Foaming Properties of Soybean Protein-Based Plywood Adhesives

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ABSTRACT: A study was conducted to evaluate the potential of soy protein-based plywood glues for foam extrusion. Foaming properties were the first criterion used to screen several soy protein sources. Foaming capacities and stabilities of glue mixes containing animal blood (control) or soy products (meals, flours, concentrates, and isolates) were compared and correlated with molecular weights and surface hydrophobicity indices (S_o) in an attempt to identify structure/function relationships. The blood-based glue mix produced more foam than any of the soy-based glues. Soy flours and concentrates generally produced greater foam volumes and more stable foams than soy meal and isolates. Differences in foaming properties could not be explained by solubility profiles or S_o. However, results of gel electrophoresis indicated that soy products with poor foaming properties had extensive structure modifications or contained considerably lesser amounts of protein available for foaming reactions. Glue mixes containing the soy flours ISU-CCUR, Honeysoy 90, Nutrisoy 7B, and defatted Soyafluff and the soy concentrates Arcon F, ISU-CCUR, and Procon 2000 demonstrated the desired mixing and foaming properties for foam extrusion.

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KEY WORDS: Animal blood protein, foaming capacity, foam extrusion, foam stability, plywood glue, soy proteins.

Foam extrusion is a method of applying glue to plywood where the glue is foamed with air and then extruded into long strands of such diameter as to cover the entire veneer surface when pressed (1). Glues for foamed extrusion contain very little water (20 vs. 60% in the traditional plywood glues) and only one extender, the protein. These distinctive properties impart several advantages to foamed plywood glues. The lower moisture content makes them less sensitive to veneer moisture and permits use of high-moisture panels. They provide more uniform veneer coverage, thus requiring lower spreads, which leads to lower gluing costs. There are also fewer variables in the glue mixing process, so production is more consistent (1).

The very nature of foam extrusion requires not only foaming capability for the glue but also foam stability. The foamed glue strands must withstand collapse during periods of stoppage in the production of plywood (1). These attributes are provided by the protein extender in the glue mix, which is currently spray-dried animal blood. In recent years, however, concerns have been raised about handling or inhaling blood particulates that may contain possible disease agents. Animal blood also degrades rapidly and has limited suppliers (Foucht, M., and Demaree, T., personal communications).

Soy protein appears to be a viable alternative to animal blood as an extender in foamed glues. It has demonstrated excellent foaming and other functional properties (2–4). Various sources of soy proteins (meal, flour, concentrate, isolate) from several processors are available commercially. Soy meal and flour are also cheaper than animal blood ($0.22/lb soy flour vs. $0.40/lb spray-dried animal blood).

Foaming properties were the first criterion that we used to evaluate the potential of soy protein as a replacement for animal blood in foamed plywood glues. This paper presents comparisons of foaming capacities and stabilities of plywood glues containing animal blood and several soy protein products (meals, flours, concentrates, and isolates) and correlates these properties with surface hydrophobicity indices and molecular weights in an attempt to identify structure/function relationships.

EXPERIMENTAL PROCEDURES

Materials. Spray-dried animal blood (APC 301) was obtained from American Protein Co. (Ames, IA). Soybean meal, flours, protein concentrates, and protein isolates were acquired from several sources (Table 1). Soy polymer samples were granular and looked very different from typical soy flours and concentrates, but they were included in the tests because their protein contents were similar to those of flours and concentrates, and thus they were arbitrarily classified as such products. GP 4445 phenol-formaldehyde resin (41.5% nonvolatiles) was provided by Georgia-Pacific Resins Inc. (Decatur, GA). Glu-X, wheat flour that is specific for plywood glues, was provided by The Robertson Corp. (Brownstown, IN). Foaming additive Carsonol SHS, a brand of sodium 2-ethylhexyl sulfate, was from Lonza Inc. (Fairlawn, NJ).

Proximate analyses. Moisture contents of the animal blood protein and soy products were determined by weighing out 10 g of sample onto a moisture determination balance (Ohaus Corp., Florham Park, NJ). The sample was heated at 105°C for 20 min. Crude protein (N × 6.25) and oil contents were determined by AOCS standard methods Ba 4c-87 and Bc 3-49, respectively (5).

Other protein analyses. Solubilities and surface hydrophobicity indices (S_o) were determined by following the methods of Sorgentini *et al*. (6); however, pH 10 was used for the analyses instead of pH 7 because of the alkalinity of foamed glue mixes. The basic solution used to disperse/dissolve the soy protein samples was $NaHCO_3/Na_2CO_3$ buffer. Fluorescence

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TABLE 1
Soy Products Evaluated for Foaming Properties

Product type	Product name	Source
Soybean meal	—	Central Soya Co., Inc. (Fort Wayne, IN)
Soy flour	ISU-CCUR	Iowa State University—Center for Crops Utilization Research (Ames, IA)
	Honeysoy 70	Cenex Harvest States (Mankato, MN)
	Honeysoy 90	Cenex Harvest States (Mankato, MN)
	Nutrisoy 7B	Archer-Daniels-Midland Co. (Decatur, IL)
	Soyafluff	Central Soya Co., Inc. (Fort Wayne, IN)
Textured flour	Centex 4030	Central Soya Co., Inc. (Fort Wayne, IN)
Protein concentrate	Arcon F	Archer-Daniels-Midland Co. (Decatur, IL)
	ISU-CCUR	Iowa State University—Center for Crops Utilization Research (Ames, IA)
	Procon 2000	Central Soya Co., Inc. (Fort Wayne, IN)
	Promax 70	Central Soya Co., Inc. (Fort Wayne, IN)
	Promine HV	Central Soya Co., Inc. (Fort Wayne, IN)
Textured concentrate	Response 4400	Central Soya Co., Inc. (Fort Wayne, IN)
Protein isolate	Arpro 1100	Archer-Daniels-Midland Co. (Decatur, IL)
Soy polymer	ProCote 150	Protein Technologies Int'l. (St. Louis, MO)
	ProCote 180	Protein Technologies Int'l. (St. Louis, MO)
	ProCote PC4200	Protein Technologies Int'l. (St. Louis, MO)
	ProCote PC5000	Protein Technologies Int'l. (St. Louis, MO)
	ProCote PX245	Protein Technologies Int'l. (St. Louis, MO)
	ProCote PX255	Protein Technologies Int'l. (St. Louis, MO)
	ProCote PX256	Protein Technologies Int'l. (St. Louis, MO)

intensities (FI) were measured by a Hitachi fluorescence spectrophotometer (model F-1200; Hitachi Ltd., Tokyo, Japan) at wavelengths of 350 nm (excitation) and 525 nm (emission) and sensitivity dial set at 0.2. FI values were plotted against protein concentration to determine S_o, which corresponded to the initial slope of the graph as calculated by linear regression.

Sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) was done according to the Wolf and Nelsen (7) modification of the Fling and Gregerson method (8). Samples were weighed out to provide 1 mg of protein in 500 μL of sample buffer [42 mM Tris-HCl (pH 6.8)], 2% SDS, 7% glycerol, 4.4% β-mercaptoethanol, 5 M urea, and 2 drops of 0.1% bromophenol blue) then heated in a boiling water bath for 5 min. Protein samples were loaded onto 15% acrylamide vertical slab mini-gels having a 32:1 ratio of acrylamide/AcrylAide (FMC BioProducts, Rockland, ME) and stabilized on Gel-Bond PAG film (FMC BioProducts). Bio-Rad (Bio-Rad Laboratories, Hercules, CA) broad-range molecular weight (6.5–200 kD) protein standards (consisting of aprotinin, lysozyme, trypsin inhibitor, carbonic anhydrase, ovalbumin, bovine serum albumin, phosphorylase b, β-galactosidase, and myosin) were included in each gel. Electrophoresis was done in a Mini-PROTEAN II system (Bio-Rad Laboratories).

Evaluation of foaming properties. The whipping method (3) was used to evaluate foaming capacities and stabilities of glue mixes containing blood (control) or soy proteins. Standard formulation for foamed plywood glues consisted of 22.0 g water, 6.0 g Glu-X, 3.5 g protein source, 65.1 g phenol-formaldehyde resin, 3.0 g 50% NaOH, and 0.3 g foaming additive per 100 g glue mix. Ingredients were added one at a time in the order presented, with each addition followed by 2–7 min of mixing at slow speed (setting no. 2) using the flat paddle blade of a KitchenAid mixer (model KSM 90, KitchenAid, St. Joseph, MI). Two hundred grams of glue mix was prepared for the foaming test and allowed to stand overnight at room temperature. The glue was poured into a mixing bowl and then whipped at maximum speed (setting no. 10) for 5 min using the KitchenAid mixer. The whipped glue mix was transferred into a tared, graduated beaker. Foam volume and mass were recorded to calculate foam density. Foam volumes after 1 and 3 h were recorded to determine foam stability. Duplicate determinations were done for each protein sample. Soy products that produced substantial and stable foamed glue mixes, as well as four nonfoaming samples, were brought to Georgia-Pacific Resins Inc. in Decatur, GA, to verify the accuracy of the results of the laboratory whipping test. The additional foaming tests were done on a bench-scale foam extrusion system (model 2MT.5 continuous mixer/foamer; E.T. Oakes Corp., Hauppauge, NY) using 2-kg glue mixes. Those products that continued to demonstrate the desired foaming qualities were then considered for later evaluations of adhesive strengths in plywood.

Statistical analyses. Statistical analyses were performed using the SAS® Systems for Windows software (SAS Institute Inc., Cary, NC). Duncan's multiple range tests were performed on all data to determine significant differences among the various protein sources that were evaluated. Correlation analyses were also done to determine any significant relationships among the variables.

RESULTS AND DISCUSSION

Partial proximate composition. There was considerable variability in the moisture contents of the various protein sources, but all the samples contained less than 10% moisture (Table 2). Crude protein contents indicated that the commer-

TABLE 2
Moisture, Protein, and Oil Contents of Spray-dried Animal Blood and Various Soy Products

Protein source	Moisture content (%)	Protein content[a] (% db)	Oil content (% db)
Blood	7.20	99.28	0.02
Meal and flours			
Soybean meal	6.33	51.46	1.43
Centex 4030	9.63	57.69	0.55
Honeysoy 70	6.47	58.71	0.37
Honeysoy 90	5.97	56.70	0.22
ISU-CCUR (defatted)	8.63	58.70	0.21
Nutrisoy 7B	6.50	55.22	0.36
ProCote PX245	5.60	54.84	0.02
ProCote PX255	5.54	58.65	0.03
Soyafluff	6.30	55.64	0.84
Protein concentrates			
Arcon F	5.50	69.85	0.21
ISU-CCUR	5.44	69.40	0.25
Procon 2000	7.00	70.87	0.24
ProCote 180	7.90	71.93	0.01
ProCote PC4200	7.09	81.62	0.03
Promax 70	5.00	70.01	0.32
Promine HV	6.63	73.30	0.17
Response 4400	5.97	69.27	0.14
Protein isolates			
Arpro 1100	8.00	91.55	0.13
ProCote 150	7.90	86.93	0.09
ProCote PC5000	9.11	90.77	0.06
ProCote PX256	5.27	94.13	0.25

[a]Kjeldahl N × 6.25. db = dry basis.

cially available soy products essentially met the industry's protein standards for flour (55%), concentrate (70%), and isolate (at least 90%). The spray-dried animal blood was nearly pure protein (Table 2). Sufficient protein must be present in the glue extender so that a strong network can be formed with the resin as well as the functional groups on the wood surface. Very low amounts of residual oil were detected in almost all the samples. Only soybean meal, Centex 4030 texturized flour, and Soyafluff flour contained more than 0.5% oil (Table 2). Oil is a very effective defoaming agent, so its presence is not desirable in any foamed product. The adverse effect of oil on foaming was evident in the case of Soyafluff. The original sample produced a foamed glue mix that was fairly stable for only an hour (Table 3). When Soyafluff was defatted with hexane to a residual oil content of 0.21% (dry basis: db) and then used in the glue mix, the foam that was produced was considerably more stable, even after 3 h of standing (Table 3).

Foaming properties. The control glue mix that contained animal blood produced significantly greater foam volume than almost all the soy-based glues, except those that contained Honeysoy 90 and ISU-CCUR flour (Table 3). Glue mixes containing ProCote PX256, Promine HV, and Promax 70 produced the least amount of foam (Table 4). Among product types, soy flour-based glue mixes produced markedly greater foam volumes than did concentrate- and isolate-based glues. Among soy meal and flours, Honeysoy 90 and ISU-CCUR produced significantly greater foam volumes, while Centex 4030 and soy meal produced the least. All other flour-based mixes produced similar foam volumes (Table 3). Among soy concentrates, ISU-CCUR, ProCote PC 4200, and ProCote 180 produced the greatest amounts of foam (Table 4). None of the soy isolates generated more than 400 mL of foam (Table 4).

After 1 h of standing, the most stable foamed glue mixes were those containing blood, Honeysoy 90, Honeysoy 70, defatted ISU-CCUR flour, Nutrisoy 7B, defatted Soyafluff, Arcon F, ISU-CCUR concentrate, Procon 2000, and Promine HV (Tables 3 and 4). Among soy isolates, only ProCote 150 produced a fairly stable foamed mix, but at 70% remaining foam, its stability was still considerably less than those of the control and the other soy products just mentioned.

After 3 h of standing, the glue mix containing Promine HV was the most stable, with 95% of the foam still remaining. Other stable glue mixes (at least 80% remaining foam) were those that contained Procon 2000, Honeysoy flours, ISU-CCUR flours and concentrate, Nutrisoy 7B, defatted Soyafluff, Arcon F, and the control (Tables 3 and 4). None of the isolates had any foam remaining after 3 h and none of the soy polymers (ProCote samples) produced stable foams.

Electrophoresis results. Protein bands for soy meal and

TABLE 3
Foaming Properties of Blood- and Soy Flour-Based Plywood Glue Mixes[a]

Protein extender	Initial foam volume (mL)	Remaining foam after 1 h (%)	Remaining foam after 3 h (%)	Foamed at Georgia-Pacific
Blood	588 ± 13^{a}	93 ± 1^{a}	81 ± 3^{b}	Yes
Meal and flours				
Soybean meal	$350 \pm 0^{g,h,i}$	70 ± 13^{b}	24 ± 10^{c}	Not tested
Centex 4030	$350 \pm 0^{g,h,i}$	0 ± 0^{f}	0 ± 0^{d}	No
Honeysoy 70	$480 \pm 20^{b,c,d,e}$	96 ± 4^{a}	$84 \pm 1^{a,b}$	Yes
Honeysoy 90	$563 \pm 38^{a,b}$	89 ± 1^{a}	$85 \pm 2^{a,b}$	Yes
ISU-CCUR (defatted)	$550 \pm 0^{a,b,c}$	91 ± 0^{a}	82 ± 0^{b}	Not tested
Nutrisoy 7B	$475 \pm 0^{b,c,d,e,f}$	95 ± 0^{a}	83 ± 4^{b}	Yes
ProCote PX245	$425 \pm 25^{d,e,f,g,h}$	1 ± 1^{f}	1 ± 1^{d}	Not tested
ProCote PX255	$488 \pm 38^{b,c,d}$	17 ± 2^{e}	3 ± 3^{d}	Not tested
Soyafluff (defatted)	$475 \pm 25^{b,c,d,e,f}$	95 ± 3^{e}	81 ± 9^{b}	Not tested
Soyafluff (as is)	$425 \pm 0^{d,e,f,g,h}$	76 ± 6^{b}	11 ± 1^{d}	No

[a]Values represent mean ± standard deviation of two determinations. Means within columns followed by different roman superscript letters are significantly different ($P \leq 0.05$).

TABLE 4
Foaming Properties of Blood- and Soy Concentrate/Isolate–Based Plywood Glue Mixes[a]

Protein extender	Initial foam volume (mL)	Remaining foam after 1 h (%)	Remaining foam after 3 h (%)	Foamed at Georgia-Pacific
Blood	588 ± 13[a]	93 ± 1[a]	81 ± 3[b]	Yes
Protein concentrates				
Arcon F	380 ± 20[e,f,g,h]	91 ± 3[a]	81 ± 4[b]	Yes
ISU-CCUR	475 ± 25[b,c,d,e,f]	90 ± 1[a]	80 ± 0[b]	Not tested
Procon 2000	370 ± 20[f,g,h,i]	92 ± 5[a]	88 ± 3[a,b]	Yes
ProCote 180	405 ± 5[d,e,f,g,h]	37 ± 0[d]	0 ± 0[d]	Not tested
ProCote PC4200	435 ± 5[d,e,f,g,h]	20 ± 3[e]	0 ± 0[d]	No
Promax 70	270 ± 20[i]	0 ± 0[f]	0 ± 0[d]	No
Promine HV	330 ± 5[h,i]	95 ± 1[a]	95 ± 1[a]	Yes
Response	355 ± 5[g,h,i]	10 ± 0[e,f]	0 ± 0[d]	No
Protein isolates				
Arpro 1100	388 ± 38[d,e,f,g,h]	0 ± 0[f]	0 ± 0[d]	Not tested
ProCote 150	375 ± 0[e,f,g,h]	70 ± 3[b]	0 ± 0[d]	Not tested
ProCote PC5000	350 ± 0[g,h,i]	0 ± 0[f]	0 ± 0[d]	No
ProCote PX 256	333 ± 8[h,i]	48 ± 4[c]	1 ± 1[d]	Not tested

[a]Values represent mean ± standard deviation of two determinations. Means within columns followed by different roman superscript letters are significantly different ($P \leq 0.05$).

flours (Fig. 1) were generally similar to those of undenatured water-extractable soybean proteins (9). Bands for β-conglycinin (molecular weights greater than 45 kDa) and glycinin were well defined. The excellent foaming properties of Honeysoy, Nutrisoy, and Soyafluff may be attributed to the presence of intact protein fractions. In contrast, ProCote PX 245 (lane 4) had only one distinct protein band (just above the 21.5 kDa marker); the rest of the major protein bands were faint or missing altogether, and there was considerable streaking of the gel pattern. There was also noticeable aggregated protein that did not penetrate the gel. This pattern indicated major modification or denaturation during processing, which may explain the sample's inability to generate stable foam. Streaking and aggregated protein were likewise pronounced for soy meal (lane 5) and Centex 4030 (lane 6), reflecting more extreme processing conditions. In addition, the protein bands for Centex 4030 were not as dark as those in the other soy flours, suggesting that the amounts of protein fractions were less than those present in Honeysoy, Nutrisoy, and Soyafluff flours.

Almost all the soy protein concentrate had band patterns that were also similar to those of undenatured soy proteins (Fig. 2 and lanes 7 and 8 of Fig. 3). There were indications, though, of modification, such as the disappearance of the 31 kDa glycinin fraction and the faintness of the 66 kDa β-conglycinin bands. ProCote 180 (lane 2) lacked all the major protein bands and had only the aggregated protein at the top of the gel, indicating that it may have undergone massive denaturation during processing, which prevented the formation of stable foam. ProCote PX 255 (lane 7) and ProCote 4200 (Fig. 3, lane 7) were also missing several major protein bands,

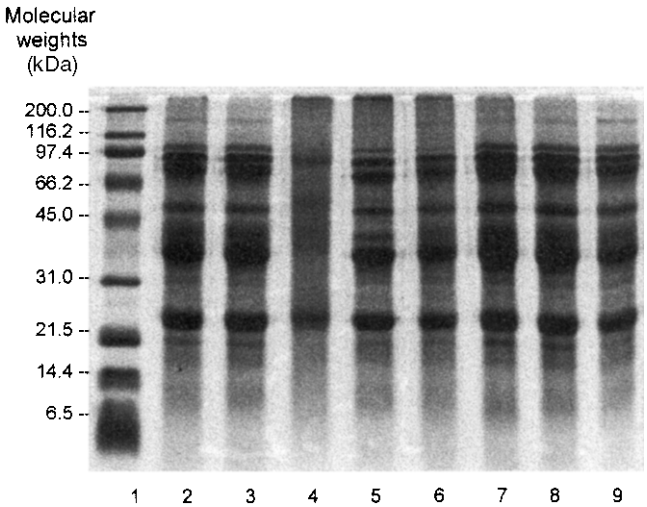

FIG. 1. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS- PAGE) band patterns for (1) molecular weight standards, (2) Soyafluff flour, (3) Nutrisoy 7B, (4) ProCote PX 245, (5) soy meal, (6) Centex 4030, (7) Honeysoy 70, (8) Honeysoy 90, and (9) ISU-CCUR soy flour. See text for manufacturers.

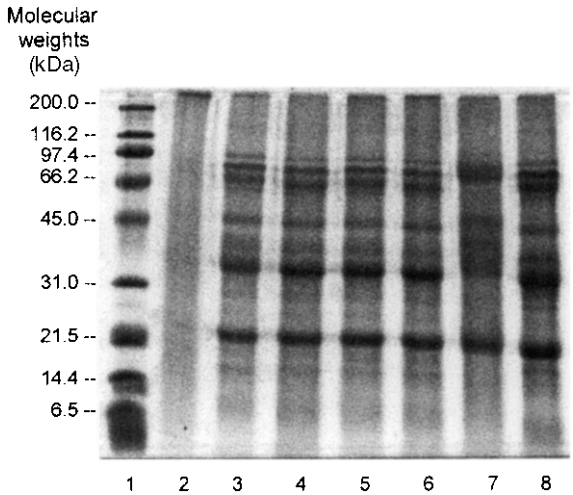

FIG. 2. SDS-PAGE band patterns for (1) molecular weight standards, (2) ProCote 180, (3) Procon 2000, (4) Promax 70, (5) Arcon F, (6) Response 4400, (7) ProCote PX 255, and (8) Promine HV. See Figure 1 for abbreviations and text for manufacturers.

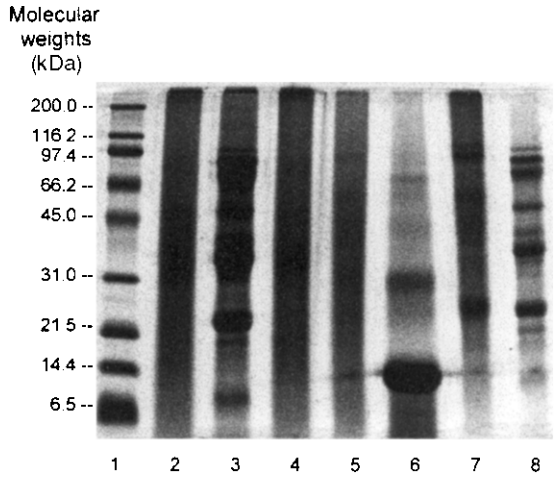

FIG. 3. SDS-PAGE band patterns for (1) molecular weight standards, (2) ProCote 150, (3) ProCote PX256, (4) Arpro 1100, (5) ProCote 5000, (6) animal blood, (7) ProCote 4200, and (8) ISU-CCUR soy concentrate. See Figure 1 for abbreviations and text for manufacturers.

and their gel patterns showed considerable streaking. Product literature for the ProCote samples describe them as soybean-derived natural polymers that were modified for use as coating binder or additive. It is highly probable that such modification involved hydrolysis by alkali treatment (10,11).

Soy protein isolates appeared to have undergone the most significant degree of denaturation and/or hydrolysis, as indicated by the substantial streaking of the gel patterns and presence of aggregated protein at the top of the gel. Many of the major protein bands were also missing or barely visible (Fig. 3). The lack of these protein fractions prevented the isolates from producing any stable foams.

Solubility and surface hydrophobicity. Solubility and surface hydrophobicity are two important properties that influence foaming ability and foam stability of proteins (2–4,12). Proteins must be soluble first before they can express their functionality (2). At pH 10, animal blood protein was the most soluble among the protein sources, but there were also several soy flours, concentrates, and isolates that showed high protein solubilities (Table 5). Statistical analysis indicated that high solubility tended to increase the volume of foam produced by the protein extenders, but no significant correlation was found between solubility and foam stability. The presence of alkali usually improves solubility of soy proteins, especially if the pH is greater than 10.5 (as is the case in foamed glue formulations), by causing dissociation and disaggregation of proteins (2). During foam formation, proteins that are soluble can rapidly reach the interface, lower the interfacial tension, and unfold to form surface films around air droplets, thus retarding the coalescence and collapse of bubbles (2,3). Kinsella (2), however, also cautioned that high solubility may indicate extensive proteolysis and disaggregation, causing impaired functional properties. This may be the reason for the poor foaming properties, particularly foam stability, of Arpro 1100 soy protein isolate and the ProCote soy polymer samples (Tables 3 and 4), despite their fairly high protein solubility values (Table 5).

Several studies have reported on the relationship between surface hydrophobicity and foaming properties of proteins (13–17). Unfolding of proteins improves their foaming properties by allowing greater hydrophobic interactions (13). Kato *et al*. (14) reported that high surface hydrophobicity improved foaming power but had no correlation with foam stability. Townsend and Nakai (15) also found no relationship between foam stability and surface hydrophobicity but reported a correlation with average hydrophobicity. Our results appear to confirm these earlier findings, as we found no definitive trends in the surface hydrophobicity indices (S_o) of the various blood and soy protein products that may explain their differences in foaming properties (Table 5). Animal blood had a very low S_o value, and one would expect that it would show poor foaming properties, but the glue mix containing blood protein produced substantial and stable foam. In contrast, several of the soy products had very high S_o values, but their glue

TABLE 5
Solubilities and Surface Hydrophobicity Indices (S_o) at pH 10 of Spray-Dried Animal Blood and Various Soy Products[a]

Protein source	Soluble protein (%)	S_o	Protein source	Soluble protein (%)	S_o
			Protein concentrates		
Blood	100 ± 2^{a}	385 ± 22^{j}	Arcon F	13 ± 0^{k}	$1261 \pm 22^{c,d}$
Meal and flours			ISU-CCUR	66 ± 2^{d}	$1379 \pm 29^{b,c}$
Soybean meal	40 ± 2^{g}	$805 \pm 58^{h,i}$	Procon 2000	19 ± 0^{j}	253 ± 19^{j}
Centex 4030	$21 \pm 1^{i,j}$	$995 \pm 38^{f,g,h}$	ProCote 180	71 ± 8^{c}	$1077 \pm 26^{e,f}$
Honeysoy 70	47 ± 2^{f}	672 ± 153^{i}	ProCote PC4200	83 ± 2^{b}	686 ± 23^{i}
Honeysoy 90	55 ± 1^{e}	$831 \pm 39^{g,h,i}$	Promax 70	30 ± 2^{h}	$1346 \pm 81^{b,c}$
ISU-CCUR (defatted)	62 ± 2^{d}	$1376 \pm 24^{b,c}$	Promine HV	24 ± 1^{I}	1475 ± 65^{b}
Nutrisoy 7B	71 ± 2^{c}	$1335 \pm 63^{b,c}$	Response 4400	13 ± 0^{k}	706 ± 30^{i}
ProCote PX245	55 ± 2^{e}	744 ± 18^{i}	Protein isolates		
ProCote PX255	59 ± 3^{d}	742 ± 41^{i}	Arpro 1100	70 ± 1^{c}	$1007 \pm 71^{f,g}$
Soyafluff (defatted)	$57 \pm 3^{d,e}$	$1122 \pm 69^{d,e,f}$	ProCote 150	72 ± 1^{c}	$1206 \pm 43^{c,d,e}$
			ProCote PC5000	81 ± 3^{b}	328 ± 10^{j}
			ProCote PX 256	39 ± 2^{g}	1682 ± 65^{a}

[a]Values represent mean ± standard deviation of three replicates. Means within columns followed by different roman superscript letters are significantly different ($P \leq 0.05$).

mixes produced less foam volume and/or very unstable foams (Table 5). No significant statistical correlations were detected between S_o and foam volume, foam stability, or solubility; although, among soy flours, high S_o values tended to produce greater foam volumes.

Our results showed that data on foaming properties from the laboratory whipping method correlated well with the results obtained at the Georgia-Pacific plant (Tables 3 and 4), which indicated that the whipping method may be used to screen various soy products for evaluation as blood replacement in foamed glues. At Georgia-Pacific, glues containing the flours Honeysoy 90 and Nutrisoy 7B or the concentrates Arcon F and Procon 2000 were easy to mix and produced smooth, continuous foam strands using mixer speeds that were only slightly higher than the 400 rpm needed to foam the blood-based glue (data not shown). Glue with Promine HV was very thick and required long periods of soaking in hot water to thin out the glue to the recommended viscosity of 1000 cP. Glue that used Honeysoy 70 flour also foamed, but at a pump speed of nearly 1000 rpm, more than double that needed to foam the control glue. Based on their performance in the laboratory and at the pilot plant, the glues containing the soy flours ISU-CCUR, Honeysoy 90, Nutrisoy 7B, and defatted Soyafluff and the soy protein concentrates Arcon F, ISU-CCUR, and Procon 2000 were identified as having mixing and foaming properties desirable for foam extrusion and comparable with those of the blood-based glue, thereby meriting further investigation on their adhesive qualities in plywood.

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