Characteristics of Extruded Mixtures of Cornmeal and Glandless Cottonseed Flour[1]

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ABSTRACT

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The effect of protein and dietary fiber supplementation on physical, chemical, and sensory quality properties were evaluated by extrusion cooking of mixtures of cornmeal and glandless cottonseed flour. Response surface analysis was used to determine the effect of the level of cottonseed flour (0–25%, w/w), barrel temperature (65.6–93.3°C), screw speed (350–450 rpm), and moisture content (18–21%) on the characteristics of the dried extrudates. Increased levels of cottonseed flour reduced collet bulk density and resistance to shear and increased diametric expansion and darkness compared with cornmeal controls that were similarly processed. Extrusion reduced protein solubility and available lysine in samples. Water absorption capacity was dependent largely on the moisture content of the mixture. A sensory panel found the samples containing cottonseed flour to be less yellow, softer, and possessing a nutty flavor. Snacks containing 12.5% cottonseed flour were as acceptable overall as those containing only corn. Products containing higher levels of cottonseed flour may require seasoning to improve palatability.

For the past 20 years, glandless cottonseed flour (CSF) has been studied as a source of protein supplementation (Lusas and Jividen 1987). The high levels of protein and dietary fiber in CSF affect water-holding capacity and other physical characteristics (Liao 1987, Zarins and Marshall 1988), whereas the pigments and flavor compounds in CSF may affect the sensory quality of some foods containing CSF (Wan et al 1979, Blouin et al 1981).

Expanded corn-meal snacks are low in nutrient density but are popular worldwide. Fortifying snacks with CSF could be more successful than trying to modify staple foods. It would result in higher levels of protein, dietary fiber, and minerals due to the differences in composition between CSF and corn meal (Table I). The objective of this study was to evaluate the effects of CSF and extrusion conditions on physical, chemical, and sensory characteristics of corn-meal snacks.

MATERIALS AND METHODS

Corn Meal and Glandless Cottonseed Flours

Yellow degerminated enriched corn meal (Lauhoff Grain Co., Danville, IL) was supplied by Frito Lay, Inc., Irving, TX. Partially defatted glandless CSF was obtained through the Natural Fibers and Food Proteins Commission of Texas. The two materials were blended before extrusion in a ribbon blender to produce mixtures containing 12.5 and 25% CSF by weight (proximate analyses are listed in Table I).

Experimental Design

A design for analyzing central composite response surface (Cochran and Cox 1957) was created using a computer software program (CADE Optimization, International Qual-Tech, Ltd., Plymouth, MN). Three levels of four independent variables were studied (Table II). Eight centerpoint trials were distributed throughout the study to provide an internal estimate of experimental error. Thirty-two trials were conducted; the sequence was not random with respect to material and barrel temperature since those parameters were difficult to change rapidly in preliminary experiments. Analysis of variance was used to determine linear, quadratic, and interaction effects of the four variables on the 19 dependent variables. Lack of fit was also determined for the regression models.

Extrusion Conditions

A twin screw extruder (APV Baker Perkins MPF50D) with an L-D ratio of 15 was used. The corotating, intermeshing screws had the following profile: 250-mm double-lead feed screw; 87.5-mm 60° reversing paddle; 75-mm single-lead screw; 37.5-mm 60° reversing paddle; 75-mm single-lead screw; 25-mm 90° forwarding paddle; 25-mm 45° reversing paddle; 62.5-mm single-lead screw; cone. The die had three 4-mm holes, and a back plate was used. The standard operating temperature was 43°C at the feed end (zone 1), 49°C, zone 2, and 54°C, zone 3. The temperatures of the fourth and fifth zones were varied simultaneously as follows: 60 and 65.5°C, 65.5 and 79°C, and 79 and 93.3°C. The temperature of zone 5, which was located just before the die, was an independent variable in the study.

A twin-screw volumetric feeder (K Tron Corp., Pitman, NJ) delivered the raw materials to the extruder inlet at a feed rate of 56.8 kg/hr. Moisture contents of the materials were adjusted at the inlet by adding water controlled by a mass flow meter (Micro Motion Inc., model MC-12, Boulder, CO). Screw speed was adjusted from the control panel. Torque (percent) was read directly from the panel. Cutter speed was adjusted manually to yield collets approximately 50 mm long. Samples were collected in plastic bags after equilibrium was reached, as indicated by constant torque in each trial. Except for samples taken for moisture analysis, samples were dried at 149°C in a forced-air oven (Enersyst, Dallas, TX). Samples were stored at room temperature.

Physical Measurements

Collet bulk density was determined immediately after extrusion by weighing the collets in a container. Two measurements were made during each trial; bulk density was recorded as kilograms per cubic meter. Diametric expansion was calculated as the average diameter of five collets divided by the diameter of the die hole. The color of the samples was read on the laboratory scale using a color difference meter (Hunterlab Labscan, Reston, VA) with a D-65 illuminant. Whole collets were placed in the sample cup, and an opaque cup was placed over the sample cup to exclude incident light. Sample hardness was measured with a testing machine (Instron Universal, model 1122, Canton, MA). A shear press cell (Kramer) with a 10-kg load was used with chart and cross-head speeds of 1,000 mm/min. Hardness was recorded as the ratio of the maximum required to shear or compress an individual collet divided by the weight of the collet. Five measurements per trial were made.

Chemical Characteristics

Collets were ground to pass through a 0.7-mm screen; the moisture content of 1 g of ground material was determined using a forced-air oven and drying overnight at 110°C. The hydration capacity of intact collets was determined by AACC method 56-20 (AACC 1983).

Protein solubility was measured on raw materials and on ex-

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TABLE I
Proximate Analysis (%) of Materials Used in Study

Material	Moisture	Protein (N × 6.25)	Fat	Crude Fiber	Ash	Carbohydrates[a]
Corn meal	13.0	7.2	0.4	0.4	0.36	78.61
CSF[b]	7.7	55.2	2.5	2.0	7.78	24.82
87.5% Corn, 12.5% CSF	12.3	13.4	0.5	0.7	1.37	71.75
75% Corn, 25% CSF	11.9	18.6	0.7	0.6	2.16	66.01

[a] Calculated by differences.
[b] Partially defatted glandless cottonseed flour.

TABLE II
Experimental Design Used in Study

	Independent Variables				
Trial	Run Order	CSF[a] (%)	Temp. (°C)[b]	Screw Speed (rpm)	Water (%)
1	13	0	65.5	350	18.0
2	20	25	65.5	350	18.0
3	1	0	93.3	350	18.0
4	31	25	93.3	350	18.0
5	14	0	65.5	450	18.0
6	19	25	65.5	450	18.0
7	2	0	93.3	450	18.0
8	30	25	93.3	450	18.0
9	15	0	65.5	350	21.0
10	18	25	65.5	350	21.0
11	3	0	93.3	350	21.0
12	29	25	93.3	350	21.0
13	16	0	65.5	450	21.0
14	17	25	65.5	450	21.0
15	4	0	93.3	450	21.0
16	28	25	93.3	450	21.0
17	26	0	79.4	400	19.5
18	27	25	79.4	400	19.5
19	21	12.5	65.5	400	19.5
20	5	12.5	93.3	400	19.5
21	7	12.5	79.4	350	19.5
22	8	12.5	79.4	450	19.5
23	10	12.5	79.4	400	18.0
24	11	12.5	79.4	400	21.0
25–32[c]		12.5	79.4	400	19.5

[a] Percent replacement (wet weight basis) of cornmeal with glandless cottonseed flour.
[b] At zone 5 of the extruder barrel.
[c] Centerpoint trials.

Color

1	2	3	4	5	6	7	8	9
Tan		Light Tan		Somewhat Tan and Yellow		Light Yellow		Yellow

Hardness

1	2	3	4	5	6	7	8	9
Very Soft		Fairly Soft		Neither Soft nor Hard		Fairly Hard		Very Hard

Flavor

1	2	3	4	5	6	7	8	9
Very Nutty		Fairly Nutty		Bland		Fairly Corny		Very Corny

Ease of Removal from Teeth/Adhesiveness

1	2	3	4	5	6	7	8	9
Very Easy		Fairly Easy		Neither Easy nor Difficult		Fairly Difficult		Very Difficult

Fig. 1. Intensity scale for sensory evaluation of extruded samples.

truded samples that were ground to pass through a 0.7-mm mesh screen. Protein was extracted overnight from duplicate 1-g samples with 50 ml of 0.0249*M* phosphate buffer according to AOAC method 50.007b (AOAC 1984). The sample and solvent were divided into two 50-ml tubes and centrifuged at 4°C for 20 min at 40,000 × *g* in a superspeed centrifuge (Sorvall RC-5B). The supernatants from each sample were decanted and pooled. Sample duplicates (2 ml of each) were analyzed for nitrogen content by the AACC micro-Kjeldahl method 46-13 (AACC 1983), modified by using copper sulfate as a digestion catalyst. Protein was recorded as N × 6.25. Samples from the extremes of extrusion conditions were also extracted with 1% sodium dodecyl sulfate (SDS) in the phosphate buffer and with 1% SDS plus 1% 2-mercaptoethanol in the buffer. Protein solubility was determined as described above. The nitrogen solubility index was calculated as the fraction of total protein that was soluble in the given buffer.

Changes in the available lysine content due to extrusion were measured by the method of Booth (1971). Raw materials and samples selected to represent extremes of processing conditions were ground to pass through a 0.7-mm mesh screen; 1.5 g of ground material was evaluated. Available lysine loss was reported as the amount in the raw materials less the amount recovered from the extruded samples.

Sensory Evaluation

Twelve students and staff members of the Department of Nutrition and Food Sciences of Texas Woman's University were trained in a one-hour session to evaluate the color, hardness, adhesiveness, and flavor of preselected samples that represented diverse characteristics from the experiment. Commercial extruded corn-meal snacks were also used to establish textural attributes. The panel chose extreme and midpoint descriptors for nine-point intensity scales (Fig. 1). The acceptability of the color, hardness, adhesiveness, flavor, and overall quality were measured using a nine-point hedonic scale (1 = dislike very much, 5 = neither like nor dislike, 9 = like very much). Samples were evaluated approximately three months after extrusion, which represents maximum commercial shelf-life. Over an eight-day testing period, four samples were compared daily with a standard that was a centerpoint trial sample. The standard was given a rating of 5 for all attributes.

RESULTS AND DISCUSSION

Extruder Performance

Torque was 6–12% higher for blends containing 25% CSF than for samples containing only corn meal under similar extrusion conditions. Torque was lower for samples extruded at 21% moisture, but the differences between CSF levels were greater (Table III). The high water-absorption capacity of CSF (Zarins and Marshall 1988) may have prevented water from reducing the viscosity of the material during extrusion. Other researchers (Berrington et al 1984, Maga and Fapojuwo 1986) have reported that the addition of soluble fiber materials to corn and soy grits reduced torque, but the levels of soluble fiber used in those studies were lower than the amounts of soluble fiber present in the samples containing CSF.

Physical Properties

During commercial extrusion of expanded snacks, bulk density typically predicts the final textural quality of the products. Commercial corn products generally have a bulk density of about 48.1 kg/m^3 before the drying step. In the present study, bulk density was 28.5–108.9 kg/m^3. Bulk density increased with water content and decreased with higher levels of CSF (Table III). Temperature reduced bulk density ($P < 0.001$); the effect of screw speed was slightly smaller.

Compared with other food materials, CSF may have greater ability to expand during extrusion. Taranto et al (1978) reported that extrusion-texturized cottonseed meal exhibited lower bulk density and more expansion than did texturized soy flour. The unique combination of nonstarch polysaccharides and proteins in CSF may account for such differences. Breen and coworkers (1977) reported that fiber in the form of wheat millfeeds with and without added soy protein isolate reduced the bulk density of extruded corn meal extruded at 99°C and 19.5% moisture.

Larger diameters were found in the extrudates containing CSF and low water content (Table III). The higher protein levels may have facilitated expansion at the die. Higher water levels, on the other hand, may limit expansion by reducing viscosity and mass temperature.

Hardness (as measured with the testing machine) was significantly reduced by CSF. The more expanded samples were more fragile. Moisture content during extrusion was expected to significantly affect resistance to shear, but the range of moisture tested may have been too narrow. The testing machine used may

TABLE III

Physical and Chemical Characteristics of Collets

Trial	Torque (%)	Bulk Density (kg/m^3)[a]	Diametric Expansion[b]	Shear[c]	Color Scales[d] L	a	b	Moisture (%)	Hydration Capacity	Protein Solubility
1	72	59.49 (1.1)	2.64 (0.3)	4.62 (0.2)	64.18 (0.5)	7.27 (0.2)	32.58 (1.9)	11.5 (0.0)	4.79 (0.0)	0.03
2	78	45.50 (1.4)	2.88 (0.4)	4.67 (0.3)	56.98 (3.5)	5.13 (0.4)	24.01 (0.3)	10.9 (0.0)	4.51 (0.4)	0.04
3	68	53.08 (0.8)	2.78 (0.8)	4.43 (0.2)	60.20 (0.3)	7.68 (0.1)	29.36 (0.1)	10.4 (0.1)	4.10 (0.9)	0.02
4	78	33.43 (0.5)	3.26 (0.7)	3.68 (0.2)	54.44 (0.6)	5.26 (0.1)	23.32 (0.5)	9.8 (0.3)	5.06 (0.3)	0.14
5	60	50.62 (0.3)	2.26 (0.5)	7.02 (0.4)	66.39 (0.2)	6.28 (0.0)	30.65 (0.2)	10.0 (0.0)	4.46 (0.1)	0.02
6	70	33.85 (0.5)	3.00 (0.6)	3.12 (0.1)	54.12 (0.9)	6.29 (0.7)	23.51 (0.1)	10.2 (0.0)	6.10 (0.1)	0.12
7	58	47.85 (0.5)	2.32 (0.5)	5.50 (0.3)	65.32 (0.3)	6.95 (0.3)	29.40 (0.2)	9.8 (0.0)	5.51 (0.3)	0.04
8	70	28.46 (0.7)	3.28 (0.4)	3.21 (0.1)	53.64 (0.3)	5.94 (0.0)	22.29 (0.1)	9.5 (0.1)	4.93 (0.1)	0.10
9	65	108.93 (2.3)	2.22 (0.2)	4.48 (0.2)	65.70 (0.1)	9.80 (0.4)	34.83 (0.1)	14.1 (0.1)	3.77 (0.7)	0.05
10	80	66.48 (0.9)	2.64 (0.3)	2.73 (0.1)	53.04 (0.4)	4.99 (0.3)	24.21 (0.2)	12.0 (0.0)	4.12 (0.1)	0.01
11	...	88.51 (1.2)	2.34 (0.4)	5.54 (0.5)	65.41 (0.4)	9.37 (0.1)	33.26 (0.4)	13.2 (0.0)	3.96 (0.1)	0.03
12	70	53.56 (0.8)	2.86 (0.3)	2.65 (0.1)	52.78 (0.1)	4.90 (0.3)	23.89 (0.1)	13.3 (0.0)	4.25 (0.2)	0.08
13	55	104.93 (1.3)	2.08 (0.1)	5.76 (0.7)	67.07 (0.5)	9.29 (0.4)	34.27 (0.2)	13.3 (0.2)	3.26 (0.1)	0.03
14	66	63.28 (3.2)	2.56 (0.9)	3.53 (0.6)	54.33 (0.4)	5.06 (0.4)	24.46 (0.0)	11.7 (0.1)	4.14 (0.0)	0.10
15	54	73.00 (2.6)	2.12 (0.3)	7.07 (0.8)	66.19 (0.0)	8.60 (0.1)	31.70 (0.1)	12.0 (0.1)	3.92 (0.1)	0.07
16	70	47.90 (1.1)	2.90 (0.4)	4.86 (0.4)	54.51 (0.1)	5.04 (0.0)	24.29 (0.2)	11.7 (0.1)	4.33 (0.0)	0.15
17	60	70.33 (1.0)	2.06 (0.2)	5.54 (0.5)	66.59 (0.1)	7.59 (0.2)	31.56 (0.2)	12.5 (0.2)	3.83 (0.0)	0.03
18	70	46.09 (0.6)	2.80 (0.6)	3.30 (0.3)	54.85 (0.1)	5.48 (0.1)	24.19 (0.1)	10.6 (0.0)	4.20 (0.2)	0.12
19	75	47.42 (1.5)	2.64 (0.8)	3.71 (0.3)	54.24 (0.3)	5.13 (0.0)	23.90 (0.1)	11.2 (0.2)	4.23 (0.3)	0.02
20	70	49.45 (1.1)	2.56 (0.4)	3.80 (0.1)	58.56 (0.0)	7.32 (0.6)	27.49 (0.1)	10.8 (0.3)	4.43 (0.1)	0.06
21	80	55.91 (2.3)	3.00 (0.7)	3.78 (0.4)	56.82 (0.6)	7.31 (0.1)	27.26 (0.1)	11.5 (0.4)	4.33 (0.3)	0.03
22	70	49.26 (0.8)	2.56 (0.5)	4.69 (0.4)	58.42 (0.5)	6.70 (0.2)	26.42 (0.3)	11.2 (0.5)	4.43 (0.0)	0.09
23	72	39.30 (1.0)	3.02 (0.2)	3.47 (0.3)	55.23 (0.4)	7.42 (0.1)	24.99 (0.3)	9.7 (0.8)	6.10 (1.5)	0.05
24	70	70.25 (1.5)	2.20 (0.7)	3.79 (0.2)	57.87 (0.7)	7.04 (0.1)	27.43 (0.1)	12.0 (0.4)	3.95 (0.0)	0.06
25	70	49.13 (1.4)	2.48 (0.7)	4.09 (0.3)	57.36 (0.2)	7.21 (0.2)	26.65 (0.3)	11.1 (0.7)	4.52 (0.3)	...
26	72	53.43 (0.3)	2.70 (0.5)	4.12 (0.3)	57.38 (0.1)	7.04 (0.1)	26.18 (0.1)	10.9 (0.5)	4.28 (0.2)	0.03
27	68	59.83 (0.1)	2.60 (0.9)	4.92 (0.5)	58.22 (0.4)	7.67 (0.1)	27.57 (0.4)	11.1 (0.9)	4.36 (0.4)	0.05
28	75	40.37 (0.9)	2.84 (0.3)	...	54.79 (0.1)	5.45 (0.2)	23.86 (0.3)	10.6 (0.3)	4.72 (0.0)	0.05
29	70	42.40 (0.7)	2.66 (0.3)	...	55.19 (0.2)	5.63 (0.1)	24.35 (0.1)	11.0 (0.3)	4.79 (0.2)	0.11
30	70	50.73 (0.8)	2.40 (0.5)	4.41 (0.3)	58.70 (0.5)	6.01 (0.1)	26.26 (0.7)	11.1 (0.5)	4.61 (0.2)	0.07
31	70	52.33 (1.5)	2.30 (0.8)	4.44 (0.3)	59.87 (0.1)	5.64 (0.0)	26.73 (0.1)	...	4.05 (0.0)	...
32	70	56.28 (1.9)	...	4.84 (0.6)	59.20 (0.0)	5.95 (0.4)	26.69 (0.2)	...	4.28 (0.0)	0.03

[a] Means of two determinations; SD in parentheses.

[b] Means of 10 determinations; values are the diameters of samples divided by the diameter of the die hole.

[c] Means of five determinations; values are the peak force required to shear collets divided by collet weight.

[d] Color scales: L = brightness, 0 = black, 100 = white; +a = red, −a = green; +b = yellow, −b = blue.

TABLE IV

Effects of Glandless Cottonseed Flour (CSF) and Extrusion Conditions on Physical Characteristics of Samples

Independent Variables	Torque (%)	Bulk Density (kg/m)	Diametric Expansion	Resistance to Shear	Color L[a]	a	b	Moisture (%)	Hydration Capacity	Protein Solubility
CSF	5.59***[b]	−0.83***	0.30***	−1.01***	−5.46***	−1.37***	−4.08***	−0.41***	0.22*	0.88***
Temperature, °C	−1.31*	−0.36***	0.08*					−0.25*		
Screw speed	−4.30***	−0.23**	−0.09*					−0.40***		
Water	−2.03**	0.99***	−0.20***				1.01**	1.20***	−0.55***	
CSF × CSF	−6.98***				3.44**		1.66*			
Screw speed × screw speed	3.02*									
CSF × water		−0.29**				−0.72**				
Temperature × screw speed	1.29*									
Temperature × water		−0.21*								

[a] L = brightness, a = redness, b = yellow color.

[b] *** = $P \leq 0.001$, ** = $P < 0.01$, * $P < 0.05$; omitted values, interactions, and quadratic effects were not significant.

not have been sensitive to all the differences, since lack of fit for the model was high ($P < 0.05$).

Color

Adding CSF reduced color, or brightness (L). Samples with CSF were generally 10 L-units lower than were corn meal samples processed under the same conditions. McAuley et al (1987) found a correlation between reduced L values and loss of available lysine in extruded breakfast cereals, but a similar relationship was not observed in this experiment.

Increased use of CSF also reduced hue values (Table IV). The interaction between CSF and water level reduced redness ($P < 0.01$). Wan and coworkers (1979) also noted that green color increased when CSF was wetted. Yellow color decreased significantly with the addition of CSF, but moisture slightly offset this effect ($0.01 < P < 0.05$). These differences in color between corn-meal samples and those containing CSF could be minimized by applying colored seasoning to the exterior.

Moisture Characteristics

Moisture content of the samples before drying depended primarily on the moisture content of the material before extrusion (Table I), but there was significant lack of fit ($P \leq 0.01$) by the full response surface model. Higher moisture contents were asso-

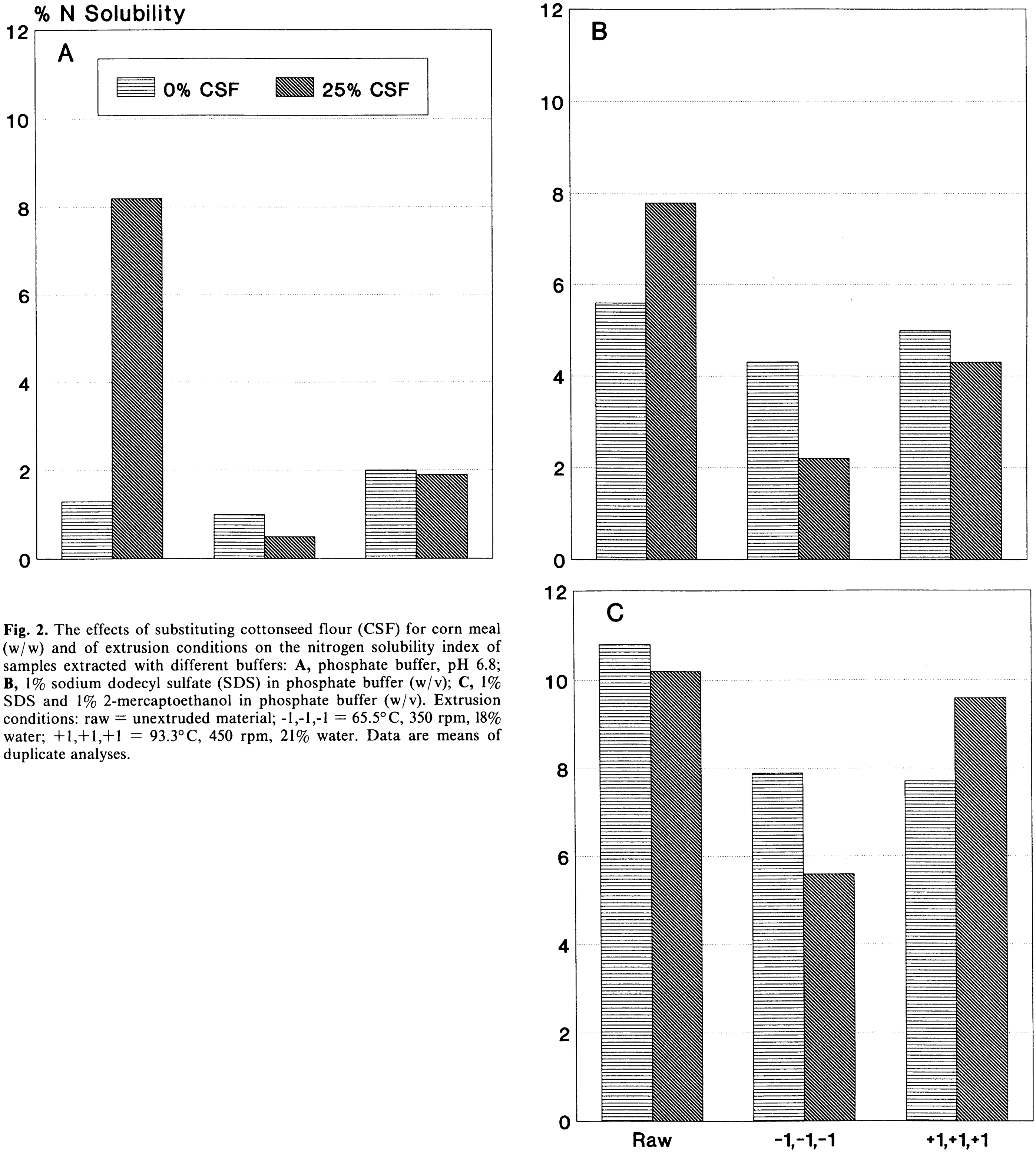

Fig. 2. The effects of substituting cottonseed flour (CSF) for corn meal (w/w) and of extrusion conditions on the nitrogen solubility index of samples extracted with different buffers: **A,** phosphate buffer, pH 6.8; **B,** 1% sodium dodecyl sulfate (SDS) in phosphate buffer (w/v); **C,** 1% SDS and 1% 2-mercaptoethanol in phosphate buffer (w/v). Extrusion conditions: raw = unextruded material; -1,-1,-1 = 65.5°C, 350 rpm, 18% water; +1,+1,+1 = 93.3°C, 450 rpm, 21% water. Data are means of duplicate analyses.

ciated with the less expanded extrudates and required additional energy input to remove that water before storage. As indicated in Table IV, screw speed and CSF level negatively affected moisture content. High temperature, screw speed, and CSF level favor expansion and thus loss of water by steam flash-off.

Hydration capacity was significantly affected only by water content. Water-binding sites on macromolecules may be occupied in samples with more moisture, thereby preventing the samples from absorbing additional water. Water absorption was not affected by the amount of CSF in the samples. However, collets containing CSF retained structural integrity during the evaluation, but the corn-meal samples disintegrated. Thus, CSF may have potential use in ready-to-eat breakfast cereals because the structure would remain as milk was absorbed.

Protein Changes

Protein solubility was measured to estimate the degree of protein denaturation resulting from extrusion. The amount of protein extracted with phosphate buffer from samples increased with the level of CSF (Table III) because more protein was available for extraction (Table I). Other variables slightly increased solubility of the proteins.

The effects of the materials and the extrusion conditions used on the nitrogen solubility index become evident when different solvent systems are used (Fig. 2). A greater percentage of total corn protein became soluble in the SDS and SDS-mercaptoethanol solutions than in phosphate buffer alone, indicating that both noncovalent and covalent forces were responsible for stabilizing the proteins. Cottonseed protein, being more hydrophilic, was responsible for the greater nitrogen solubility index of the unextruded 25% CSF mixture in buffer only. Nitrogen solubility generally decreased in the samples extruded under low conditions (Trials 1 and 2). The samples extruded at higher temperature and screw speed with 21% water had greater proportions of soluble nitrogen, perhaps because of a reduction in material temperature that resulted in less denaturation. Pham and Del Rosario (1984) also reported lower nitrogen solubility index values for legume products extruded at higher temperatures or lower water contents.

In general, the loss of available lysine in selected samples was not significantly affected by extrusion conditions (Fig. 3). The differences between the samples containing 0 and 25% CSF resulted were due to different protein content and amino acid patterns of the respective materials. These losses may not be important, provided that these types of foods are not a significant source of protein, and corn and CSF proteins are not considered adequate sources of lysine.

Sensory Quality

CSF level was the only significant factor in evaluating color intensity and acceptability (Table V). Samples containing 25% CSF were rated as tan in color and were disliked by the sensory panel. The 12.5% CSF samples were considered "somewhat tan and yellow," which was equivalent to a rating of 5 on the intensity scale; corn-only samples were yellow and scored 7 or above.

Hardness was reduced by CSF and increased by water (Table V). Hardness intensity correlated with bulk density ($r = +0.83$). Samples with hardness intensity ratings of less than 4 or more than 7 were typically disliked by the panel.

The flavor of the samples containing CSF was rated as more "nutty" than "corny." Whereas other factors had no significant effects (Table V), none of the samples had strong flavors because volatiles were lost during extrusion. Some panelists preferred the nutty flavor of the samples with CSF; others found that flavor unacceptable.

The degree of adhesiveness, which was described as the ease of removing the chewed samples from one's teeth, was not significantly influenced by any of the variables in the study. The teeth of the panelists, sample size offered during testing, and order of presentation may have contributed to the lack of discrimination between samples. Only two samples (2 and 4) were rated as difficult to remove from the teeth. Those samples contained 25% CSF and were extruded at low screw speed and moisture content, and stickiness may have been caused by incomplete cooking of the nonstarch polysaccharides. In general, samples were neither liked nor disliked with respect to their adhesiveness.

Overall acceptability of the samples with 0 or 12.5% CSF was

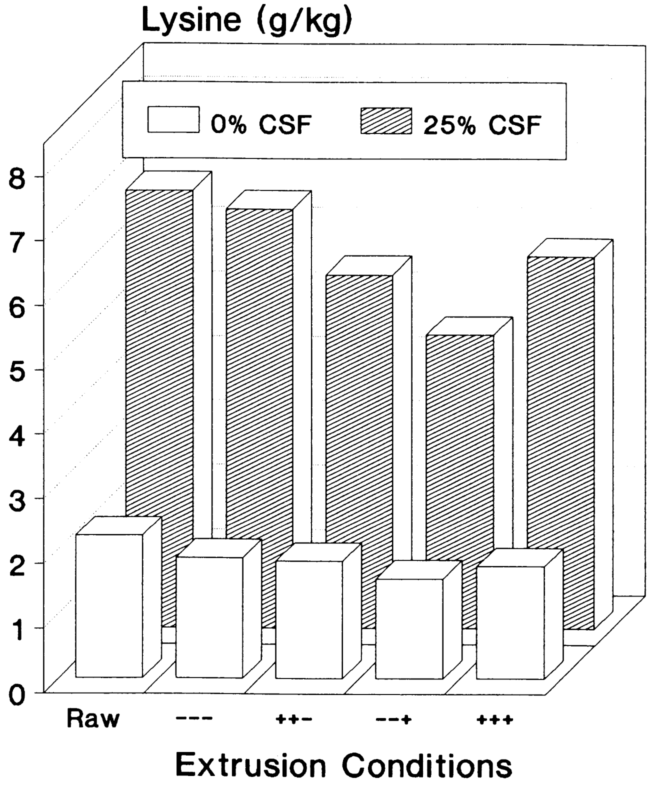

Fig. 3. Effects of extrusion conditions on available lysine per kilogram of corn meal containing 0 or 25% cottonseed flour (CSF, w/w): raw = unextruded; --- = 65.6°C, 350 rpm, 18% water; ++- = 93.3°C, 450 rpm, 18% water; --+ = 65.6°C, 350 rpm, 21% water; +++ = 93.3°C, 450 rpm, 21% water. Data are means of duplicate analyses.

TABLE V
Effects of Glandless Cottonseed Flour (CSF) and Extrusion Conditions on Sensory Characteristics of Samples

Independent Variables	Color		Hardness		Flavor		Adhesiveness		Overall Acceptance
	Intensity	Acceptance	Intensity	Acceptance	Intensity	Acceptance	Intensity	Acceptance	
CSF	−2.23***[a]	−1.33***	−1.31***	−0.36**	−1.73***	−0.63**	−0.39**	−0.44**	−0.63**
Temp., °C[b]		+0.31*							
Screw speed									
Water			+1.03***						
Temp. × temp.		−0.77*		−0.79*			+0.75*	−1.08**	−0.67
CSF × temp.			−0.47*	−0.37*					
CSF × water				+0.41**	−0.39*				
Temp. × water							−0.29*	+0.38*	

[a] *** = $P < 0.001$, ** = $P < 0.01$, * = $P < 0.05$; omitted variables and values were not significant.
[b] At zone 5 of extruder barrel.

higher than was that of the 25% CSF samples. Further consumer testing with added seasoning is needed before a nutrient-dense snack containing CSF can be considered feasible. With seasonings added, a snack containing more than 12.5% CSF may be acceptable to consumers.

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