%, db)	39.80	20.63	34.43	53.17
Fat (%, db)	19.78	50.98	32.47	1.01
Ash (%, db)	5.30	2.70	3.42	4.50
Carbohydrate (%, db)	35.12	25.69	29.68	41.32

[a]Mean of 3 determinations, db = dry basis.
[b]Corsoy variety.
[c]Raw, Ontario grown.
[d]Partially defatted.
[e]Defatted.

TABLE 2

Properties of Soymilk, Whey and Tofu Made From Blends of Soybeans (SB) and Raw Peanuts (PN)

	100%SB	90%SB + 10%PN	80%SB + 20%PN
Soymilk			
pH	6.55[a]	6.53[a]	6.46[b]
Total solids (%)	9.09[a]	8.96[a]	8.89[a]
Protein (%,db)	51.38[a]	47.56[b]	45.38[c]
Whey			
Volume (ML)	82[c]	104[b]	134[a]
Total solids (%)	2.78[a]	2.75[a]	2.71[a]
Tofu			
Fresh yield (kg/kg material)	4.69[a]	4.23[b]	3.54[c]
Moisture (%)	87.05[a]	85.84[b]	83.81[c]
Peak Force(N)	1.65[b]	1.80[a]	1.66[b]
Firmness (N/mm)	0.30[a]	0.26[b]	0.24[b]
Protein (%, db)	50.23[a]	47.24[b]	45.19[c]
Fat (%, db)	20.14[c]	25.91[b]	30.52[a]
Ash (%, db)	11.84[a]	11.06[b]	10.24[c]
Carbohydrate (%, db)	17.79[a]	15.79[b]	14.04[c]

Values in row with the same superscript are not significantly different ($p>0.05$).

Compared with the soymilk and tofu made from 100% soybeans, the protein content of both the soymilk and tofu decreased significantly when 10 and 20% of the soybeans were replaced with peanuts. This is because the peanuts contained about one-half of the amount of protein present in soybeans (Table 1).

Compared with the whey volume of tofu made from 100% soybeans, substituting 10 and 20% of the soybeans with peanuts increased the volume of the whey by more than 25 and 60%, respectively (Table 2). Therefore, the interactions of the components of soybean and peanuts had decreased the water-holding capacity of the tofu. This has also resulted in a significant decrease in the moisture content and the fresh yield of tofu made from the soy-peanut blends (Table 2). Compared with the tofu made from 100% soybeans, replacing 20% of the soybeans with peanuts caused a decrease in the fresh yield of tofu of about 25%. Such a large reduction in the fresh yield of tofu is economically unacceptable.

Tofu made from soy/peanut blends contained a significantly higher fat content than tofu made from 100% soybeans (Table 2). This is due to the higher fat content of peanuts (Table 1).

Tofu made from soy/peanut blends also contained a significantly lower amount of carbohydrate and ash than the tofu made from 100% soybeans. This is because raw peanuts contain less ash and carbohydrate (Table 1).

Substituting 10% of the soybeans with peanuts produced tofu with a significantly harder texture (as measured by the peak force at 50% deformation) than tofu made from 100% soybeans (Table 2). When compared with tofu made from 100% soybeans, the hardness of tofu made from a blend of 80% soybeans and 20% peanuts was not significantly different. Therefore, partial substitution of soybeans by peanuts initially caused an increase and then a decrease in the hardness of tofu as increasing levels of substitution were used. The firmness of tofu made from the soy/peanut blends was significantly lower than that of the tofu made from 100% soybeans (Table 2). The increase in hardness of tofu from 90% soybeans and 10% peanuts was not followed by a corresponding increase in firmness.

The results obtained indicate that, under the conditions used in this study, satisfactory tofu can be made from a blend of soybeans and peanuts (10%). Higher levels of peanut substitution are not recommended, as a lower yield and less firm tofu is likely to result.

Tofu made from blends of soybeans and partially defatted peanut flour. The raw peanuts used in this study contained about 51% (db) fat (Table 1). It was not known whether peanut products with lower fat content would give a higher yield of tofu. Therefore, the effect of substituting soybeans with partially defatted peanut flour on the yield and quality of tofu was studied. The partially defatted peanut flour contained about 18% less fat but 14% more protein than the raw peanuts (Table 1). Partially defatted peanut flour had less moisture, protein, ash, and carbohydrate but more fat (by about 13%) than the soybeans (Table 1).

The properties of soymilk, whey and tofu made from soybeans and soy/partially defatted peanut flour blends are shown in Table 3. The pH values of soymilk made from the different soy/partially defatted peanut flour blends were significantly lower than the soymilk made from 100% soybeans. There was, however, no significant difference between the pH of the soymilk made from the different soy/partially defatted peanut flour blends (Table 3).

Replacement of 20 and 30% of the soybeans with partially defatted peanut flour yielded soy/peanut milk with significantly higher total solids content than soymilk made from 100% soybeans (Table 3). This indicates a more efficient extraction of soluble solids from the partially defatted peanut flour.

Since the partially defatted peanut flour contained less protein than the soybeans, the protein contents of soymilk and tofu made from the soy/partially defatted peanut flour blends were significantly lower than those of the soymilk and tofu made from 100% soybeans (Table 3).

The fat content of tofu made from blends of soybeans with 20 and 30% of partially defatted peanut flour was significantly higher than that of the tofu made from 100%

TABLE 3

Properties of Soymilk, Whey and Tofu Made From Blends of Soybeans (SB) and Partially Defatted Peanut Flour (PDF)

	100%SB	90%SB + 10%PDF	80%SB + 20%PDF	70%SB + 30%PDF
Soymilk				
pH	6.55[a]	6.44[b]	6.45[b]	6.45[b]
Total solids (%)	9.09[a]	9.29[a,b]	9.45[a]	9.46[a]
Protein (%,db)	51.38[a]	50.38[b]	49.56[c]	48.91[c]
Whey				
Volumes (ML)	82[b]	91[a]	93[a]	94[a]
Total Solids (%)	2.78[b]	2.82[b]	2.84[a]	2.96[a]
Tofu				
Fresh yield (kg/kg material)	4.69[a]	4.50[b]	4.45[b]	4.42[b]
Moisture (%)	87.05[a]	85.53[b]	84.91[b]	84.08[c]
Peak Force(N)	1.65[d]	1.89[a]	2.07[a]	1.72[c]
Firmness (N/mm)	0.30[a]	0.25[b]	0.23[c]	0.20[d]
Protein (%, db)	50.23[a]	45.50[b]	44.86[b]	42.70[c]
Fat (%, db)	20.14[c]	20.77[c]	22.05[b]	26.76[a]
Ash (%, db)	11.84[a]	10.96[b]	10.51[b,c]	10.18[c]
Carbohydrate (%, db)	17.79[c]	22.77[a]	22.59[a]	20.36[b]

Values in row with the same superscript are not significantly different ($p>0.05$).

TABLE 4

Properties of Soymilk, Whey and Tofu Made From Blends of Soybeans (SB) and Defatted Peanut Flour (DF)

	100%SB	90%SB + 10%DF	80%SB + 20%DF	70%SB + 30%DF
Soymilk				
pH	6.55[a]	6.46[b]	8.69[b]	6.45[b]
Total solids (%)	9.09[a]	8.89[b]	8.69[c]	8.65[c]
Protein (%,db)	51.38[c]	52.29[c]	55.00[b]	57.30[a]
Whey				
Volumes (ML)	82[a]	85[a]	87[a]	89[a]
Total Solids (%)	2.78[c]	2.80[c]	2.97[b]	3.10[a]
Tofu				
Fresh yield (kg/kg material)	4.69[a]	4.57[a]	4.56[a]	4.51[a]
Moisture (%)	87.05[a]	87.01[a]	87.72[a]	87.76[a]
Peak force (N)	1.65[c]	2.01[a]	1.79[b]	1.50[c]
Firmness (N/mm)	0.30[a]	0.24[b]	0.21[c]	0.17[d]
Protein (%, db)	50.23[c]	50.92[c]	53.36[b]	56.75[a]
Fat (%, db)	20.14[a]	19.47[a]	18.30[b]	16.06[c]
Ash (%, db)	11.84[a]	11.53[b]	11.43[b]	11.44[b]
Carbohydrate (%, db)	17.79[a]	18.08[a]	16.91[a,b]	15.75[b]

Values in row with the same superscript are not significantly different ($p>0.05$).

soybeans (Table 3). This is due to the higher fat content of the partially defatted peanut flour (Table 1).

The ash content of tofu made from the three blends of soy/partially defatted peanut flour was significantly lower than that of the tofu made from 100% soybeans (Table 3). The carbohydrate content of tofu made from the blends was significantly higher than that of the tofu made from 100% soybeans. This indicates that the extracability (solubility) of the carbohydrates of partially defatted peanut flour was higher than that of the soybeans. When blended with 30% partially defatted peanut flour, the carbohydrate content of the tofu was significantly lower than that of the tofu made from blends containing 10 and 20% partially defatted peanut flour. Soymilk made from 70% soybeans and 30% partially defatted peanut flour appeared to be more viscous, probably due to the gelatinization of the peanut starch. This may result in a lower recovery of carbohydrates during the filtration of soy/peanut milk.

The yield of tofu made from the soy/partially defatted peanut flour blends was significantly lower (about 4 to 6%) than the yield of tofu made from 100% soybeans (Table 3). The whey volume of tofu made from the soy/partially defatted peanut flour blends was significantly greater than that of the tofu made from 100% soybeans. There was, however, no significant difference in the yield of tofu and the volume of whey between the three soy/partially defatted peanut flour blends. The moisture content of tofu made from the soy/partially defatted peanut flour blends was significantly lower than that of the 100% soybean tofu. Therefore, addition of partially defatted peanut flour to the soybeans caused a decrease in the water-holding capacity of the tofu, a decrease in the yield of tofu and a greater whey volume. The negative effect of the partially defatted peanut flour on the yield of tofu was, therefore, similar to that observed with the addition of raw peanuts (Table 2).

The whey produced by the tofu made from a blend of 70% soybeans and 30% partially defatted peanut flour was slightly cloudy. This resulted in a significantly higher total solids content of the whey (Table 3).

Tofu made from the soy/partially defatted peanut flour blends was significantly harder (as measured by the peak force) than the 100% soybean tofu (Table 3). The hardest tofu was made from a blend of 80% soybeans and 20% partially defatted peanut flour. The firmness of tofu made from the blends of soy/partially defatted peanut flour was significantly lower than that of the 100% soybeans tofu. (Table 3). Similar to the trend observed for 90% soybeans-10% peanuts blend, the increase in the hardness of the tofu made from these blends was not followed by a corresponding increase in firmness. Therefore, addition of partially defatted peanut flour resulted in different rheological properties of the tofu.

The results obtained indicate that, under the conditions used in this study, satisfactory tofu can be made with the partial replacement of soybeans with partially defatted peanut flour. Cloudy whey was obtained at a replacement level of 30% indicating an incomplete coagulation. Therefore, the replacement of soybeans with partially defatted peanut flour should not exceed 20%.

Tofu made from blends of soybeans and defatted peanut flour. Defatted peanut flour contained only about 1% fat (Table 1). Its protein content was about 13% higher than that of the soybeans. The properties of the soymilk, soy/peanut milk, whey and tofu made from 100% soybeans or blends of soybeans and defatted peanut flour are shown in Table 4. The pH of soymilk made from the soy/defatted peanut flour blends was significantly lower than that of the 100% soybean milk. Therefore, the addition of peanuts, partially defatted peanut flour and defatted peanut flour to soybeans tends to decrease the pH of the soymilk.

Replacing 10, 20 and 30% of the soybeans with defatted peanut flour resulted in soy/peanut milk with significantly lower total solids content than the 100% soybean milk

(Table 4). This seems to be the opposite of what was observed with the partially defatted peanut flour (Table 3). Desolventization of the flour requires heat treatment which may result in reduced solubility of the protein and carbohydrates (19). The NSI of the defatted peanut flour was lower than that of the partially defatted peanut flour, 78.1 and 90.1% respectively.

Substituting 20 and 30% of the soybeans with defatted peanut flour produced tofu with a fat content significantly lower than that of the 100% soybean tofu (Table 4). This is due to the low fat content of defatted peanut flour. The ash content of tofu made from the three soy/defatted peanut flour blends was also significantly lower than that of the 100% soybean tofu. This is due to the lower ash content of the defatted peanut flour.

In spite of the fact that the defatted peanut flour contained about 6% (db) more carbohydrates than soybeans, the carbohydrate content of tofu made from the blend of 70% soybeans and 30% defatted peanut flour was significantly lower than that made from 100% soybeans (Table 4). Therefore, some of the carbohydrates of defatted peanut flour were not extracted into the soymilk.

The protein contents of soymilk and tofu made from blends containing 20 or 30% of defatted peanut flour were significantly higher than those made from 100% soybeans (Table 4). This is due to the higher protein content of defatted peanut flour.

There were no significant differences between the volume of whey, moisture content of tofu and fresh yield of tofu made from 100% soybeans and those made from the blends of soy/defatted peanut flour (Table 4). These results are different from those obtained with the soy/peanut blends (Table 2) or soy/partially defatted peanut flour blends (Table 3). Substituting defatted peanut flour for 10 to 30% of the soybeans did not change the water-holding capacity of the tofu. When raw peanuts and partially defatted peanut flour were added to the soybeans, the lowering of the water-holding capacity of tofu was probably due to the interference of increased levels of fat. During the making of soymilk, fat is extracted into the soymilk as a stable emulsion. The protein-lipid interaction in the emulsion involves mainly hydrophobic interaction between apolar aliphatic chains of the lipid and the apolar regions of the proteins (20). Such a protein-lipid interaction may modify the physical and chemical properties of the soymilk proteins, and hence alter the properties of the protein network of tofu. Therefore, it is possible that an increased level of fat will decrease the water-holding capacity of tofu by interfering with the protein-water interaction.

The total solids content of the whey obtained from the blends containing 20 or 30% of defatted peanut flour was significantly higher than that obtained with 100% soybeans (Table 4). The whey obtained from the blend containing 30% defatted peanut flour was cloudy, indicating poor coagulation of the soy/peanut milk.

As the amounts of the soybeans replaced by defatted peanut flour increased from 10, 20 to 30%, there was a corresponding significant decrease in the firmness of tofu from that of the 100% soybean tofu (Table 4). Tofu made from the blends with 10 and 20% of defatted peanut flour was significantly harder than tofu made from 100% soybeans. Tofu made from the blend containing 30% defatted peanut flour was, however, significantly softer than the 100% soybean tofu. Therefore, judging from the softer tofu texture and the cloudiness of the whey obtained, the blend containing 30% defatted peanut flour did not coagulate properly.

Microstructure of tofu made from soybeans and soy/peanut blends. Valuable information on the molecular interactions that are invloved in the formation of the tofu network structure can be obtained by studying its microstructure.

Figure 1 shows the SEM images of tofu examined in a scanning electron microscope fitted with a cryo unit. Fixation of specimens for observation under a scanning electron microscope presents a major challenge as most of the commonly used fixatives attack one or more components which results in structural damage. The utilization of a cryo unit allows observation of fragile specimens such as tofu in their natural state without fixation, therefore minimizing artifacts of sample preparation.

Sublimation of frozen tofu removes the surface ice coating to expose the underlying network structure. When tofu was exposed to 5, 10 and 15 min of sublimation at -80°C, the surface was still mostly covered with ice. The network structure was, however, clearly visible after 20 min of sublimation.

When compared with the SEM images of tofu prepared by the conventional methods involving sample fixation, dehydration and freeze drying (21), SEM images of tofu obtained with the cryotechnique are more honeycomb-like and the network structure more uniform and finer.

Figure 1a shows a fine and uniform honeycomb-like protein network structure of tofu made from 100% soybeans. The network structure is continuous with small holes that allow large quantites of water to be trapped in the three-dimensional matrix. The surface of the tofu made from 100% soybeans was also visually judged to be smooth, which correlates well with the uniform network structure shown on the SEM image.

When 10% of the soybeans was replaced by raw peanuts, the honeycomb-like structure of the tofu was still intact but the protein strands were thicker (Fig. 1b). The thicker protein strands probably require a greater force for a given deformation. This may be responsible for the greater hardness of tofu made from the 90% soybean:10% raw peanut blend than that made of 100% soybean (Table 2).

Figure 1c shows the SEM image of tofu made from 80% soybean and 20% raw peanut. The network structure is more irregular and compact than that shown in figures 1a and 1b. The surface of the protein strands that make up the network structure shown in Figure 1c is perforated, which probably requires less forces for a given deformation. This perforated protein network structure may account for the lower hardness of tofu made from this blend than that of the tofu made from 90% soybeans and 10% raw peanuts (Table 2).

Figure 1d shows that the SEM image of tofu made from 90% soybeans and 10% partially defatted peanut flour. The honeycomb-like network is still intact but the protein strands are thicker than those of the tofu made from 100% soybeans (Figure 1a). The thicker protein strands may explain the harder texture of the tofu made from this blend than that of the tofu made from 100% soybeans (Table 3).

Replacement of 20% of the soybeans with partially defatted peanut flour produced tofu with a more dense and irregular protein network structure (Fig. 1e). This may

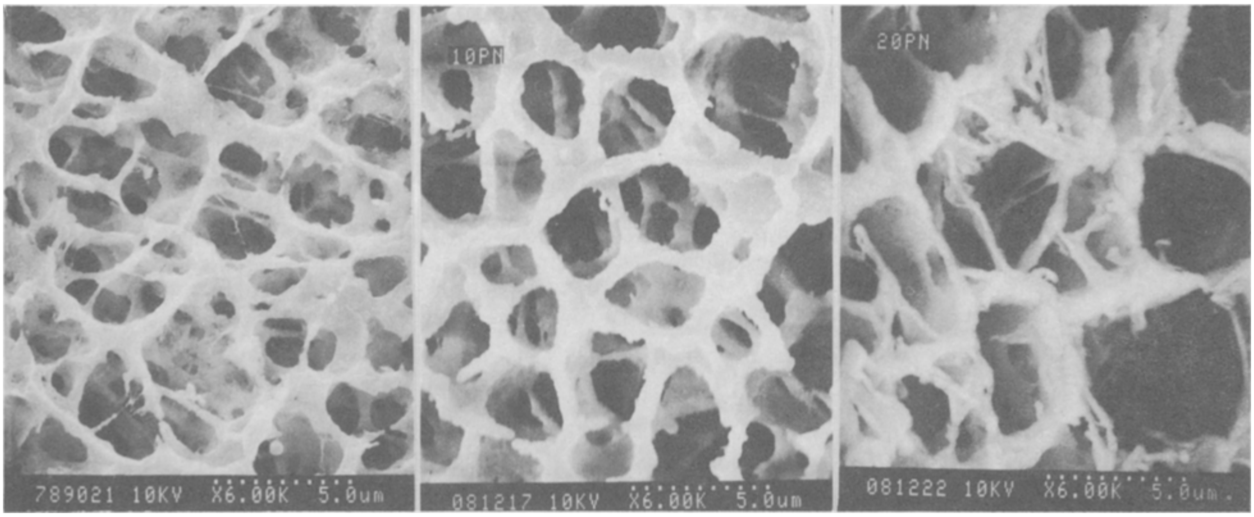
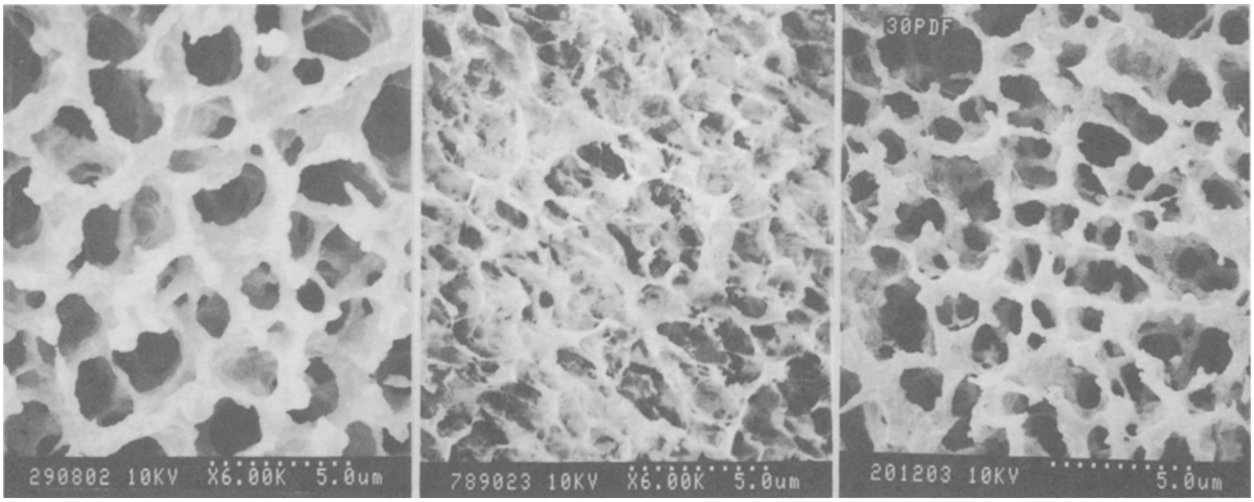
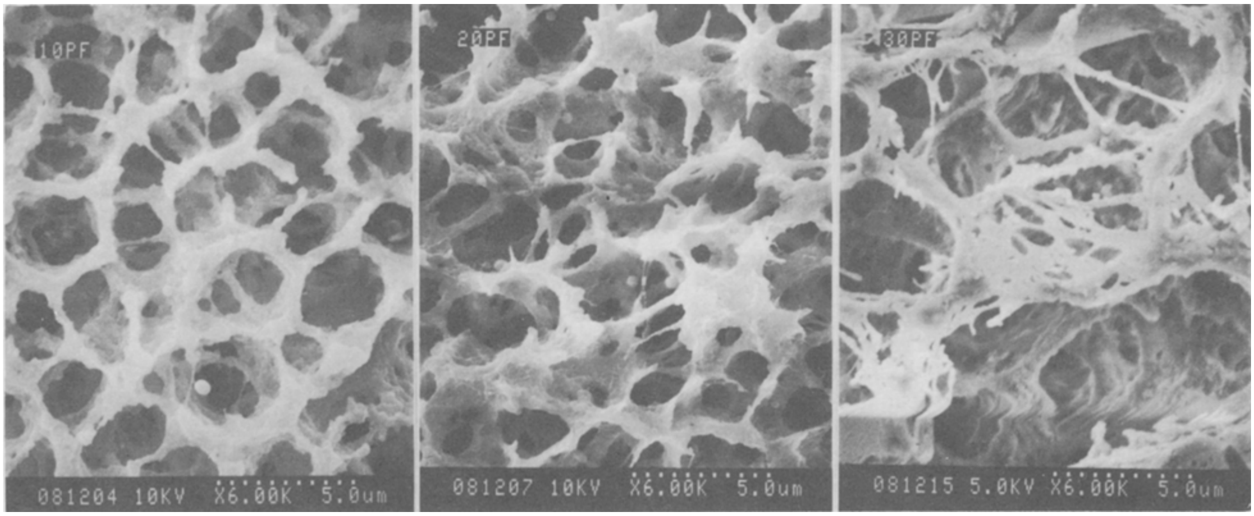


FIG. 1. SEM images of tofu from soybeans and soy/peanut blends: a) 100% soybeans; b) 90% soybeans + 10% raw peanuts; c) 80% soybeans + 20% raw peanuts



d) 90% soybeans + 10% partially defatted peanut flour; e) 80% soybeans + 20% partially defatted peanut flour; f) 70% soybeans + 30% partially defatted peanut flour



g) 90% soybeans + 10% defatted peanut flour; h) 80% soybeans + 20% defatted peanut flour; i) 70% soybeans + 30% defatted peanut flour.

be responsible for the higher hardness of tofu made from this blend than that of the tofu made from the 90% soybean and 10% partially defatted peanut flour blend (Table 3).

Figure 1f shows the SEM image of tofu made from 70% soybeans and 30% partially defatted peanut flour. The network structure is less compact than that shown in Figure 1e and not as continuous as that shown in Figure 1d. This may explain the softer texture of this tofu (Table 3). The whey of the tofu obtained from this blend was cloudy. This indicates that the coagulation of the soymlk was poor, which may result in the softer tofu texture obtained.

The SEM image of tofu made from 90% soybeans and 10% defatted peanut flour is shown in Figure 1g. The protein strands that make up the network structure are thicker than that of the tofu made from 100% soybeans (Figure 1a). These thicker protein strands probably account for the higher hardness of this blend of tofu than that of the tofu made from 100% soybeans (Table 4).

Figure 1h shows the SEM image of tofu made from 80% soybeans and 20% defatted peanut flour. The protein strands of the network structure are still thick, but more irregular and less continuous than those shown in Figure 1g. This less continuous network structure is probably weaker resulting in its lower hardness (Table 4).

The SEM image of tofu made from the 70% soybeans and 30% defatted peanut flour is shown in Figure 1i. The protein strands that make up the network structure are thinner than those in figures 1g and 1h. The surface of the protein strands (Fig. 1i) is extensively perforated. These perforated protein strands weaken the network structure, and require less forces for a given deformation, resulting in the softer texture of tofu made from this blend than that of the tofu made from 100% soybean (Table 4).

Conclusions. Addition of raw peanuts, partially defatted peanut flour or defatted peanut flour to soybeans changes the microstructure and rheological properties of the tofu. The changes in the hardness of tofu can be explained by changes in the microstructure of tofu.

The results obtained indicate that satisfactory tofu can be made by substituting 10 or 20% of the soybeans with defatted peanut flour. Substitution at 30% is not recommended, as the tofu becomes soft and the whey cloudy. Among the three peanut products tested, the defatted peanut flour seems to be most compatible with soybeans in tofu-making, followed by the partially defatted peanut flour and then the raw peanuts.

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REFERENCES

1. Schroder, D.J., and H. Jackson, *J. Food Sci. 37*:450 (1972).
2. Nelson, A.I., M.P. Steinberg and L.S. Wei, *Ibid. 41*:57 (1976).
3. Kuntz, D.A., M.P. Nelson, M.P. Steinberg and L.S. Wei, *Ibid. 43*:1279 (1978).
4. Johnson, L.A., C.W. DeYoe and W.J. Hoover, *Ibid. 46*:239 (9181).
5. Steel, R.G.D., and J.H. Torrie, *Principles and Procedures of Statistics. A Biometrical Approach*, 2nd edn., McGraw-Hill Book Co., New York, 1980.
6. SAS User's Guide, 1982, SAS Institute Inc., Cary, North Carolina.
7. Tsai, S.J., C.Y. Lan, C.S. Kao and S.C. Chen, *J. Food Sci. 46*:1734 (1981).
8. *Official and Tentative Methods of The American Oil Chemists' Society*, 3rd edn., 1981, Method Ac 2-41.
9. *Ibid.*, 1981, Method Ab 2-49.
10. *Ibid.*, 1981, Method Bc 2-49.
11. *Official Methods of Analysis*, 14th edn., 1984, A.O.A.C.
12. Individual/Simultaneous Determination of Nitrogen and/or Phosphorous in Block Digester Acid Digests, Technicion Instruments Corporation, Tarrytown, New York, 1976.
13. *Official and Tentative Methods of the American Oil Chemists' Society*, 3rd edn., 1981, Method Ac 3-44.
14. *Ibid.*, 1981, Method Ab 3-49.
15. *Standard Methods for the Examination of Dairy Products*, 13th edn., edited by W.J. Hausler, American Public Health Association, Washington, D.C., 1972.
16. *Official and Tentative Methods of the American Oil Chemists' Society*, 3rd edn., 1981, Method Ba 5-49.
17. Smith, A.K., and S.J. Circle, *Soybeans: Chemistry and Technology*, AVI Publishing Co., Westport, Connecticut, 19, pp. 81-90, 1972.
18. Woodroof, J.G., *Peanuts: Production, Processing, Products*, AVI Publishing Co., Westport, Connecticut, 1973.
19. Harris, H., E.Y. Davis, M.S. Van de Mark, K.S. Rymal and J.J. Spadaro, *Development and Use of Defatted Peanut Flours, Meals and Grits*, Agricultural Experiment Station Bulletin 431, Auburn University, Auburn, Alabama, 1972.
20. Cheftel, J.C., J.L. Cuq and D. Lorient, in *Food Chemistry*, edited by O.R. Fennema, Marcel Dekker Inc., New York, NY, 1985.
21. deMan, J.M., L. deMan and S. Gupta, *Food Microstruct. 5*:83 (1986).

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