HIGH-FIBER BREAD CONTAINING BREWER'S SPENT GRAIN[1]

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ABSTRACT

A commercial sample of brewer's spent grain (BSG) that had been dried in the brewery at 45°C was given separate additional heat treatments at 45°, 100°, and 150°C. All samples were milled finely, including a portion of the material that had received no additional heat treatment. These BSG samples replaced 5, 10, and 15% of a hard red spring white flour in a conventional bread formula. Baking performance and consumer acceptance were compared with bread made from flour consisting of 70% white flour and 30% whole-wheat flour. Flour blends containing BSG had a higher farinograph and baking absorption than the same flour without BSG. At 5, 10, and 15% levels of substitution, the loaf volumes of 1-lb loaves of bread were reduced by 0, 11, and 17%, respectively, relative to the control. Consumer panels accepted favorably the bread made with the BSG in flour replacement at 5 and 10% levels if the BSG had not received additional drying at 100° and 150°C. These high temperatures seemed to impart an undesirable flavor. At the 10% substitution level the protein in flour and bread crumb was increased by 10% relative to the 30% whole-wheat flour and bread made from it. Similarly, crude fiber and acid-detergent fiber were approximately doubled in flour with 10% BSG substitution. These results indicate a potential use for the brewery by-product which may be beneficial in view of current data regarding nutritional benefits of high-fiber foods.

During the mashing stage of brewing, the major constituents of malt and a carbohydrate adjunct, such as corn grits or rice, are subjected to enzyme-catalyzed hydrolysis. The solid residue (spent grain) after filtering the mash is mainly husk, bran, and embryo residues of the malt kernel, and corn bran if corn grits were used as adjunct.

The wort is hopped and then boiled to extract flavoring constituents from the hops and to increase the specific gravity of the wort. During this boiling, a complex precipitate called "trub" forms which consists mainly of proteins, phenolic compounds, and lipids. This trub and the solid hop residue are removed and are usually added to the spent grain for disposal; the cooled, clear wort is inoculated with yeast for the fermentation process.

The spent grain-hop-trub mixture, currently about 700,000 tons dry weight annually in the U.S., is one of the main by-products of brewing and has traditionally presented a disposal problem (1).

Recently, interest has developed in dietary fibrous materials which may play a role in the prevention of certain noninfectious diseases such as diverticulosis,

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colon cancer, hemorrhoids, arteriosclerosis, varicose veins, and appendicitis (2). Since spent grain is high in fiber as well as protein, it may have useful application in human nutrition. This report describes the functionality and consumer acceptance of brewer's spent grain (BSG) in bread.

MATERIALS AND METHODS

BSG

BSG from a malt-corn grits mash was obtained from a commercial brewery. The BSG had been dried to 7.2% moisture in a Heil drum dryer at 45°C. It contained about 2.9% trub and 0.5% hop residue on a dry-weight basis.

Drying Treatment

Since the flavor and color of some cereal preparations, *e.g.*, malt, can be improved by heating, separate samples of BSG were dried further in a forced-air oven at: 45°C for 24 hr; 100°C for 24 hr; and 150°C for 1.5 hr. These samples, stored in plastic bags, had a final moisture content of 1%.

Milling

BSG as received from the brewery or after subsequent drying was milled with a Cyclone Sample Mill (Tecator-Udy Co., Boulder, CO 80302).

Particle-Size Determination

Particle-size distribution of the milled BSG was determined by separating 20-g portions on a nest of sieves (32, 65, 80, 100, 150, and 200 mesh/in.) for 5 min with a Tyler Ro-Tap machine. The sieve separates were analyzed for nitrogen to determine the relation of particle size to nitrogen distribution.

Chemical Analyses

Samples were analyzed for Kjeldahl nitrogen, crude fat, crude fiber, ash, and moisture (3), and for acid-detergent fiber, cellulose, and lignin (4). Amino acids were evaluated with a Beckman 121 amino acid analyzer (5).

TABLE I
Per Cent Composition of BSG and Flours[a]

	Protein[b]	Ash	Crude Fiber	Crude Fat	Acid Detergent Fiber	Cellulose	Lignin
BSG	34.4	3.6	14	8.3	36	10	17
White flour	16.5	0.41	0.05	1.3	...	...	...
Whole-wheat flour	16.8	2.1	2.0	2.4	7	2.1	2.1
95% White, 5% BSG	17.1	0.56	0.7	1.7	2	0.5	0.9
90% White, 10% BSG	18.0	0.73	1.4	2.0	4	1.0	1.7
85% White, 15% BSG	18.9	0.88	2.1	2.3	6	1.5	2.6
70% White, 30% whole-wheat	16.4	0.92	1.0	1.6	2	0.6	0.6

[a]Values are on a dry basis.
[b]Calculated on the basis of wheat protein = N × 5.7 and BSG protein = N × 6.25.

Preparation of Flour Blends

Blends containing 5, 10, and 15% of the BSG, dried under the different conditions, were prepared using a hard red spring wheat white flour. The wheat flour (unbleached and unmalted) was a commercially milled high-gluten flour containing 14.2% protein (N × 5.7) on a 14% moisture basis. The 30% whole-wheat blend (the control) was prepared by blending 30% whole-wheat flour with the high-gluten flour. Prior to blending, the whole-wheat flour was sieved to remove the bran whose particle size was reduced by grinding. The bran was then homogeneously recombined in the flour from which it was obtained.

Physical Dough Properties

The farinograph and extensigraph were used to determine the physical dough properties of all flours. Fifty-gram samples of flour in the 50-g bowl were used for farinograph studies. One hundred-gram samples of flour were used in the extensigraph.

Bread-Baking

To estimate overall baking performance, initial studies were done by making 100-g pup loaves.

One-pound loaves of bread for the preliminary and consumer taste panels were produced by a straight-dough baking procedure with 3 hr fermentation. The baking formula, based on flour weight, was as follows:

Salt	2%
Sugar	5%
Shortening	3%
Compressed yeast	3%
Malt	0.05%
Potassium bromate	10 ppm
Water	Variable

For the taste panel evaluations, the flour sample (1700 g) was mixed with the remaining ingredients in a 20-qt Hobart mixer (The Hobart Manufacturing Co.,

TABLE II
Yield and Nitrogen Levels of BSG Fractions

	Sieve Mesh in.	Fraction Yield %	N, Dry Basis %
BSG	32	1.4	5.1
	65	40.5	4.8
	80	8.0	5.1
	100	13.8	5.8
	150	13.7	6.8
	200	14.7	7.4
	Thru 200	7.9	8.0
	Parent	100	5.5

Troy, OH) until the dough was properly developed.

After 3 hr fermentation, the dough mass was divided into dough pieces of 540 g, rounded, and allowed to rest for 10 min prior to sheeting and molding. The dough balls were sheeted by machine and molded by hand. Loaves were proofed for 55 min and baked at 220°C for 25 min. The loaf volume of the bread was

TABLE III
Amino Acid Composition of White Flour, Whole-Wheat Flour, and BSG

Amino Acid	White Flour	BSG	Whole-Wheat Flour
	g amino acid/100 g sample, dry basis		
Lysine	0.41	1.00	0.58
Histidine	0.43	0.98	0.50
Ammonia	0.78	1.14	0.78
Arginine	0.72	1.59	1.01
Aspartic acid	0.85	2.04	1.14
Threonine	0.47	1.20	0.55
Serine	0.75	1.54	0.80
Glutamic acid	6.03	8.36	5.88
Proline	2.36	4.22	2.18
Half cystine	0.24	0.35	0.24
Glycine	0.64	1.18	0.79
Alanine	0.54	2.17	0.69
Valine	0.88	2.03	0.96
Methionine	0.49	0.75	0.45
Isoleucine	0.68	1.45	0.70
Leucine	1.25	3.93	1.31
Tyrosine	0.49	1.35	0.55
Phenylalanine	0.91	2.04	0.93
N recovery, %	100	91.6	105

TABLE IV
Farinograph Data for Flours and Flour Blends

Flour Type and BSG Drying Treatment	Blend %	Absorption[a] %	Dough Developing Time min	Stability min
White flour	...	62.6	6.5	12.5
30% Whole-wheat	...	65.4	5.0	9.0
BSG, None	5	65.0	6.5	12.5
	10	65.6	6.5	15.0
BSG, 45°C	5	64.2	6.5	12.0
	10	66.4	6.5	13.5
BSG, 100°C	5	64.2	6.5	12.0
	10	66.6	7.0	15.5
BSG, 150°C	5	64.2	5.5	12.0
	10	64.0	6.0	10.5

[a]Expressed on a 14% moisture basis.

measured 30 min after removal from the oven. The bread was sliced 2 hr after removal from the oven, placed in plastic bags, and frozen until required for taste panel evaluation.

Organoleptic Evaluation

Preliminary Panels. These small panels provided an estimation of the levels of flour replacement by BSG and the drying treatment of the BSG that would be chosen for breads to be supplied for the larger panel (consumer panel).

Bread was evaluated on a scale of 1 to 7 for: crumb texture, mouthfeel, flavor intensity, off-flavor, and overall preference (6). Values of 1 to 7, used for variance analysis, corresponded to increasing intensity or desirability as follows:

Crumb texture: 1 = smooth and moist, 7 = coarse and dry.
Mouthfeel: 1 = nonabrasive, 7 = abrasive.
Flavor intensity: 1 = mild, 7 = pronounced.

TABLE V
Extensigraph Data for Flours and Flour Blends

Flour Type and BSG Drying Treatment	Blend %	Proportional Number[a] 45-min rest	180-min rest
White flour	...	0.32	0.70
30% Whole-wheat	...	0.25	0.70
BSG, None	5	0.42	0.83
	10	0.49	1.01
BSG, 45°C	5	0.37	0.85
	10	0.46	1.11
BSG, 100°C	5	0.41	0.73
	10	0.55	1.08
BSG, 150°C	5	0.44	0.83
	10	0.45	1.23

[a]Resistance to Extension ÷ Extensibility.

TABLE VI
Per Cent Decrease in Specific Loaf Volume of One-Pound Loaves of Bread with Incorporation of BSG[a]

BSG Drying	Blend BSG %	Decrease in Specific Loaf Volume %
None	5	0
	10	11.4
	15	17.0
100°C	5	5.7
	10	11.6

[a]Values are based on an average of 20 loaves of bread, using the 30% whole-wheat bread as control.

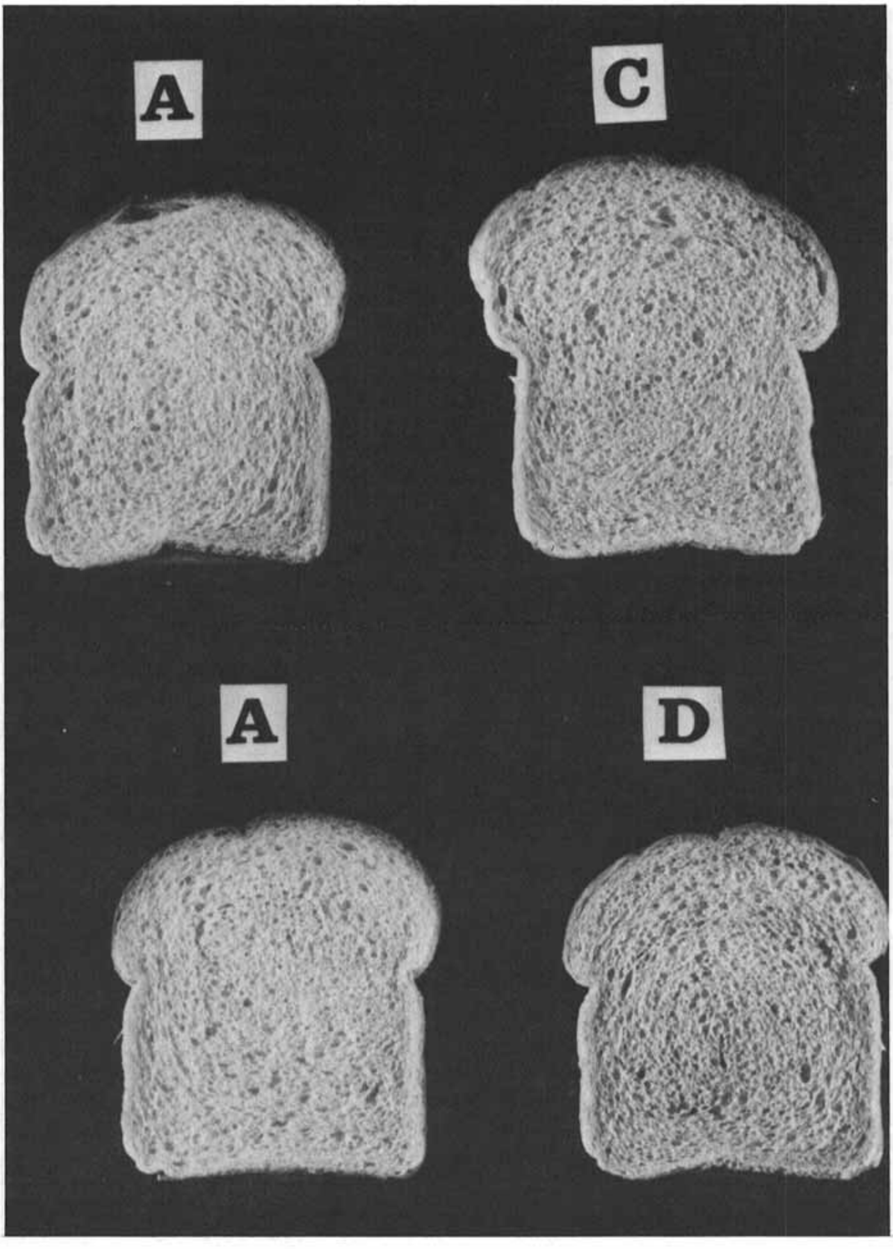

Fig. 1. Crumb structure of breads. A, 30% whole-wheat; C, 5% BSG; and D, 10% BSG. BSG received no additional drying.

Off-flavor: 1 = imperceptible, 7 = pronounced.

Overall preference: 1 = dislike very much, 2 = dislike moderately, 3 = dislike slightly, 4 = like slightly, 5 = like moderately, 6 = like very much, 7 = like extremely.

A numerical value of 3.5 was taken as the lowest level of acceptability for overall preference. Toasted bread slices were scored visually as follows:

Browning: 1 = light brown, 7 = very dark brown.

Uniformity of browning: 1 = uniform, 7 = nonuniform, streaked.

Overall preference: as for the bread evaluation.

Consumer Panels. Panel members received a quarter-slice of the whole-wheat control and a quarter-slice of BSG bread. One-half-ounce portions of sweet-cream, salted (2%) butter were served to the panelists as a free-choice condiment for the bread samples. Overall preference was determined as for the preliminary panel.

RESULTS AND DISCUSSION

Chemical and Physical Analyses of Flours and BSG

The compositions of the various flours and flour constituents are given in Table I. The protein of flours containing 5, 10, and 15% BSG is increased by 4.3,

TABLE VII
Preliminary Panel Evaluation of 30% Whole-Wheat Breads and BSG Bread at 5% Substitution Level

Flour Type and BSG Drying Treatment	Sample Attribute: Crumb texture[a]	Mouthfeel[b]	Flavor intensity[c]	Off-flavor[d]	Overall preference[e]
	Mean scores N = 29				
30% Whole-wheat	4.50[f]	4.65[f]	4.26[f]	3.02[f]	3.91[f]
BSG, 45°C	3.49[g]	3.20[g]	3.05[g]	2.36[g]	4.20[f]
	Mean scores N = 29				
30% Whole-wheat	3.92[f]	3.61[f]	3.26[f]	2.28[f]	4.57[f]
BSG, None	3.37[g]	3.35[f]	3.27[f]	2.63[f]	4.25[f]
100°C	3.52[g]	3.43[f]	3.41[f]	2.61[f]	4.44[f]
	Mean scores N = 28				
30% Whole-wheat	4.51[f]	4.30[f]	4.04[f]	2.85[f]	4.01[f]
BSG, 150°C	3.83[g]	3.42[g]	2.89[g]	2.44[f]	4.11[f]

[a]Crumb texture scale: 1 = Smooth, moist; 7 = coarse, dry.
[b]Mouthfeel scale: 1 = Nonabrasive; 7 = abrasive.
[c]Flavor intensity scale: 1 = Mild; 7 = pronounced.
[d]Off-flavor scale: 1 = Imperceptible; 7 = pronounced.
[e]Overall preference scale: 1 = Dislike extremely; 7 = like extremely; 3.5 = minimum acceptance.
[f,g]Mean scores with an experiment in the same column with the same superscript are not significantly different at the 5% level.

9.8, and 15.2%, respectively, compared with the 30% whole-wheat control.

For advantage to be taken of increases in crude fiber or acid-detergent fiber relative to the 30% whole-wheat-flour control, a minimum of 10% replacement of white flour by BSG would have to be used.

The particle-size nitrogen distribution of the milled BSG is shown in Table II. The largest portion of the material was retained on the 65-mesh sieve and, as with that retained on the 32- and 80-mesh sieves, contained a lower concentration of nitrogen than the parent material; these fractions appeared to be mainly fibrous husk tissue. The finer fractions (150-, 200-, and through 200-mesh) were higher in nitrogen by 1.25- to 1.5-fold than the parent and likely to contain a high proportion of aleurone and embryo tissue. For example, the protein level (N × 6.25) of the fraction retained on the 200-mesh sieve is 46%; this fraction would increase crumb protein significantly if 5 to 10% of the white flour were substituted with it.

Table III shows the amino acid composition of the parent BSG in comparison with the amino acid levels of the white flour and the whole-wheat flour. The protein level of the BSG is about twice that of the wheats; this relation exists for the constituent amino acids, except for glutamic acid, methionine, glycine, arginine, and cystine.

TABLE VIII

Preliminary Panel Evaluation of 30% Whole-Wheat Bread and BSG Bread at 10% Substitution Level

Flour Type and BSG Drying Treatment	Sample Attribute: Crumb texutre[a]	Mouthfeel[b]	Flavor intensity[c]	Off-flavor[d]	Overall preference[e]
			Mean scores N = 26		
30% Whole-wheat	4.01[f]	4.12[f]	3.22[f]	2.88[f]	3.82[f]
BSG, 45°C	3.85[f]	3.63[f]	3.47[f]	2.76[f]	3.87[f]
			Mean scores N = 29		
30% Whole-wheat	3.76[f]	3.55[f]	3.52[f]	2.36[f]	4.40[f]
BSG, 100°C	3.90[f]	3.85[f]	4.39[g]	3.13[g]	3.67[g]
			Mean scores N = 27		
30% Whole-wheat	4.00[f]	3.86[f]	3.32[f]	2.48[f]	4.15[f]
BSG, None	4.16[f]	3.95[f]	3.59[f,g]	2.95[f]	3.44[g]
150°C	4.74[g]	4.51[g]	4.04[g]	3.94[g]	2.86[h]

[a]Crumb texture scale: 1 = Smooth, moist; 7 = coarse, dry.
[b]Mouthfeel scale: 1 = Nonabrasive; 7 = abrasive.
[c]Flavor intensity scale: 1 = Mild; 7 = pronounced.
[d]Off-flavor scale: 1 = Imperceptible; 7 = pronounced.
[e]Overall preference scale: 1 = Dislike extremely; 7 = like extremely; 3.5 = minimum acceptance.
[f,g,h]Mean scores within an experiment in the same column with the same superscript are not significantly different at the 5% level.

Physical Dough Properties

Tables IV and V show the farinograph and extensigraph data for the hard red spring wheat flour, the 30% whole-wheat flour, and the flours containing 5 and 10% BSG dried under various conditions. The absorption of the flour blends containing the BSG increased as the level of BSG increased. With the BSG dried at 150° C, the increase in absorption was lowest compared to the other methods of drying. The dough-developing time was similar in all cases, whereas, with the higher level of BSG, the stability of the dough increased with the exception of the BSG dried at 150° C. The flour blend containing the 30% whole-wheat flour showed a reduction in dough-developing time and stability. The proportional number, as shown in Table V, increased as the amount of BSG in the blend was increased. Since the proportional number is obtained by dividing the resistance to extension by extensibility, the values obtained indicate that there was an increase in resistance to extension and/or a decrease in extensibility of the dough with the incorporation of the BSG. These results agree with the increase in stability values noted with the farinograph.

Bread-Baking

Based on preliminary studies with pup loaves, we decided to produce for the preliminary taste panels 1-lb loaves of bread made with flours containing 5 and 10% unheated BSG and BSG dried at 45°, 100°, and 150° C. The 30% whole-

TABLE IX
Preliminary Panel Visual Evaluation of Toast Prepared from 30% Whole-Wheat Bread and 5% and 10% Substitution of BSG

Flour Type and BSG Drying Treatment	Sample Attributes: Browning[a]	Uniformity of browning[b]	Overall preference[c]
		Mean scores N = 24	
30% Whole-wheat	4.22[f]	3.63[e]	4.02[d,e]
5% BSG			
None	4.74[d]	2.80[d]	4.08[d,e]
45° C	2.98[e]	2.94[d]	4.82[f]
100° C	3.33[e]	3.23[d,e]	4.48[e,f]
150°	2.43[d]	4.43[f]	3.63[d]
		Mean scores N = 24	
30% Whole-wheat	4.69[f]	3.32[d]	4.70[f]
10% BSG			
None	4.30[e]	3.22[d]	4.34[e,f]
45° C	2.75[d]	3.74[d,e]	3.82[d,e]
100° C	2.72[d]	4.09[e]	3.68[d]
150° C	2.57[d]	3.79[d,e]	3.55[d]

[a]Browning scale: 1 = Light brown; 7 = burnt.
[b]Uniformity of browning scale: 1 = Uniform; 7 = nonuniform, streaked.
[d]Overall preference scale: 1 = Dislike extremely; 7 = like extremely; 3.5 = minimum acceptance.
[d,e]Mean scores with an experiment in the same column with the same superscript are not significantly different at the 5% level.

wheat bread had color and other physical characteristics similar to the bread containing the BSG. Table VI shows typical effects of BSG on specific loaf volume.

Figure 1 shows the internal appearance of the control bread and bread made with flours that contained 5 and 10% BSG which had received no further drying. The grain appears acceptable at both levels of BSG incorporation. As the BSG drying temperature increased, the crumb color darkened, and as the level of BSG increased, the crust color became more dull.

Organoleptic Evaluation

Evaluation by the Preliminary Panel. Table VII shows the evaluation of breads made from BSG with various drying treatments at the 5% level of

TABLE X
Consumer Panel Evaluation of 30% Whole-Wheat Bread and BSG Breads at 5, 10, and 15% Levels of BSG

Flour Description	BSG Heat Treatment	Substitution Level %	Overall Preference[a]
			Mean scores N = 195
30% Whole-wheat	...	...	5.25[b]
BSG	None	5	5.14[b]
			Mean scores N = 199
30% Whole-wheat	...	...	5.05[b]
BSG	100°C	5	5.03[b]
			Mean scores N = 210
30% Whole-wheat	...	...	5.12[b]
BSG	None	10	5.20[b]
			Mean scores N = 194
30% Whole-wheat	...	...	5.19[b]
BSG	100°C	10	5.18[b]
			Mean scores N = 199
30% Whole-wheat	...	...	5.24[b]
BSG	None	15	4.94[c]

[a]Scale: 1 = Dislike extremely; 7 = like extremely; 3.5 = minimum acceptability.
[b,c]Mean scores within an experiment in the same column with the same superscript are not significantly different at the 5% level.

incorporation in flour. Crumb texture was less coarse than that of the 30% whole-wheat-bread control, and in some cases there was less abrasive mouthfeel. Bread containing BSG treated at 150° C appeared to be somewhat less flavorful than the whole-wheat control bread. Off-flavor was not a problem. The breads containing 5% BSG replacement of flour had the same overall preference as the control regardless of heat treatment.

At the 10% level of substitution (Table VIII), however, the BSG showed deleterious effects relative to the 30% whole-wheat control, particularly the BSG which had been dried at 150° C. In this case, crumb texture was more abrasive. Flavor intensity was increased, and this was judged to be an off-flavor. The 150° C-treated material reduced overall acceptability. It is evident that there was no advantage in treating BSG at high temperatures. Similarly, substitution at the 10% level by BSG treated at 100° C seemed undesirable. While this did not change crumb texture or mouthfeel, flavor intensity was increased and this was judged to be an off-flavor which resulted in significantly decreased overall preference. BSG with no additional heat treatment and BSG treated at 45° C at the 10% level showed no significant differences in any category, except for an inexplicably lowered overall preference for the BSG with no additional heat treatment.

Table IX shows the effects of BSG at the 5 and 10% levels on the visual characteristics of toast.

At both 5 and 10% levels of BSG, the overall preference was the same as for the control provided that the BSG had received no additional heat treatment. While differences in color were noted, they were not objectionable.

Evaluation by Consumer Panels. The results from the preliminary panels indicate that additional heat treatment of commercially dried BSG is of doubtful value and that 10% substitution of flour with BSG is probably the upper limit of substitution. Accordingly, the consumer panels were presented only bread containing BSG without additional drying and with BSG treated at 100° C, both at 5 and 10% levels of flour substitution. In addition, unheated BSG was evaluated at the 15% level of flour substitution.

From the consumer panels (Table X) it is apparent that the bread with the BSG at the 5 and 10% levels had the same acceptability as the whole-wheat control. Furthermore, there was no advantage in heating the commercially dried BSG. At the 15% level of BSG incorporation there was a significant decrease in consumer acceptability, but the value was still well above the minimum value, 3.5. The use of BSG in bread at the level of 5 to 15% flour replacement may be practicable, particularly if consumers are aware of the possible benefits of the increased fiber and protein levels. Improvement in the performance of BSG may be possible by proper selection of particle size. Solids in press water from BSG, however, do not perform well in either cookies or bread (7).

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