Functional Properties of Hydrothermally Cooked Soy Protein Products

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ABSTRACT: The effects of hydrothermal cooking on the functional properties of defatted soy flour, aqueous alcohol washed soy protein concentrate, and soy protein isolate were determined in samples that were treated at 154°C by infusing steam under pressure for 11, 19, 30, and 42 s, and then spray dried. Hydrothermal cooking increased the nitrogen solubility index (NSI) of the concentrate from 15 to 56% and altered the solubility profile from a flat profile to one more typical of native soy protein. Hydrothermal cooking also improved foaming and emulsifying properties of the concentrate. For isolate, hydrothermal cooking also improved NSI and foaming and emulsifying properties, although the improvements were less dramatic than with concentrate. NSI and emulsifying properties of the flour were improved by some processing conditions, but foaming properties were not improved by hydrothermal cooking. Dramatically increased protein solubility of concentrate and modestly improved protein solubilities of flour and isolate by hydrothermal cooking, which will also inactivate trypsin inhibitors and microorganisms, have considerable practical significance to protein ingredient manufacturers and those who use these ingredients in foods and industrial products.

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KEY WORDS: Functional properties, hydrothermal cooking, jet cooking, protein functionality, soybean protein, soy flour, soy protein concentrate, soy protein isolate.

Soybeans are an abundant source of proteins that have long been recognized for high nutritional value and excellent functional properties in food (1). However, flatulence caused by fermentation of oligosaccharides in the colon, undesirable flavors formed by lipoxygenase-catalyzed lipid oxidation, and low protein digestibility because of trypsin inhibitors (TI) are obstacles for increasing acceptance of soy-protein ingredients in food, and processing procedures are selected based on their abilities to minimize these problems. Procedures such as heat treatment to inactivate lipoxygenase and TI and aqueous alcohol washing to remove oligosaccharides and off-flavors, usually denature and insolubilize proteins, rendering them poorly functional in foods (2) and industrial applications (i.e., paper coatings and adhesives).

Defatted soy flour (referred to as flour), alcohol-washed soy protein concentrate (referred to as concentrate), and soy protein isolate (referred to as isolate) are three major soy protein products having different protein contents and functional properties; they are used in different applications. Flour, the least refined form of the three, contains 40–50% protein (moisture-free basis, mfb) depending on whether refined fat or lecithin is added. Flash desolventizing produces flour with minimal protein denaturation and high protein solubility. Different degrees of subsequent heat treatment produce flour with widely divergent functional properties (3). However, flour contains oligosaccharides and high TI activity (unless extensively heat-treated). The nitrogen solubility index (NSI) of flour is often as low as 20 when treated with moist heat to inactivate TI (1) and indigenous enzymes. Soy protein concentrate contains more than 65% protein because soluble carbohydrates are removed by washing with either acid or aqueous alcohol. Aqueous alcohol washing, the most widely used method to produce soy protein concentrate, reduces protein solubility to less than 10% but produces very bland flavor (1). Isolate is the most refined soy protein product and contains more than 90% protein. It is made by alkali extraction of protein to remove insoluble fiber and subsequent acid precipitation to remove soluble sugars. Without heat treatment, high levels of TI and potentially high levels of microbial contamination remain.

Hydrothermal cooking, a steam-infusion treatment often known as jet cooking, was used to process full-fat soybean flour into soymilk (4). At optimal conditions, the process increased recoveries of solids and protein from 60 and 70% and in the traditional Oriental process to 87 and 90%, respectively (5,6). The process also achieved over 90% reduction in TI activity (7) and sterilized the product. Later, it was even reported that all but the hulls of soybeans could be recovered as a stable soymilk (8). Soymilk with significantly less flavor was made by minimizing cold water contact time for lipoxygenase to be active (9). Functional properties (protein solubility, water absorption, oil absorption, ability to be whipped, foam stability, and emulsifying properties) of spray-dried soymilk made from whole or dehulled soybeans by using hydrothermal cooking were superior to those of spray-dried soymilk prepared by the traditional method (8).

Heating has been recognized as a means of altering functional properties of soy protein, and these effects were reviewed by Nakai and Li-Chen (10). These functional changes

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have been attributed to changes in protein hydrophobicity, which accompanies protein denaturation. Most studies to date have focused on heating at modest temperatures (<100°C) under low shear. Hydrothermal cooking, on the other hand, is unique in that it exposes the product to very high temperatures (120–155°C) for short periods (1–240 s), and the come-up time to cooking temperature and cooling time to the boiling point of the slurry are instantaneous, allowing precise control of the cooking process.

Thus far, hydrothermal cooking has not been applied to flour, concentrate, or isolate to alter protein functionality. Based on previous observations with soymilk, we hypothesized that we could improve the functional properties of soy protein products by employing hydrothermal cooking. The objective of the present study was to investigate effects of hydrothermal cooking conditions on functional properties of flour, concentrate, and isolate.

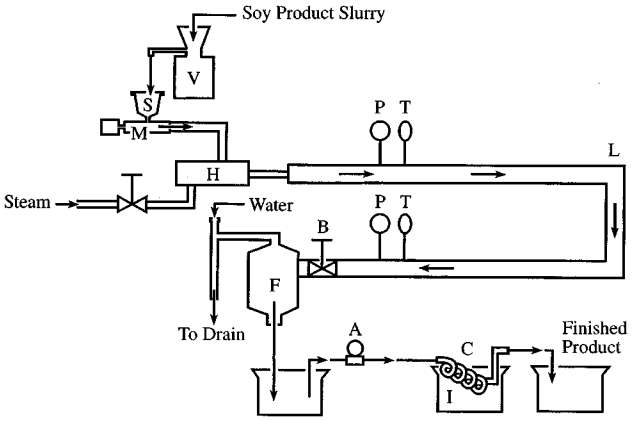

FIG. 1. Hydrothermal cooking system (V, Vibroreactor; S, surge tank; M, Moyno pump; H, hydroheater; L, holding tube; P, pressure gauges; T, thermocouples; B, back-pressure valve; A, air-driven pump; F, flash chamber; C, cooling coil; and I, ice water bath).

MATERIALS AND METHODS

Soy protein products. Flour [NutriSoy 7B Flakes, 59.8% (mfb) protein and 71.3 NSI] and concentrate [NutriSoy Protein Concentrate, 65.4% (mfb) protein and 8.1 NSI] were purchased from the Archer Daniels Midland Co. (ADM, Decatur, IL). ADM prepares NutriSoy 7B Flakes by dehulling, extracting oil with hexane, and flash desolventizing. ADM prepares NutriSoy Protein Concentrate from the same flour but follows with aqueous alcohol washing. Both protein materials were ground by using a hammer mill equipped with a 100-mesh screen.

Isolate was prepared in our laboratory from ground NutriSoy 7B Flakes by using modified procedures described by Smith and Circle (1). We chose to prepare our own isolate so that it would not be exposed to two spray-drying steps and would be produced under known, nonproprietary conditions. Flour was slurried in 50°C distilled water at 15% solids. The slurry was adjusted to pH 8 with 1 N NaOH and stirred for 1 h. The slurry was then filtered with cheesecloth and centrifuged at 1,000 × *g* to remove insoluble residue (fiber). The extract was adjusted with 1 N HCl to pH 4.5, the isoelectric point for soy protein, and the protein curd was allowed to settle for 2 h. The whey was decanted and an equal amount of fresh distilled water was added back to the curd for washing. The washed curd was allowed to settle for 2 h before the clear whey was decanted again. The pH of the washed slurry was adjusted to 7.0 with 1 N NaOH. The protein content of the isolate was 90.6% (mfb).

Hydrothermal cooking system and processing conditions. All soy protein products were fed into the hydrothermal cooking system (Fig. 1) at 5% solids adjusted with deionized water. Slurries of flour and concentrate, but not isolate, were ground by using a Vibroreactor (model JM14/E/3; Cherry-Burrell Co., Cedar Rapids, IA) to reduce particle size. A variable-speed Moyno pump (2MI type SSQ; Robin and Myers, Inc., Springfield, OH) was used to pump the slurry into the hydroheater (size 300 type B; Hydrothermal Co., Milwaukee, WI) where it was infused with 90 psi (6.5 kg/cm^2) culinary-grade steam. The slurry flowed through an insulated stainless-steel holding tube (2.54 cm i.d. and 2.66 cm o.d.) of variable length (described below), passed through a back-pressure valve, and discharged into a flash chamber. Cooking temperatures and pressures were monitored by thermocouples and pressure gauges, respectively, installed at both the beginning and the ending of the holding tube. The cooking temperature was controlled by adjusting the back-pressure valve. The slurry exiting the flash chamber was immediately cooled by pumping it through a cooling coil immersed in an ice-water bath. The final temperature was approximately 35°C.

All samples were cooked at one temperature, 154°C, the temperature identified as being optimal for soymilk (4). Four different holding tube lengths of 8.3, 14.5, 30.7, and 38.8 ft (2.5, 4.4, 9.3, and 11.8 m) were used to obtain four different cooking times of 11, 19, 30, and 42 s, respectively. Cooking times were regularly checked with a food-grade dye. The hydrothermal cooking system was designed to process about 10 L/min of slurry, and 15–20 L of each cooked sample was collected. All samples were collected after achieving steady-state operation (about 5 min between process adjustments).

A 20-T (20 lb/h) pilot-plant tower spray dryer (Food Processing Center, University of Nebraska-Lincoln, Lincoln, NE) was used to spray-dry 10 L of each slurry. To increase drying efficiency, samples were pumped through a heating coil to obtain 60°C before spraying into the drying chamber; an external mixing nozzle (3.2 mm diameter) was used. Air inlet and outlet temperatures were 168 and 76°C, respectively. All samples were dried under the same conditions.

Determining functional properties. (i) NSI. American Oil Chemists' Society official method Ba 11-65 (11) was used to determine NSI. Nitrogen contents of both the original samples and the soluble fractions were determined with the macro-Kjeldahl method.

(ii) Solubility profile. Protein solubility profiles were determined by using the method of Hamada and Marshall (12).

(iii) Foaming properties. Foaming capacity and foam stability were determined by using modified methods of Lin *et al.* (13). A 200-mL slurry containing 3% protein (or solids) was stirred for 10 min. The solids were further dispersed by using a food mixer (KitchenAid, St. Joseph, MI) at low speed for 1 min. Heavy beating at top speed for 5 min was used to generate foam. The foam was transferred to a 2,000-mL graduated cylinder to measure total volume (foam plus liquid) and foam volume. Total and foam volumes were also recorded at 1-, 10-, 30-, 60-, and 120-min intervals. Foaming capacity was calculated as the total volume after beating as a percentage of the original slurry volume. Foam stability was calculated as the percentage of the original foam volume remaining after 120 min of standing. Determinations were made at both equivalent protein levels and equivalent solids levels.

(iv) Emulsifying properties. Emulsifying capacity was determined by modifying the method of Hung (8). A 50-mL slurry of 1.0% solids (or protein) was prepared in a 600-mL beaker with distilled water, and the slurry was stirred for 10 min. A hand-held mixer (Braun Inc., Lynnfield, MA) was used to homogenize the samples. The slurry was mixed for 1 min at 5,000 rpm before the mixer speed was increased to 10,000 rpm and corn oil was added. The amount of oil required to take the emulsion to the breaking point, which was recognized by a profound drop in emulsion viscosity, was used as a measure of emulsifying capacity. Determinations were made at equivalent levels of both protein and solids.

(v) Oil absorption capacity. The Lin *et al.* method (13) was used for measuring oil absorption capacity, except corn oil was used.

(vi) Moisture adsorption and hydration properties. One-gram samples of powder were placed in 50-mL plastic centrifuge tubes, and the tubes were kept at 20°C in a 100% relative-humidity moisture chamber. The centrifuge tubes were weighed during and after 1-wk storage to determine the amount of moisture adsorbed. Moisture adsorption values were calculated as the amounts of water adsorbed per gram of sample over a 1-wk period.

Chemical and physical properties. (i) Composition. Moisture contents of spray-dried samples were determined by using AOAC method 14.003 (14). Nitrogen content was determined by using a Kjeltec system (Tecator, Inc., Hogana, Sweden). The nitrogen-protein conversion factor was N × 6.25.

(ii) Bulk density. The method of Wang and Kinsella (15) was modified to determine bulk density. Samples were gently packed in 50-mL plastic centrifuge tubes by tapping them on the bench 10 times from a height of 5 cm. Extra sample remaining on top of the centrifuge tube was removed by drawing a ruler across the top of the tube. The centrifuge tube was tared and its volume was determined by measuring the amount of distilled water required to fill.

(iii) Color. Colors of the protein powders were measured by using a Hunter colorimeter (Hunter Associates Laboratory, Reston, VA). The Lab unit system was used, in which *L* value measured lightness, *a* measured red (+) and green (−), and *b* measured yellow (+) and blue (−). Tile LS-12414 was used for standardization.

Experimental design and statistical analysis. Each hydrothermal cooking treatment was replicated three times in a complete random design. The results were analyzed by using the General Linear Model of the Statistical Analysis System. *t*-Tests were performed to compare means.

RESULTS AND DISCUSSION

Functional properties. (i) NSI. Water solubility is probably the most important property of protein in foods, not only because soy ingredients must form stable dispersions when incorporated into beverages and other food systems but also because other functionalities, such as gelling, emulsifying and foaming, are closely associated with solubility (2). NSI is routinely used to evaluate protein solubility.

Hydrothermal cooking significantly improved the NSI of concentrate (Table 1). NSI steadily increased to a maximum value occurring after 30 s of treatment. Most notably, hydrothermal cooking increased the NSI of concentrate from 15 to 56% (treated for 30 s), nearly a threefold increase.

NSI of both flour and isolate were also improved by hydrothermal cooking, although the effects were not as significant as for concentrate. Flour treated for 11 s had the highest NSI; NSI dropped when the treatment time increased to 19 s; and then improved again with increasing treatment time. Isolate had a similar pattern; however, the peak NSI occurred at 19 s of cooking.

It is not readily apparent why hydrothermal cooking improved soy protein solubility, but we speculate that more than one mechanism was involved. In some samples we noted ammonia-like odors indicative of deamidation. However, improved solubility must be due to more than just deamidation because otherwise it would be expected to occur in the three protein forms, and we observed different effects. Hydrothermal cooking may disrupt large particles or any previously aggregated proteins due to earlier heat or other treatments. Hydrothermal cooking could also prevent further formation of large aggregates by high-shear mixing during cooking.

(ii) Protein solubility profile. During the manufacture of commercial soy flour, flash desolventizing of hexane is used. The heat of this operation reduces somewhat the solubility of soy protein from that of raw soy flour. In general, protein sol-

TABLE 1
Effects of Hydrothermal Cooking Time on Nitrogen Solubility Indices of Soy Protein Products[a]

	Holding time (s)				
Product	0[b]	11	19	30	42
Flour	$64.5^{b,c,d,e,f}$	79.4^{a}	$59.9^{d,e,f}$	$67.7^{a,b,c,d,e}$	$72.6^{a,b,c,d}$
Concentrate	14.8^{h}	28.5^{g}	54.2^{f}	$56.4^{e,f}$	$55.3^{e,f}$
Isolate	$63.6^{c,d,e,f}$	$71.9^{a,b,c,d}$	$77.3^{a,b}$	$73.0^{a,b,c,d}$	$75.6^{a,b,c}$

[a]Means with common superscripts are not significantly different. Least significant difference ($P < 0.05$) was 13.2.
[b]Controls; no hydrothermal cooking treatment.

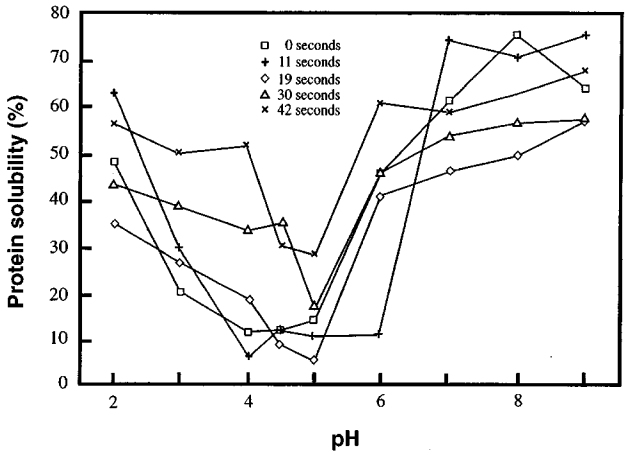

FIG. 2. Effects of hydrothermal cooking time on the protein solubility profiles of flour. Least significant difference ($P < 0.05$) was 8.26%.

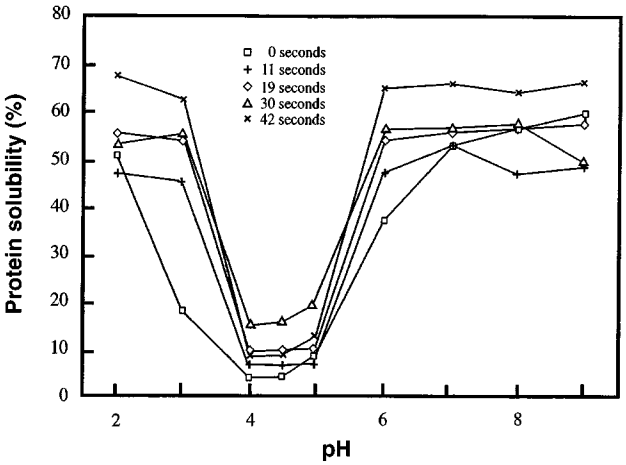

FIG. 4. Effects of hydrothermal cooking time on the protein solubility profile of isolate. Least significant difference ($P < 0.05$) was 4.60%.

ubility of flour was significantly improved by hydrothermal cooking, especially at longer processing times (Fig. 2). The isoelectric point (minimum solubility) shifted from pH 4.5 to 5.0 when flour was processed for 19 s or longer. These high protein solubilities were unexpected considering that Johnson *et al.* (7) have shown that over 90% of the original TI activity was inactivated by this treatment. Usually heat treatments to inactivate TI also greatly reduce the solubilities of bulk storage proteins.

The protein solubility profiles of untreated concentrates or those processed for only 11 s were not very responsive to changes in pH; solubilities were low over the pH range of 2 to 9 (Fig. 3). Concentrate treated longer than 19 s exhibited protein solubility profiles more typical of undenatured soy protein. Concentrate treated for 19 s was less soluble in the acid range and more soluble in the alkaline range than was observed in concentrate treated for 35 and 42 s. The isoelectric point also shifted from pH 4.5 to 5.0 with concentrate treated for 35 and 42 s. Hydrothermal cooking restored solubility properties of concentrate to nearly that of native soy protein.

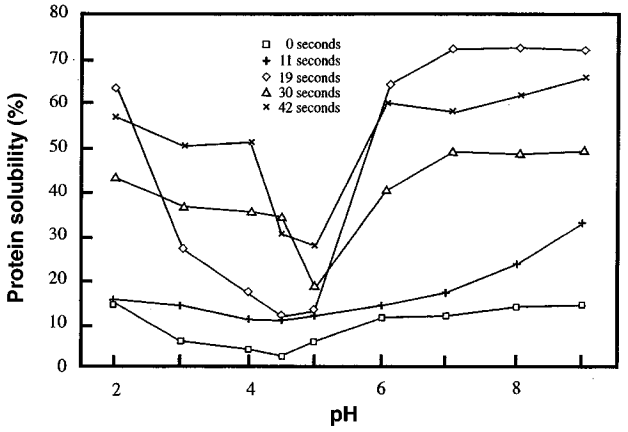

FIG. 3. Effects of hydrothermal cooking time on the protein solubility profiles of concentrate. Least significant difference ($P < 0.05$) was 5.45%.

All isolates showed the typical solubility profiles of soy proteins (Fig. 4). However, longer hydrothermal cooking time led to greater protein solubilities at all pH values. The curves uniformly shifted to greater levels as cooking time increased.

The reason for the shift in the isoelectric point is not understood. When deamidation occurs, the isoelectric pH should have shifted to the acid side rather than to the alkaline side as was observed. Decarboxylation would be expected to shift the isoelectric point to the alkaline side.

(iii) Foaming properties. Effects of hydrothermal cooking on foaming capacities (equivalent protein levels) of the three soy protein products are shown in Table 2. Hydrothermal cooking decreased the foaming capacity of flour. There were no significant differences among treated flour samples.

Hydrothermal cooking significantly improved foaming capacities of concentrates. Generally, the longer the concentrate was hydrothermally cooked, the greater the foaming capacity. Hydrothermal cooking increased the foaming capacity of concentrate by almost three times when cooked for 42 s.

Improvement was also observed in treated isolate; however, the effects were not as significant as that with concentrate. It was also noted that, whether treated or not, isolate had the highest foaming capacity, followed (in descending order) by concentrate and then flour. This was partially due to differences in composition and protein solubility. Residual lipids and fiber of flour and residual fiber of concentrate probably reduced foaming capacity.

Foaming capacities were also determined on equivalent solids level (data not shown). The general trends were the same as those observed in experiments in which the same protein level was used.

Foam stabilities determined on the same protein level are shown in Table 3. Foam stabilities of flour were reduced when treated for 11 s but were improved to nearly the same value of untreated flour as cooking time increased. However, those of concentrate were significantly improved by hydrothermal

TABLE 2
Effects of Hydrothermal Cooking Time on Foaming Capacities (%) of Soy Protein Products[a]

	Holding time (s)				
Product	0[b]	11	19	30	42
Flour	490[f]	287[g]	304[g]	302[g]	325[g]
Concentrate	193[g]	551[e,f]	517[e,f]	653[e,f]	736[d]
Isolate	925[c]	1,060[b,c]	1,260[a]	1,170[a,b]	1,200[a,b]

[a]Foaming tests were performed at the same level of protein. Means with common superscripts are not significantly different. Least significant difference ($P < 0.05$) was 13.2.
[b]Controls; no hydrothermal cooking treatment.

TABLE 5
Effects of Hydrothermal Cooking Time on Oil Absorption Capacities (g oil/100 g sample) of Soy Products[a]

	Holding time (s)				
Product	0[b]	11	19	30	42
Flour	262[d]	238[d]	236[d]	225[d]	225[d]
Concentrate	283[c,d]	240[d]	264[d]	264[d]	268[d]
Isolate	204[d]	511[a]	392[b,c]	386[b,c]	408[a,b]

[a]Means with common superscripts are not significantly different. Least significant difference ($P < 0.05$) was 110.0 g oil/100 g sample.
[b]Controls; no hydrothermal cooking treatment.

cooking. Cooking time had no significant effect. The foam stabilities of isolate decreased when treated for 19 s or longer.

These observations could be attributed to protein denaturation and deamidation. Kato *et al.* (16) reported that heat denaturation of soy globulins increased foaming capacity and foam stability due to increased surface hydrophobicity. Also, enzyme-catalyzed deamidation was shown to increase foaming capacity but had no effect on foam stability (12).

(iv) Emulsifying capacity. Table 4 shows emulsifying capacities (equivalent protein levels) of soy protein products treated under different conditions. Emulsifying capacities of flour were initially reduced (samples processed for 11 or 19 s), but emulsifying capacity was restored at longer cooking times. At 42 s of cooking the emulsifying capacity of treated flour was significantly better than that of untreated flour. Emulsifying capacities of concentrates were dramatically improved. The emulsifying capacity increased as cooking time increased. The emulsifying capacity of isolate also was significantly improved by hydrothermal cooking. There were no significant differences among isolates cooked for different times.

Overall, isolate had the highest emulsifying capacities among the three products. Unlike foaming capacity, flours generally had better emulsifying properties than concentrates.

Emulsifying capacities determined on the same solids level were basically the same as described for those performed on an equivalent protein level (data not shown), except that isolate had the highest emulsifying capacities, followed by flour and concentrate. This was probably due to differences in protein contents.

(v) Oil absorption. Hydrothermal cooking had no significant effect on oil absorption capacities of flour and concentrate (Table 5). However, isolates had significantly higher oil absorption capacities when hydrothermally cooked. The improved oil absorption of isolate should be useful in meat systems where substantial amounts of isolate are used to reduce cooking losses.

(vi) Moisture adsorption and hydration capacity. Moisture adsorption of flour was reduced by hydrothermal cooking (Table 6). There were no significant differences among treated flours or treated concentrates. However, hydrothermal cooking significantly improved moisture adsorption of isolate.

We attempted to measure the hydration properties by using the American Association of Cereal Chemists method (No. 8804) (17). However, our treated samples hydrated unevenly when water was added and the results were not very reproducible.

Physical properties. (i) Drying characteristics. The flours, concentrates, and isolates had moisture content ranges of

TABLE 3
Effects of Hydrothermal Cooking Time on Foam Stabilities (%) of Soy Protein Products[a]

	Holding time (s)				
Product	0[b]	11	19	30	42
Flour	82.4[a,b]	28.2[f]	60.7[d,e]	66.0[c,d,e]	73.1[b,c,d]
Concentrate	8.7[g]	88.3[a,b]	87.8[a,b]	89.2[a]	90.2[a]
Isolate	87.8[a,b]	92.0[a]	57.2[e]	79.0[a,b,c]	66.4[c,d,e]

[a]Foaming tests were performed at the same level of protein. Means with common superscripts are not significantly different. Least significant difference ($P < 0.05$) was 15.2%.
[b]Controls; no hydrothermal cooking treatment.

TABLE 4
Effects of Hydrothermal Cooking Time on Emulsifying Capacities (mL oil/g protein) of Soy Protein Products[a]

	Holding time (s)				
Product	0[b]	11	19	30	42
Flour	820[d,e]	487[h]	570[g]	847[c,d,e]	920[a,b]
Concentrate	170[i]	437[h]	723[f]	787[e,f]	750[f]
Isolate	790[e,f]	927[a,b]	957[a]	870[c,d,e]	907[a,b,c]

[a]Emulsifying tests were performed at the same level of protein. Means with common superscripts are not significantly different. Least significant difference ($P < 0.05$) was 68.3 mL oil/g protein.
[b]Controls; no hydrothermal cooking treatment.

TABLE 6
Effects of Hydrothermal Cooking Time on Moisture Absorption of Soy-Protein Products (percentage moisture content after 1 wk)[a]

	Holding time (s)				
Product	0[b]	11	19	30	42
Flour	9.6[d,e]	9.2[f]	9.2[f]	9.3[e,f]	9.4[e,f]
Concentrate	10.0[b,c]	9.7[c,d]	9.8[b,c,d]	9.6[d,e]	9.7[c]
Isolate	10.0[b]	10.8[a]	10.7[a]	10.8[a]	10.7[a]

[a]Means with common superscripts are not significantly different. Least significant difference ($P < 0.05$) was 0.3%.
[b]Controls; no hydrothermal cooking treatment.

TABLE 7
Effects of Hydrothermal Cooking Time on Bulk Densities (g/cc) of Soy Protein Products[a]

	Holding time (s)				
Product	0[b]	11	19	30	42
Flour	0.33^{d,e}	0.35^{c,d}	0.33^{d,e}	0.38^{b}	0.38^{b,c}
Concentrate	0.35^{b,c,d}	0.36^{b,c}	0.32^{e,f}	0.31^{e,f}	0.29^{f}
Isolate	0.47^{a}	0.19^{g}	0.18^{g}	0.19^{g}	0.17^{g}

[a]Means with common superscripts are not significantly different. Least significant difference ($P < 0.05$) was 0.03 g/cc.
[b]Controls; no hydrothermal cooking treatment.

1.60–2.23, 0.156–2.60, and 1.37–2.40%, respectively (data not shown). There was a general trend of samples without hydrothermal cooking to have greater moisture contents than treated samples. As cooking time increased, moisture content after spray drying decreased. Thus, hydrothermal cooking seemed to facilitate drying.

(ii) Bulk density. Flour became denser at longer cooking times (Table 7). Both treated concentrate and treated isolate, however, were less dense than untreated samples. The treated isolate had much lower bulk density (0.17–0.19 g/cc) compared with untreated isolate (0.47 g/cc). Changes in bulk densities were probably the result of changes in particle size and particle shape, but the precise mechanism by which hydrothermal cooking altered these physical properties was not clear.

(iii) Color. Spray-dried soy protein products had *L* values ranging from 90 to 94 (Table 8). At very short cooking times (11 and 19 s), the colors of treated flour and isolate were lighter than untreated controls. This has also been observed in hydrothermally cooked soymilk (4). As cooking time increased, all samples became slightly darker because of the generation of Maillard reaction products; however, the extent of darkening was not great. The redness (*a* values) of samples ranged from −1.80 to 0.27. For all the samples, *a* values increased with increasing treatment time, going from negative values to positive values (i.e., the color changed from green to red). The change from green to red was probably the result of the destruction of natural green color (chlorophyll) and the generation of dark-colored Maillard reaction products. The yellowness (*b* values) of samples ranged from 8.8 to 14.1. As cooking time increased, there was generally an initial decrease of yellowness and then a gradual increase. This was likely caused by the destruction of natural yellow pigments and generation of Maillard reaction products.

Although these changes are generally undesirable, the extent of color development is regarded as being of little practical significance, especially in food. Only in the most demanding applications, such as paper coatings, would these small changes be regarded as important.

Hydrothermal cooking proved to be very effective in improving functional properties of soy protein products. Hydrothermal cooking markedly increased the solubility, foaming capacity, and emulsifying capacity of concentrate. Although concentrate is often preferred in food because of its bland flavor and low tendency to produce flatulence, it lacks desirable functional properties. Hydrothermal cooking restored functional properties to nearly those of native soy protein. Hydrothermal cooking also improved functional properties of flour and isolate, but the effects of hydrothermal cooking were not as dramatic with these products as with concentrate. However, protein solubilities of flour and isolate were maintained, while hydrothermal cooking inactivated TI. Because it is now possible to combine the attributes of concentrate (less flavor, reduced flatulence, and low cost) with the functional properties of isolate, hydrothermal cooking has considerable commercial potential to increase soy protein utilization in food and industrial products.

TABLE 8
Effects of Hydrothermal Cooking Time on Colors of Soy Protein Products[a]

	Holding	Hunter color values		
Product	time (s)	*L*	*a*	*b*
Flour	0[b]	92.2^{b,c,d,f}	−0.85^{e,f}	10.3^{e}
	11	93.1^{a,b}	−0.62^{c,d}	11.0^{c}
	19	93.0^{a,b,c}	−0.43^{c}	10.8^{c,d}
	30	90.8^{g,h,i}	0.15^{b}	11.7^{b}
	42	90.5^{h,i}	0.38^{a}	12.0^{b}
Concentrate	0	93.7^{a}	−1.80^{h}	11.7^{b}
	11	91.9^{c,d,e,f}	0.26^{a,b}	8.75^{h}
	19	91.7^{d,e,f,g}	0.22^{a,b}	9.01^{g,h}
	30	90.8^{f,g,h,i}	0.27^{a,b}	9.35^{f,g}
	42	89.9^{i}	0.21^{a,b}	9.56^{f}
Isolate	0	92.7^{a,b,c,d}	−2.76^{i}	14.1^{a}
	11	93.2^{a,b}	−1.55^{g}	10.4^{d,e}
	19	91.6^{e,f,g,h}	−1.39^{g}	10.3^{e}
	30	91.8^{d,e,g,f}	−0.96^{f}	
10.7^{c,d,e}				
	42	91.0^{f,g,h,i}	−0.69^{e,d}	10.8^{c,d}

[a]Means with common superscripts are not significantly different. Least significant differences ($P < 0.05$) for *L*, *a*, and *b* were 1.13, 0.23, and 0.50, respectively.
[b]Controls, no hydrothermal cooking treatment.

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