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Nutrient-based Corn and Soy Products by Twin-screw Extrusion

ABSTRACT

Blends were developed to provide 20% protein, 12% fat, 68% carbohydrate and 8% moisture. High protein soy products (full fat flakes, protein isolate and/or concentrate) were formulated with corn meal and soybean oil to provide high protein and fat. The blends were extruded to provide pre-cooked foods that could be reconstituted at 40°C to a porridge or gruel, eliminating prolonged cooking or degradation of heat labile nutrients. Two types of soy isolate and concentrate were evaluated under extrusion temperatures from 100 to 130°C and feed moistures 8.5 to 18%. The extrusion of lower valued concentrates at 100 to 115°C with moisture from 12 to 18% produced a precooked mix that was high in nutrients and contained the most available lysine.

Key Words: extrusion, corn, soy, precooked, consistency, nutrition

INTRODUCTION

THE BENEFICIAL EFFECTS OF CORN/SOY COMBINATIONS AND their complementary improvement of amino acid balance, have long been recognized by nutritionists (Bressani and Elias, 1966). Extrusion has been used to process cereal-legume blends for many years (Jansen et al., 1978). The cereal portion has been precooked in a single-screw extruder and then blended with the legume portion (usually soy) which is processed separately. Extrusion cooking is an effective method to pre-cook grains and flours. Complete gelatinization of wheat flour resulted at a processing temperature of 110°C and moisture content of 24 to 27% (Chiang and Johnson, 1977). Almost complete gelatinization was found in maize, corn starch and wheat starch at extrusion temperatures of 150 to 170°C and moisture contents ranging from 16 to 22% (Rabe et al., 1980). Increases in extrusion temperature and moisture content lead to a higher degree of gelatinization. Extruding the corn-soy mixture, instead of only the cereal portion would enable the production of a nutritious precooked blended product. The advantages of such a product would be the elimination of prolonged cooking by the consumer and less degradation of nutrients. Protease inhibitors have a harmful effect on the digestion of soy protein by blocking proteolytic enzymes (Krogdahl and Holm, 1979). Inactivation of trypsin inhibitors in the extrusion process can be accomplished through the heat treatment. Mustakas et al. (1964) showed that extrusion of full fat soy flour, in the 135°C range was enough to inactivate 95% or more of the trypsin inhibitor that was in the unprocessed material.

The use of nutritious proteinaceous food ingredients, such as soy concentrates and soy isolates can provide highly concentrated protein sources, high lysine, bland flavor and reduction of flatulence factors and reducing sugars and are hypothesized to lead to improved overall product quality (Jacob et. al., 1996).

Our objective was to determine extruder conditions for various blends using soy isolates and/or soy concentrates to produce a final precooked product that would exhibit minimal trypsin inhibition and compare favorably with porridges from existing corn soy-blends in consistency and color.

MATERIALS & METHODS

DEGERMED, ENRICHED CORNMEAL WAS RECEIVED FROM LAUHOFF Grain Company (Decatur, IL), raw full fat soy flakes from Cargill Foods/Protein Products (Cedar Rapids, IA), soy isolates from Protein Technologies International (St. Louis, MO) and soy isolates and concentrates from Archer Daniels Midland (Decatur, IL); pure soybean oil (America's Choice) was purchased locally. Proximate analyses of these materials were determined (Table 1).

The materials were blended by adding soy flakes, soy isolate and or concentrate to a preweighed quantity of cornmeal in a Hobart kettle and mixing using a wire whip for 1 min. The prescribed amount of soybean oil was then added and mixing continued for an additional 5 min. The contents were transferred to a V-blender and blended for 30 min (Table 2).

The blends were extruded in a ZSK30 twin screw extruder (Werner & Plfleiderer Company, Ramsey, NJ) with nine individual barrel sections, each with its separate temperature control. The die plate was fitted with two circular inserts 3.18 mm dia. Screw speed was maintained at a constant 300 RPM. The blends were fed into the extruder using a series 6300 digital feeder, type 35 twin screw volumetric feeder (K-tron Corp., Pitman, NJ) at a constant setting of 600 rpm yielding feed rates for blends 1, 2, 3, 4, and 5 of 68, 65, 78, 60, and 67 g/min respectively). Water was added using an electromagnetic dosing pump (Milton Roy, Acton, MA) with the pump setting (stroke

Table 1—Proximate analysis of raw materials

	%Protein N × 6.25	%Carbohydrates	%Total Fat	%Moisture
Corn Meal	6.5	82.21	1.14	10.15
FF Soy Flakes[a]	39.1	33.23	20.00	7.67
Soy Oil	—	—	100.00	—
Soy Isolate A[b]	85.8	8.31	0.32	5.57
Soy Isolate B[c]	89.3	5.6	0.04	5.06
Soy Conc. A[d]	64.1	28.81	0.29	6.70
Soy Conc. B[e]	64.7	28.28	0.16	6.86

[a]Raw full fat soy flakes.
[b]Supro 500E.
[c]ProFam 974.
[d]ARCON F.
[e]ARCON G.

Table 2—Composition of blends

	Blend 1	2	3	4	5
Corn meal	66.25	66.25	64.15	66.05	66.05
FF Soy Flakes[1]	12.80	12.80	13.50	12.90	12.90
Soy Oil	8.25	8.25	8.35	8.35	8.37
Soy Isolate A[2]	8.70	8.70	—	—	—
Soy Isolate B[3]	—	—	—	8.70	8.70
Soy Conc. A[4]	4.00	—	7.00	4.00	—
Soy Conc. B[5]	—	4.00	7.00	—	4.00

length/frequency) as the independent variable. A 5 × 3 × 3 experimental design was employed where five blends were extruded at three temperatures (100, 115, and 130°C) measured at zone 9 of the extruder, and three levels of added moisture (settings 40/5, 40/8 and 40/11 corresponding to 4.4, 7 and 9.7 mL/min added water). The screw configuration (Fig. 1) incorporated kneading blocks to enhance mixing, dispersing and cooking, and reverse pitch screw elements to create back pressure or shear.

Analyses

Water absorption index (WAI), the weight of gel obtained/g dry ground sample, was determined as reported by Jin et al. (1995). Samples were ground and sifted through a 210 micron sieve. Two analyses were conducted for each treatment sample. To measure trypsin inhibitor activity, samples were ground to pass a 250μ screen in a coffee-spice mill (Food Preparer, Model 505, Moulinex, France). The powder (5g) was extracted three times with 25 mL of petroleum ether and air dried. After drying, 1g of sample was diluted with 19 mL water, adjusted to pH 7.6 with 0.1N HCl, shaken for 1h and centrifuged at 700 × *g* for 30 min. The supernatant extract was used without dilution for the extruded samples, at a 1:25 dilution for the corn soy blends, and at a 1:50 dilution for the full fat soy flakes. A trypsin standard curve was prepared and samples were analyzed as described by Kakede et al., 1969.

Available lysine was measured using an adaptation of the dye-binding method of Hurell et al., 1979. After reaction with propionic anhydride the samples were shaken with the dye overnight (16h).

Gelatinization

The extruded, undried product was analyzed for degree of gelatinization using a Perkin-Elmer DSC7 (Perkin Elmer Inc., Norwalk, CT). Samples were heated at 10°C/min to above 120°C. Data were reported as the percentage of the enthalpy or heat of fusion of totally ungelatinized material (15.5 J/g). The melting transition appeared on the thermogram at about 75°C.

Analysis of ground material

The extrudate was dried at 130°C for 10 to 40 min, depending on moisture content from the extruder, using an Isotemp Model 200 Oven (Fisher Scientific, Newark, DE) to a final moisture of <8%. Moistures were determined using the vacuum oven method (AOAC, 1990). All dried extrudates were ground in a coffee mill (Model 203, Krups North America, Inc., Closter, NJ) for 45s. Particle size of ground products was determined using a Model 770 AccuSizer (Particle Sizing Systems, Santa Barbara, CA). Samples were fed using a vibratory feeder and number-weight means were recorded.

Consistency

Samples for consistency analysis were done in quadruplicate. Ground samples were reconstituted into a porridge in accordance with specifications detailed in SIC Code 2041 for corn soy blends. The powder (37±0.2g) was gradually added to 100 mL water that was heated to 40 (±0 .2)°C while stirring vigorously. The slurry was then stirred gently for 3 min to dissolve lumps. After standing for 2 min to complete hydration, the slurry was stirred gently for 15 s and poured into the reservoir of a Bostwick Consistometer. The excess was removed from the reservoir, and after resting for 30s, the lever was released allowing the slurry to flow. The Bostwick reading was taken after 60s. The water temperature was a deviation from SIC 2041 (1996) in that the current specification deals with blends that were not fully cooked. Since this product was considered "instant," 40°C was used since it should more closely represent ambient temperature at the food distribution (or end user) site.

Back extrusion

Immediately after measuring consistency, the product was scooped into a back-extrusion cell. A TAXT2 texturometer (Texture Technologies Corp., Scarsdale, NY) fixed with a cylindrical plunger was used to determine the force-distance relationship by extruding the product up and around the edge of the plunger disc through a 2.5 mm annulus. Measurements of the area under the force-distance curve, indicating the work required to extrude, were recorded.

Color

Color difference measurements, L, a, and b were made on the porridge samples using a Colorsphere Color Analyzer (BYK Gardner, Rivers Park, MD) using a reference white standard plate (L = 98.33, a = −0.20, b = 0.19). Total color (ΔE) was calculated using:

$$\Delta E = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{1/2} \quad (1)$$

Statistical analysis

Statistical analysis of the full model was accomplished using the SAS system General Linear Models procedure. Evaluation and separability of means were analyzed using the Bonferroni multiple comparison method # (SAS Institute, Inc., 1990). Significance of differences was defined at P≤0.05.

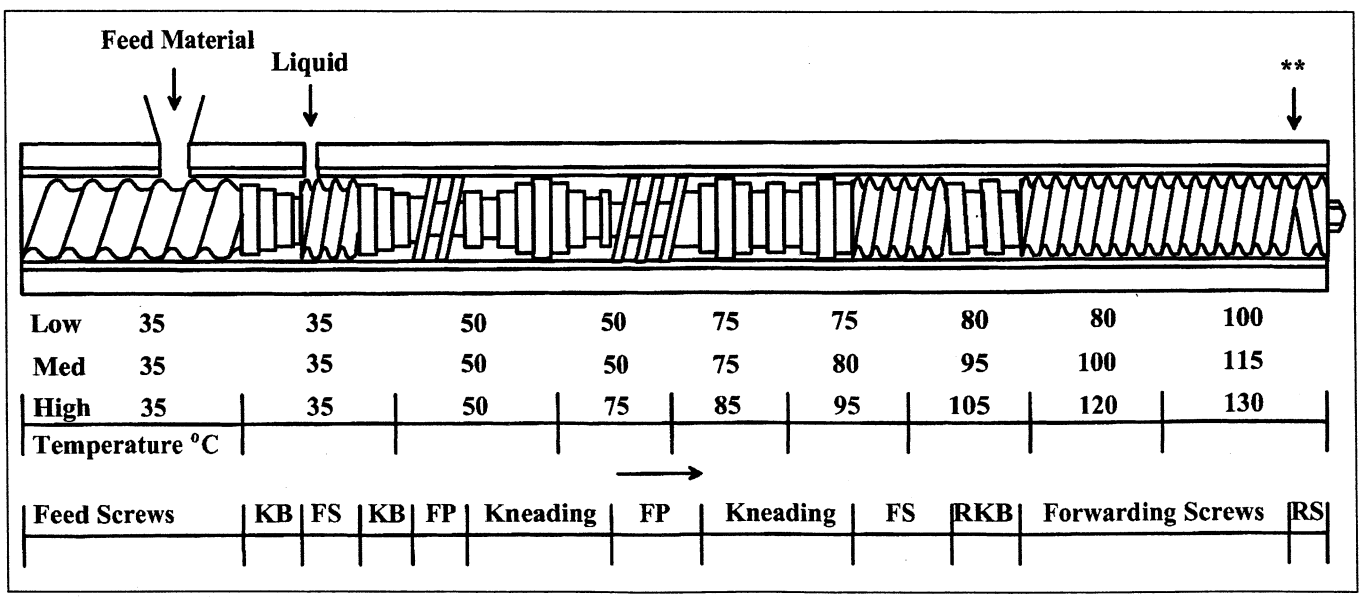

Fig. 1—Schematic of screws configuration for ZSK 30 extruder.

Table 3—Gelatinization and antitrypsin activity of components, blends and product

Sample	Percent Gelatinized		Average TIU[a]/mg sample	
	Before extrusion	After extrusion	Before extrusion	After extrusion
FF Soy Flakes[b]	68.0	n.m.	86.0	n.m.
Corn Meal	91.2	n.m.	n.m.	n.m.
Std CSB[c]	66.9	n.m.	n.d.[d]	n.m.
Blend 1	56.2	100	33.4	n.d.
2	50.9	100	35.4	n.d.
3	73.5	100	38.2	n.d.
4	90.0	100	33.9	n.d.
5	44.5	100	33.9	n.d.

[a]Trypsin Inhibitor Units.
[b] Full fat soy flakes.
[c]Std CSB.
[d]n.m. - not measured; n.d. not detected

RESULTS & DISCUSSION

Gelatinization and antitrypsin activity

The production of an instant product was considered a priority since it would enable reconstitution of the ground extrudate at temperatures considerably below 100°C. This would minimize degradation of any fortificants (vitamins and minerals) which may be added. Precooking in the extruder was measured by determining the degree of gelatinization using differential scanning calorimetry. A higher percentage or degree of gelatinization implies a higher degree of cook (Bhattacharya and Hanna, 1987). The gelatinization of two of the raw materials, before and after extrusion (Table 3) were compared at moistures ranging from 8 to 18%. All extrudates were 100% cooked.

Mild heat treatment of vegetable proteins can improve their digestibility through inactivation of protease inhibitors. The inactivation of trypsin inhibitor has been correlated with an increase in nutritional value. In order to reduce or eliminate this anti-nutritional factor control of processing parameters including moisture content, temperature and time are required. Under-heating results in incomplete inactivation of the trypsin inhibitor whereas over-heating may result in reduced lysine availability. (Waldroup and Smith, 1989). Anti-trypsin activity (measured as Trypsin Inhibitor Units, TIU/mg sample) was present in the raw full-fat soy flakes and, to a lesser degree, in the blends. There was no anti-trypsin activity in the standard CSB. Extrusion at all conditions was effective in totally inactivating the trypsin inhibitor.

Lysine availability

The moisture and temperature conditions normally associated with extrusion favor Maillard reactions. The reaction between reducing sugars and free amino groups can have a negative effect on digestibility and availability of amino acids (Björck and Asp, 1983). Since extrusion eliminated the trypsin inhibitor, there was some concern about the retention of available lysine. Lysine availability can be used as a measure of processing damage (Walker, 1983). Results of the measurement of available lysine in the blends were compared (Table 4), prior to, and after extrusion. Generally, the products extruded at low and intermediate temperatures, showed acceptable levels of available lysine.

Powder characteristics

Although extrudates were ground in a similar manner, there was evidence of difference in particle sizes. Mean particle sizes of all blends were compared (Fig. 2a) as they corresponded to feed moisture by pump setting). The number-mean particle size was largest at higher moisture conditions. The most significant independent variable affecting particle size was feed moisture ($P < 0.05$). The highest degree of puff, or expansion ratio, expressed as product diameter divided by the diameter of the die, was observed for blends extruded at the lowest feed moisture (Fig. 2b). Only differences between the highest and lowest feed moistures were significant ($P < 0.05$). The absence of effects due to blend differences was expected confirming

Table 4—Available lysine (mg/g protein) for corn-soy blends

Blend	Extrusion Temp	% Moisture	Available Lysine
1 (before ext)	N/A	7.79	64.39
2 (before ext)	N/A	8.44	62.64
3 (before ext)	N/A	9.43	72.98
4 (before ext)	N/A	8.13	65.73
5 (before ext)	N/A	8.13	65.72
3	100	9.00	70.00 [a]
3	115	13.04	68.44[ab]
3	100	12.15	68.03[ab]
3	115	16.37	62.22 [bc]
3	100	16.67	61.45 [bcd]
1	100	17.62	61.41 [bcd]
3	130	8.94	61.34 [bcd]
2	100	16.51	60.74 [bcde]
3	130	10.91	59.58 [cdef]
3	130	7.43	59.46 [cdef]
3	115	6.15	58.08 [cdefg]
2	115	8.41	56.88 [cdefgh]
2	115	8.01	55.76 [cdefghi]
4	115	13.01	55.38 [cdefghi]
4	115	11.77	55.36 [cdefghi]
Std Corn Soy Blend	N/A		

[a-i]Means with no letter in common are significantly ($p < 0.05$) different.
Root MSE = 1.744.

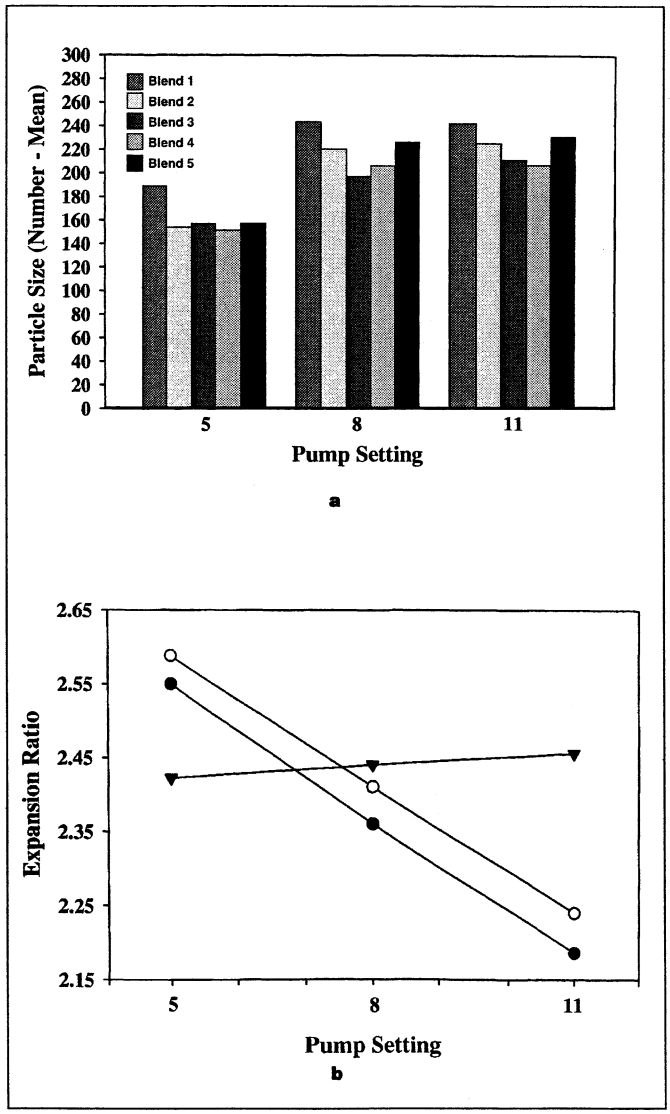

Fig. 2—(a) Particle size (number-mean) of blends as related to feed moisture (pump setting). (b) Expansion of extrudate at various feed moisture (pump setting), ● 100°C, ○ 115°C and ▼ 130°C. Pump setting 5 = 4.4 mL/min; 8 = 7.0 mL/min; 1 = 9.7 mL/min.

results of Rhee et al. (1980). Processing at 130°C resulted in expansion ratios that were unaffected by feed moisture. The degree of expansion of the extruded product affects product density and friability (Conway and Anderson, 1973) and increased expansion results in a more friable product that produces more fines upon grinding. This increase in fines often results in less dispersable powders due to inconsistent wetting of surfaces. Anderson et al. (1969) reported that the water absorption index (WAI) of extruded cereal products was higher for higher moisture extrudates and this was confirmed for all blends in our study (Fig. 3a). The lower WAI at low feed moisture may be related to an increase in shear resulting in structural modification of the starch (Diosady et al., 1985). The evidence of increased shear was observed in measurement of torque which was 25 to 75% higher in the low moisture extrusion and the behavior for all blends was similar. The effect of temperature was relatively minor and would be expected to be greater at higher temperatures.

Porridge characteristics

WAI showed a strong correlation with the consistency of the porridge (rehydrated blends) as measured by the work involved in back extrusion (W_{BE}). A linear relationship was found (Fig. 4) between these two parameters where:

$$W_{BE} = -0.018 + 0.011\,(\text{WAI});\ R^2 = 0.871 \qquad (2)$$

The higher water absorption leads to the formation of thicker slurries and the dispersion of the powders made from higher moisture extrudates was enhanced. Since specifications for the consistency of CSB were measured in Bostwick units, W_{BE} was compared to Bostwick values. The result of that comparison (Fig. 5) indicates a strong correlation:

$$\text{Bostwick Consistency} = -22.31 - 8.56 \ln W_{BE};\ R^2 = 0.903 \qquad (3)$$

The measurement of consistency using the Bostwick index provides a less quantitative analysis since it requires estimates of the flow distance at a specified time. The utilization of the back extrusion method provides a more precise measurement of consistency. The vast majority of the consistencies (Fig. 5) fell within the specifications for CSB.

Porridge color (total color E) was studied (Fig. 3b) as a function of blend, feed moisture and temperature. Total color was most dependent on the feed moisture and increased as moisture decreased in an approximate linear relation. The relatively narrow range of tem-

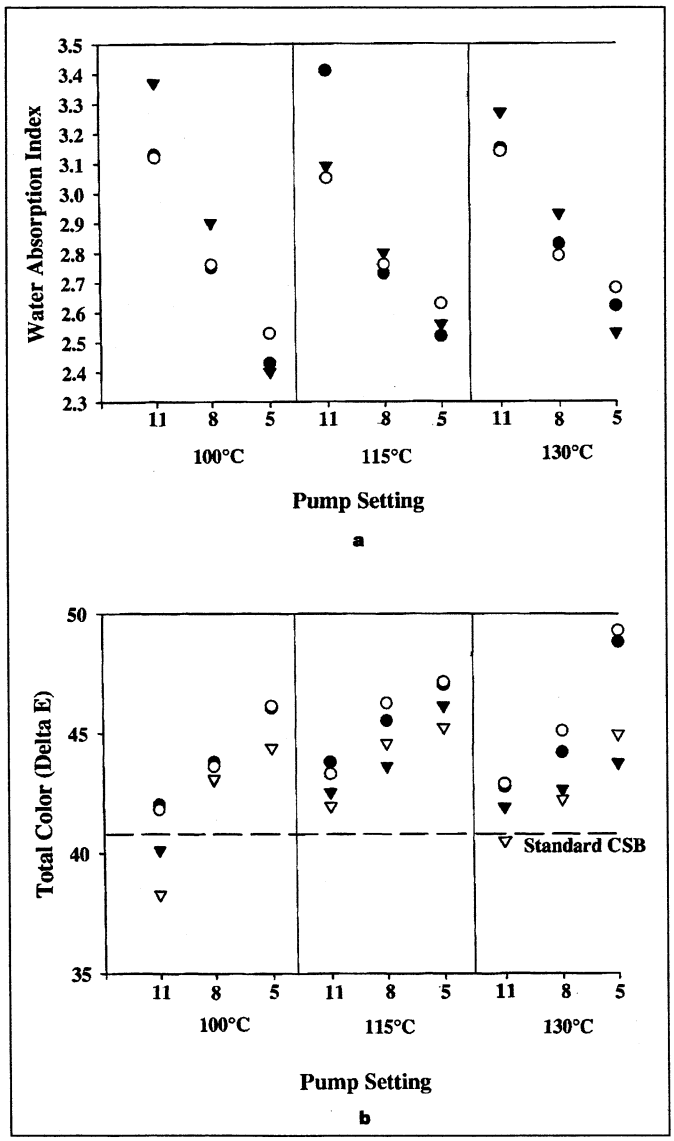

Fig. 3—(a) Water absorption index of ground blends as related to feed moisture (pump setting), ● Blend 2 , ○ Blend 3, and ▼ Blend 5; 100°C, 115°C, 130°C. (b) Total color E at various feed moisture (pump setting), ● Blend, ○ Blend 3, ▼ Blend 4, and ▽ Blend 5; 100°C, 115°C, 130°C, $\Delta E = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{1/2}$. Pump setting 5 = 4.4 mL/min; 8 = 7.0 mL/min; 11 = 9.7 mL/min.

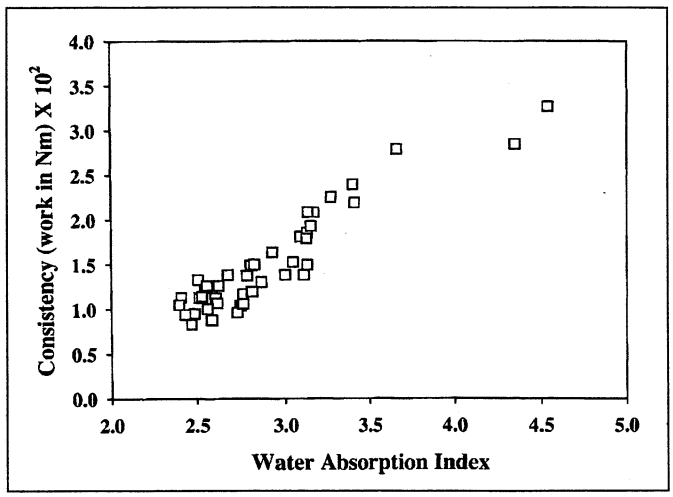

Fig. 4—Consistency (work in back extrusion N-M) and water absorption index.

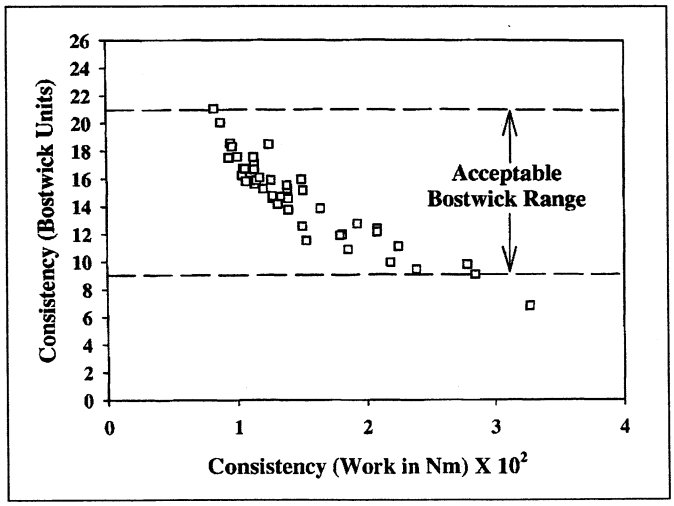

Fig. 5—Correlation of Consistency (Bostwick units) with Consistency (work in back extrusion N-M); Bostwick specifications for Cornsoy Blend shown.