THE EFFECT OF MILL BY-PRODUCTS AND SOY PROTEIN ON THE PHYSICAL CHARACTERISTICS OF EXPANDED SNACK FOODS[1]

M. D. BREEN[2], A. A. SEYAM[3], and O. J. BANASIK[4]

ABSTRACT

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By-products of wheat milling, which are now used primarily as feed, contain significant amounts of fiber. These mill fractions can be blended with other cereal products, starch, and soy proteins, and processed into high-protein and high-fiber expanded snack foods using an extruder-cooker. Wheat bran and mill dust were blended into a 50:50 mixture (millfeeds) and combined with wheat starch, corn meal, and isolated soy protein in a number of combinations. Bran was blended with semolina, wheat starch, and isolated soy protein. The expansion ratio and bulk density were determined for each product. The bulk density of the products increased as the percentage of millfeeds increased, while the addition of isolated soy proteins reduced the effect of increased bulk density by adding millfeeds. Mill by-products can be used in developing new, expanded snack foods that should be highly acceptable in the current market. The addition of isolated soy protein increases the protein content without compromising the desirable texture of expanded snack foods. High concentrations of starch tended to increase bulk density and reduce the expansion ratio. Durum wheat semolina was an excellent ingredient for snack foods.

Snack foods have become a way of life, as they are a very important part of the U.S. diet. At the manufacturers' level, the annual market is estimated to be more than 5 billion dollars (1), while extruded snacks represent less than 10% of the total. Most extrusion-cooked snacks are produced from degerminated corn meal, rice flour, wheat flour, or potato flour, in many shapes and in a wide variety of textures (2). Anderson *et al.* (3,4) used sorghum grits and triticale in extrusion-cooking and recommended their use in a variety of products. Conway and Anderson (5) studied a variety of protein-fortified products by preparing a number of two- and three-component blends. Proteins ($N \times 6.25$) varied from 9.4 to 34.4%. In their studies, they found that wheat flour and soy products tended to decrease expansion of the extruded blends.

The various methods of preparing snack foods can be grouped into three principal types according to Schaeder *et al.* (6). One method, high-pressure cooking and extruding, is becoming a popular means of preparing snack foods because of the many varieties that can be made from raw materials containing 60 to 75% of expandable starch base (7).

The quality of an expansion-cooked product depends upon the conditions of operation of the extruder and the main raw material used in the formulation as cited by Sanderude (7). Expansion as measured by bulk density and expansion ratios are measures used to express product characteristics after extrusion (5,8).

This study examines the effect of adding millfeed fractions to formulations

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[2]Cereal Technologist, Fairmont Foods, Omaha, Nebr.
[3]Borden Research Center, Syracuse, N.Y.
[4]Professor and Chairman, Department of Cereal Chemistry and Technology, North Dakota State University, Fargo, ND 58102.

used in extruder-cooked expanded snack foods. Bran and other feed streams contain substantial amounts of fiber and protein compared to their flour fractions. Inclusion of millfeeds into the expanded snack foods could make these products better-quality foods by furnishing increased fiber and protein to the diet. Other components of the formulations included various amounts of durum semolina, wheat starch, yellow corn meal, and isolated soy protein. These formulations were processed in an extruder-cooker and the physical characteristics of the products were evaluated and compared.

MATERIALS AND METHODS

Wheat bran and mill dust were obtained from a pilot plant mill as described by Shuey and Gilles (9). Wheat starch (Starbake) was obtained from Hercules Inc., Wilmington, Del., and yellow corn meal (Sunlite) was obtained from J. R. Short Milling Co., Kankakee, Ill. Isolated soy protein (Promine F) was supplied by Central Soya, Chicago, Ill. Semolina was obtained from the North Dakota Mill and Elevator, Grand Forks, N. Dak.

Wheat bran and mill dust were hammer-milled separately (Jacobsen Model No. 68 B Pulverizer, using a screen with 2-mm openings) and blended into a 50:50 mixture.

Protein (as determined by Kjeldahl using a $5.7 \times N$ factor), crude fat, ash, and crude fiber were determined by AACC Approved Methods (10).

All formulations were thoroughly blended in advance. Immediately before extrusion, the blends were mixed with water to a 19.5% moisture level, then processed using a Wenger X-5 laboratory cooker-extruder (Wenger Manufacturing Co., Sabetha, Kans.) equipped with a 1-in. screw of eight 1 5/8-in. sections. Eight-jacketed barrel sections contained either straight grooves for high work input or spiral grooves which facilitated product movement. The extruder had a 1000-g product hopper equipped with a variable speed drive for moving the material to the extruder screw. The jackets were arranged with a spiral-grooved feed section followed by 2 spiral-grooved sections, 3 straight-grooved sections, and finally 2 spiral-grooved sections, as recommended by the extruder manufacturer for wheat-flour products (11). Cooling water and steam (45 psi) were used to maintain the 5/32-in. die at a temperature of 210°F. (99°C) which produced the best product. Feed rate also was adjusted as necessary to improve the product quality.

The formulations were each blended and processed in duplicate and the averages of the results were reported. The products were allowed to cool at ambient temperatures and stored in airtight plastic containers until analyzed.

The expansion ratio of the products was determined by measuring the diameter of the product (average of six measurements) and comparing this value to the die diameter used to process that product. The error of a single determination was calculated as 0.28 ratio units. Bulk density was determined by using a bread loaf volume apparatus to determine the volume of a preweighed sample of the extruded snack product. A mounting board was placed on the bottom of the volume chamber so that the products could be set in an upright position with spaces between them. Two measurements of duplicate samples were taken. The standard error of a single determination was calculated as 1.34

g/100 cc. Amino acid profiles were determined on the formulations with a Beckman 120B amino acid analyzer by the method described by Benson and Patterson (12).

RESULTS AND DISCUSSION

Ingredient Characteristics

The chemical and physical characteristics of the materials used are given in Table I. Wheat starch and yellow corn meal have low protein contents of 0.4 and 7.3%, respectively. Semolina, bran, and millfeed protein ranged from 16.3 to 18.0%, while ioslated soy protein had the highest with 87.8%. High lipid levels were obtained for bran (3.8%) and for millfeeds (3.7%), as compared to low levels for semolina (0.89%) and soy protein (<0.1%). Bran, soy protein, and millfeeds were high in ash as compared to semolina.

Millfeeds and Wheat Starch Blends

The characteristics of the products processed from blends of millfeeds, starch, and soy protein are reported in Table II. The bulk density ranged from 11.2 g/100 cc for the 10:90 product (millfeeds:wheat starch) to 17.7 g/100 cc for the 30:70 product. Higher millfeeds content was not practical because of poor expansion and a very high bulk density. Although there is variation in the results, the trend is clear; increasing millfeeds tended to increase expansion and density. Although gelatinizing starch is the primary cause of expansion, some protein must be present to provide sufficient expansion of the mixture, as indicated by the low expansion ratio of the final two blends.

Millfeeds and wheat starch were blended with isolated soy protein to produce an expanded product containing about 22% protein (Table II). The expansion was almost the same for all products, while the bulk density was highest for the two blends containing the lowest amount of starch. The textures of these two products were the least desirable of the products shown in Table II.

TABLE I
Chemical and Physical Properties of Materials and Their Extruded Products[a]

Ingredients	Moisture %	Protein %	Crude Fiber %	Free Lipid %	Ash %
Bran	9.9	17.4	10.1	3.8	4.96
Bran and mill dust (50:50)	11.5	18.0	10.0	3.7	3.30
Wheat starch	11.6	0.4	<0.1	<0.1	...
Yellow corn meal	12.8	7.2	2.7	...	...
Isolated soy protein	9.7	87.8	...	0.1	4.50
Semolina	14.5	16.3	1.2	0.9	0.69

[a]All analytical results on a dry basis.

Millfeeds and Corn Meal Blends

Because yellow corn meal is the most commonly used base for expanded snack foods, millfeeds were combined with yellow corn meal in various ratios and processed into snack foods. Table III reports chemical and physical characteristics of these products.

The expansion ratio varied from 1.6 to 1.8 for the yellow corn meal and millfeeds formulations. These values are low when compared to the 100% corn meal product which had an expansion ratio of 2.8. Bulk density was low for the

TABLE II
Composition of Blends Containing Millfeeds, Wheat Starch, and Soy Protein and Product Analysis

Composition			Product			
Millfeeds %	Wheat starch %	Isolated soy protein %	Moisture %	Protein[a] %	Expansion ratio	Bulk density g/100 cc
10.0	90.0	...	13.2	2.3	1.2	11.2
15.0	85.0	...	13.1	3.1	1.5	12.0
20.0	80.0	...	12.9	4.0	1.8	12.9
25.0	75.0	...	12.7	4.8	1.8	12.0
30.0	70.0	...	12.9	5.7	1.6	17.7
7.7	69.2	23.1	10.8	23.0	1.8	12.0
11.6	66.0	22.4	10.8	22.5	1.8	12.8
15.7	62.7	21.6	10.9	22.7	1.8	11.2
19.8	59.4	20.8	11.1	22.7	1.7	14.3
24.0	56.1	19.9	10.8	22.7	1.7	15.7

[a]Dry basis.

TABLE III
Composition of Blends Containing Millfeeds, Yellow Corn Meal, and Soy Protein and Product Analysis

Composition			Product			
Millfeeds %	Yellow corn meal %	Isolated soy protein %	Moisture %	Protein[a] %	Expansion ratio	Bulk density g/100 cc
0.0	100.0	...	12.8	7.3	2.8	12.8
10.0	90.0	...	11.8	8.6	1.8	8.8
15.0	85.0	...	11.8	9.1	1.8	8.8
20.0	80.0	...	11.8	9.4	1.6	12.3
25.0	75.0	...	11.9	10.1	1.6	11.2
30.0	70.0	...	11.0	10.7	1.8	10.2
8.4	75.6	16.0	10.9	21.2	2.4	10.6
12.7	71.9	15.4	10.6	21.4	2.2	10.5
17.0	68.0	15.0	10.7	21.5	2.0	10.6
21.4	64.3	14.2	11.4	21.6	2.2	9.4
26.0	60.6	13.4	11.0	21.1	2.4	10.6

[a]Dry basis.

10 and 15% millfeeds, but increased for the 20, 25, and 30% millfeeds. In comparing the bulk densities in Tables II and III, it appears that blends containing wheat starch in place of yellow corn meal decreased the expansion ratio and increased the bulk density.

TABLE IV
Composition of Blends Containing Millfeeds, Yellow Corn Meal, Wheat Starch, and Soy Protein and Product Analysis

Composition				Product			
Millfeeds %	Yellow corn meal %	Wheat starch %	Isolated soy protein %	Moisture %	Protein[a] %	Expansion ratio	Bulk density g/100 cc
30.0	50.0	20.0	...	11.9	9.4	1.6	9.2
30.0	30.0	40.0	...	12.1	8.5	1.6	9.6
30.0	25.0	45.0	...	12.0	7.6	1.6	9.0
30.0	20.0	50.0	...	11.8	7.4	1.7	11.4
30.0	15.0	55.0	...	11.3	6.9	1.7	10.6
30.0	10.0	60.0	...	12.1	6.6	1.7	13.5
25.3	41.8	16.7	16.3	10.9	22.7	2.0	9.2
24.8	24.8	33.1	17.3	10.9	22.2	1.6	9.4
24.6	20.5	36.9	18.1	10.7	22.3	1.7	9.0
24.5	16.3	40.8	18.4	10.9	22.7	1.7	10.9
24.4	12.2	44.7	18.6	10.9	22.3	1.7	9.1
24.3	8.1	48.5	19.1	10.8	22.2	1.8	11.0

[a]Dry basis.

TABLE V
Composition and Product Analysis of Expanded Snack Products Containing Combinations of Semolina, Bran, and Isolated Soy Protein

Composition			Product			
Bran %	Semolina %	Isolated soy protein %	Moisture %	Protein[a] %	Expansion ratio	Bulk density g/100 cc
0.0	100.0	...	11.5	15.8	3.2	13.8
5.0	95.0	...	11.6	15.9	2.2	11.5
7.5	92.5	...	12.2	16.0	2.2	13.2
10.0	90.0	...	12.0	15.9	2.2	13.2
12.5	87.5	...	11.4	16.0	2.7	13.9
15.0	85.0	...	10.6	15.9	2.7	13.5
20.0	80.0	...	11.7	16.2	2.2	13.3
25.0	75.0	...	12.0	16.2	2.2	18.2
4.7	89.2	6.1	10.7	20.2	2.7	10.3
7.1	86.9	6.0	11.2	20.9	2.7	11.6
9.4	84.7	5.9	12.4	20.8	2.2	13.5
11.8	82.6	5.6	13.0	20.7	2.2	14.9
14.3	80.7	5.0	12.2	20.0	2.2	14.7
19.1	76.6	4.3	11.4	19.6	2.2	14.7
24.0	72.0	4.0	11.7	19.4	1.8	13.0

[a]Dry basis.

Soy protein, when added to the blends of corn meal and millfeeds to produce a product of 21% protein, increased the expansion ratio, and had a lower bulk density when compared to the 100% corn meal product. The product had excellent taste and texture, and contained a substantial amount of crude fiber.

Millfeeds, Corn Meal, and Wheat Starch Blends

Millfeeds were held at a constant 30%, while wheat starch and yellow corn meal ratios were varied. The product characteristics as shown in Table IV reveal that, as yellow corn meal content increased and wheat starch decreased, bulk density tended to decrease. This confirms the observation made in Tables II and III that increasing the amount of wheat starch in the blend increases bulk density. The expansion ratios were quite constant for the various blends.

The corn meal protein and other nonstarch components of corn meal apparently enhance the structure as measured by bulk density. Thus, nonstarch fractions have a very important role in expanded snacks.

Isolated soy protein was blended with the millfeeds-starch-corn meal to yield blends of about 22% protein to determine its effect on product quality (Table IV). The expansion ratios were variable, ranging from 1.6 to 2.0, and no specific trends were detected. The bulk density seemed to be reduced with added soy protein; however, the lower amount of wheat starch was probably the reason for lower bulk density. These products appeared to have acceptable properties as expanded food products.

Bran and Durum Semolina Blends

Blends of bran and semolina produced products with very good protein levels (15.8–16.2%), as reported in Table V. High bulk density indicated that the increased density of the blends was partially due to the higher levels of bran in the blend. This was similar to the result of adding millfeeds to wheat starch.

TABLE VI
Compositions of Blends Containing Bran, Semolina, Wheat Starch, and Soy Protein Isolate and Product Analysis

Composition				Product			
Bran %	Semolina %	Wheat starch %	Isolated soy protein %	Moisture %	Protein[a] %	Expansion ratio	Bulk density g/100 cc
15.0	65.0	20.0	...	13.0	12.8	2.7	10.3
15.0	45.0	40.0	...	12.9	9.4	2.9	10.2
15.0	40.0	45.0	...	12.8	8.8	2.2	12.3
15.0	35.0	50.0	...	13.2	8.3	2.1	15.5
15.0	30.0	55.0	...	12.6	7.4	2.1	11.0
15.0	25.0	60.0	...	12.8	5.3	2.3	10.5
13.0	56.5	17.4	13.1	11.2	22.6	1.8	13.1
12.6	37.8	33.6	16.1	11.8	22.0	2.1	10.3
12.5	33.3	37.4	15.8	10.3	22.4	2.0	12.9
12.4	28.9	41.2	17.5	10.8	22.6	1.9	10.3
12.3	24.5	45.0	18.2	11.3	22.7	1.7	10.2
12.2	20.3	48.6	18.9	11.6	23.0	1.8	13.7

[a]Dry basis.

Soy protein was added to blends of bran and semolina to produce products with about 21% protein content (Table V). The expansion ratio decreased from 2.7 for the blend with 4.7% bran to 1.8 for the blend containing 24% bran. The bulk density varied from 10.3 to 14.9 g/100 cc. Bulk density increased as bran replaced semolina in the blends containing isolated soy protein to the 11.8% bran level, and then decreased as the amount of bran was increased further. The semolina had the highest expansion ratios of any formulation or ingredient.

Bran, Semolina, Wheat Starch, and Soy Protein

The bran level was held at 15% to determine the effect of varying semolina and wheat starch. The results reported in Table VI revealed that protein content decreased as the wheat starch level increased. The expansion ratios were quite high with all the blends (above 2.0). The blends containing the highest levels of semolina (65 and 45%) had the best expansion ratios and the lowest bulk density. The bulk density was highest for intermediate levels of semolina (40 and 35%), and decreased as wheat starch levels increased to 60%. The importance of protein and other nonstarch components was again evident.

Isolated soy protein was added to produce a product of about 22% from semolina-bran-wheat starch. The expansion ratios decreased to values of 2.1 and lower. The bulk density varied from 10.2 to 13.7 g/100 cc and did not follow any trend due to increases of semolina or wheat starch.

Bran or millfeeds reduced expansion compared to the values obtained for

TABLE VII
Amino Acid Profile for Selected Snack Food Products

Amino Acid[a]	Blend 1[b] Essential Amino Acid Profile g/16 g N	Blend 1 % of FAO Recommendations[c]	Blend 2[d] Essential Amino Acid Profile g/16 g N	Blend 2 % of FAO Recommendations[c]
Lysine	6.1	126.6	6.3	115.9
Threonine	3.8	94.6	3.9	97.9
Valine	4.9	99.3	5.3	107.5
Methionine + cysteine	2.6	73.2[e]	2.4	66.7[e]
Isoleucine	5.9	147.4	5.3	131.3
Leucine	8.5	121.4	8.5	120.0
Tryptophan + phenylalanine	9.3	152.4	7.5	123.8

[a]Tryptophan not determined.
[b]Blend composition: 56.1% wheat starch, 24.0% millfeeds, and 19.9% isolated soy protein.
[c]Recommended amino acid profile for adults by the FAO (13).
[d]Blend composition: 48.5% wheat starch, 24.3% millfeeds, 8.1% corn meal, and 19.1% isolated soy protein.
[e]1st limiting amino acid.

100% semolina or corn meal. Wheat starch, blended directly with millfeed or in combination with other ingredients, tended to reduce radial expansion. Bran (or) millfeeds) blended with corn meal (Table III) or semolina (Table V) had better radial expansion, while still retaining a low bulk density. Soy protein added to the blends containing corn meal increased the expansion ratios and reduced the bulk density values.

The value of using semolina or corn meal instead of wheat starch was demonstrated (Tables IV and VI). With the millfeeds held constant, the product improved as the starch was replaced by semolina or corn meal. The products usually had a higher bulk density and a lower expansion ratio with high concentrations of wheat starch. The mouth-feel was very fragile in the high starch products, so it was doubtful if they would hold up to normal handling. The physical properties of soy protein blends were comparable to blends made with corn meal or semolina and should be considered for future commercial applications.

Amino Acid Profiles

Table VII reports the essential amino acid profiles and how they scored based on the FAO amino acid suggested requirement (chemical score) (13). Two blends were chosen. The first blend contained yellow corn meal in addition to the other materials. The chemical scores were 73.2 and 66.7 for blends 1 and 2, respectively, with the sulfur-containing amino acids first-limiting. The addition of millfeeds and soy protein produces a good-quality protein combination, as indicated by the amino acid score.

A protein efficiency ratio (PER) was determined (WARF, Madison, Wis.) on Blend 1 and a relatively high value of 1.8 was obtained. Undoubtedly, if cysteine and methionine had been added as a fortification measure, the PER would be nearer that of casein (2.5 corrected).

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