Protein and Fiber Enrichment of Cookie Flour with Brewer's Spent Grain[1]

L. T. KISSELL and N. PRENTICE[2]

ABSTRACT

Samples of laboratory-prepared and commercial brewer's spent grain (BSG) were dried at three temperatures (45, 100, and 150°C), and ground; portions separated by sieving were analyzed for protein, amino acid, and dietary fiber contents. Commercial BSG and its corresponding fraction, which passed through a 78-mesh screen, were used to fortify soft red winter (SRW) cookie flour at levels ranging from 10 to 40% BSG. Baking performance was improved by inclusion of 1 to 2% of commercial soy lecithin as emulsifier. Cookies were analyzed for protein content and amino acid composition. With lecithin surfactant and BSG dried at 150°C, it was possible to double the crumb protein and lysine contents and increase dietary fiber by more than fivefold while maintaining the physical performance of doughs. Products made with 20% sieved BSG (45°C) contained 55% more protein, 90% more lysine, and 220% greater fiber than control cookies made with SRW flour, and were within the organoleptic limitations established for taste and texture.

Cereal Chem. 56(4):261-266

The principal by-product of the brewing industry, spent-grain residue, traditionally has been used in animal feed (Linton and Siebald 1971), or has been discarded (Townsley 1974). Although brewer's spent grain (BSG) is "spent" with respect to starch content, it is actually enriched by a factor of more than two in protein, lipids, and fiber over the levels of the original barley grain. The combination of large continuing supply, relatively low cost, and potential nutritional value (Hunt 1969) makes BSG an attractive adjunct for human food. BSG has been suggested (Townsley 1974) as a raw material for processing, in the manner of soy analogs, for entry into the market now dominated by ground beef, milk, and cheese.

BSG could also be used directly as a protein and fiber supplement in conventional baked products. Prentice and D'Appolonia (1977) found that the addition of 5 to 15% of ground BSG to bread was acceptable to a consumer panel, although loaf volume was reduced by 10 to 17% at the higher levels of supplementation. Successful protein fortification of soft wheat products (cookie) has been reported using soy derivatives (Kissell and Yamazaki 1975, Tsen et al 1973) and wheat gluten (Kissell and Yamazaki 1975); fiber supplementation of cake with wheat bran and middlings has been investigated (Rajchel et al 1975). Finley et al (1976) noted that the addition of 15 to 20% of a soluble protein extract from BSG suppressed the spread of sugar-snap cookies. Prentice et al (1977) found a similar response with ground BSG but compensated for the change in functionality by adding 1.0 to 2.0% (flour basis) of soy lecithin as surfactant and conditioner. This modified dough system accomodated up to 40% of BSG in blends with soft-wheat cookie flour and still maintained spread and top-grain appearance of the control flour. Panel acceptability of the products was limited to a maximum of 15% BSG because of an undesirable flavor imparted by the supplement. A similar maximum was established for specialty cookies containing a

[1]Data presented in part at the I.C.C. Symposium on the Role and Function of Emulsifiers in Baking, London, England, May 1977. Cooperative investigation of the Soft Wheat Quality Laboratory, North Central Region, Science and Education Administration, U.S. Department of Agriculture; the Department of Agronomy, Ohio Agricultural Research and Development Center, Wooster, OH; Barley and Malt Laboratory, Science and Education Administration, U.S. Department of Agriculture; and the Department of Food Science, College of Agriculture and Life Sciences, University of Wisconsin, Madison, WI. Approved for publication as Journal Article 40-78 of the Ohio Agricultural Research and Development Center, Wooster, OH 44691. Mention of a trademark or proprietary product does not constitute a guarantee or warranty of a product by the U.S. Department of Agriculture, and does not imply its approval to the exclusion of other products that may also be suitable.

[2]Research chemists, Soft Wheat Quality Laboratory, Ohio Agricultural Research and Development Center, Wooster, OH 44691, and Barley and Malt Laboratory, Madison, WI 53705.

variety of flavors and spices.

This paper presents an extension of our work (Prentice et al 1977) on BSG in sugar-snap cookies and includes particle-size distribution and protein analysis of separates of six BSG samples, dietary-fiber determination of selected BSG samples and sieve separates, and amino acid analysis of the same series of BSG derivatives plus selected samples of ground cookie crumb.

MATERIALS AND METHODS

Samples

Laboratory-prepared (Prentice et al 1977) and commercial BSGs were dried in a forced-draft oven at 45, 100, and 150° C for 16, 8, and 1.5 hr, respectively. Dried samples were reduced by passage through a Tecator-Udy Cyclone sample mill. Twenty-gram portions from each treatment were separated on a nest of sieves (32, 65, 80, 100, 150, and 200 mesh/in.) for 5 min on a Tyler Ro-Tap machine in five replications. Preparative samples for baking tests were truncated on a 14 × 14 in. reciprocating screen of 78 mesh/in. The low-protein coarse fraction was discarded and the enriched throughs were used to blend with soft red winter (SRW) cookie flour for test baking.

Cookie Baking

In the sugar-snap cookie procedure (micro-method III) of Finney et al (1950), each parent BSG and truncated fraction (through 78 mesh) was baked in blends with SRW flour at levels ranging from 10 to 40% BSG. Each flour-BSG blend also was baked in the presence of 1 and 2% (flour weight basis) additions of soy lecithin containing 60% phosphatides (Centrol CA, Central Soya, Chicago, IL) as surfactant and dough improver. Data for cookie spread are presented as the mean diameter of two cookies from a single dough. Top-grain scores are given as integers ranging from 9 (maximum uniform break-up) to 0 (no grain formation). Representative cookies were broken and ground for 30 sec in a Waring Blendor prior to chemical analysis.

Chemical Analysis

All BSG samples and sieve separates were analyzed in duplicate for Kjeldahl nitrogen, ash, and moisture by standard AACC methods; those samples and sieve separates of commercial origin, and selected cookie crumbs therefrom, were subjected to additional analyses.

Determination of Polysaccharides

Starch, gums, hemicelluloses, and pentosans were hydrolyzed by refluxing 14 g of sample in 500 ml of 1*N* sulfuric acid for 4 hr. The reaction mixture was filtered, and the residue washed with water. Filtrate and washings were combined and volume noted. After neutralization of the supernatant with $BaCO_3$, sugars were determined by the method of Brobst et al (1973) using a 0.9 × 60-cm column of AG 50 W-X4 (20 to 30 μ) cation exchange resin (Bio-Rad Laboratories, Richmond, CA). The level of starch and β-glucan was determined as glucose in the hydrolysate.

TABLE I
Analytical Data (Dry Weight Basis) for Brewer's Spent Grain (BSG) Samples and Fractions from Laboratory and Commercial Sources, and for Soft Red Winter (SRW) Control Flours

		Laboratory		Commercial					
Drying Temp. (°C)	Sieve Separate (mesh/in.)	Yield (%)	Protein[a] (%)	Yield (%)	Protein[a] (%)	Ash (%)	Total Lipids (%)	Starch + β-Glucan (%)	Dietary Fiber (%)
45	Over 32	0.3	27.4	0.3	27.1	...	...	...	...
	Over 65	22.0	21.8	21.2	18.7	4.59	4.7	6.2	66
	Over 80	8.0	26.1	8.1	22.0	4.20	5.5	6.7	62
	Over 100	16.3	28.4	17.2	32.6	3.70	6.7	8.9	48
	Over 150	14.9	33.8	18.4	43.3	2.99	7.8	9.3	37
	Over 200	21.0	39.5	20.7	47.6	2.69	8.9	9.9	31
	Thru 200	17.5	47.0	14.1	50.7	2.75	9.8	11.0	26
	Parent	100.0	33.1	100.0	35.9	3.44	7.5	8.6	45
	Over 78	25.4	21.2	21.0	19.7	4.64	4.3	5.4	70
	Thru 78	74.6	37.3	79.0	40.1	3.22	8.6	10.1	38
100	Over 32	0.3	28.0	0.1	22.6	...	...	...	...
	Over 65	19.7	21.1	9.2	11.3	4.73	3.5	4.1	76
	Over 80	9.3	22.9	6.7	17.1	4.33	7.8	5.5	65
	Over 100	16.6	25.8	18.9	27.5	3.89	8.3	7.2	53
	Over 150	17.6	33.8	23.6	39.4	3.28	10.6	8.9	38
	Over 200	10.4	39.7	29.0	46.3	2.71	11.7	9.8	30
	Thru 200	26.1	42.5	12.5	51.0	2.62	13.4	10.1	23
	Parent	100.0	30.8	100.0	36.0	3.45	7.6	8.0	45
	Over 78	26.4	20.6	19.4	16.6	4.46	3.1	5.4	70
	Thru 78	73.6	33.8	80.6	39.7	3.24	6.6	7.8	43
150	Over 32	0.4	19.7	0.1	16.6	...	...	...	...
	Over 65	23.0	20.6	9.0	13.2	4.73	3.0	4.1	75
	Over 80	8.5	21.2	8.3	19.8	4.33	4.0	5.0	67
	Over 100	15.8	25.7	18.9	28.5	3.89	5.1	6.8	56
	Over 150	16.0	32.3	24.3	40.1	3.28	8.5	8.1	40
	Over 200	9.4	37.8	23.9	46.4	2.71	7.2	9.0	35
	Thru 200	26.9	42.4	15.5	50.2	2.62	9.3	9.2	29
	Parent	100.0	31.0	100.0	36.5	3.45	6.2	8.0	46
	Over 78	26.2	20.2	17.2	20.1	4.56	3.0	5.4	67
	Thru 78	73.8	33.8	82.8	40.1	3.24	5.7	7.7	43
SRW Control flour		...	...	...	10.1	0.46	1.3	85.0	3

[a] Protein conversion factor for BSG = 6.25; for SRW control flour = 5.70.

Determination of Total Lipids

BSG was extracted with diethyl ether to obtain free lipids. The BSG residue was then extracted with water-saturated 1-butanol and the resulting residue was reextracted with diethyl ether to obtain bound lipids. Total lipid was the sum of free and bound lipids.

Calculation of Dietary Fiber

Dietary fiber in BSG was estimated as the difference between 100% and the sum of percent compositions of starch and gums (as glucose), protein (as N × 6.25), total lipids, and ash, all on a dry weight basis. β-Glucan and hemicellulose are constituents of dietary fiber. In the above procedure, these compounds are hydrolyzed and the glucose from them is included with that from the hydrolysis of starch, which is then calculated as starch, and is subtracted from the dietary fiber. Thus, the dietary fiber values are somewhat low. Separate analyses for β-glucan and hemicellulose are complicated and not applicable to the number of samples in this study. Dietary fiber values reported are means of duplicate determinations for which normal variation is estimated to average 5%.

Amino Acid Analysis

Both BSG derivatives of commercial origin and corresponding ground cookie crumbs were analyzed for amino acid composition. About 40 mg of sample was hydrolyzed for 22 hr at 110°C in 6*N* hydrochloric acid in a tube that had been flushed with nitrogen, evacuated, and sealed. Single run amino acid analyses were made in the usual way with a Beckman Model 121 amino acid analyzer, employing norleucine as the internal standard for data correction. This procedure and the elution times for the amino acids are considered good checks on the chromatography. Independent determinations have indicated an analytical error of 5% to be representative. Tryptophan was not determined. Compositions of the BSG samples and sieve-separates are expressed as grams of amino acid per 100 grams of total amino acid recovered, adjusted to 100% nitrogen recovery. The mean recovery, based on Kjeldahl N contents, was 94.7% for ground BSG and cookie crumbs.

RESULTS AND DISCUSSION

Data resulting from sieve separation of ground BSG samples are presented in Table I. A comparison of yields for corresponding fractions from laboratory and commercial sources shows that, for

TABLE II
Analytical and Cookie-Baking Data for Blends of Commercial Brewer's Spent Grain (BSG) with Soft Red Winter (SRW) Cookie Flour

	Protein[a]		Crumb	Baking Data[b]					
				Blend		Blend +1% Soy Lecithin		Blend + 2% Soy Lecithin	
Flour-BSG Blend	Blend (%)	Cookie Crumb (%)	Dietary Fiber[c] (%)	Diam. (cm × 2)	Top Grain	Diam. (cm × 2)	Top Grain	Diam. (cm × 2)	Top Grain
SRW Control	10.1	5.3		17.7	8	18.3	9	18.6	9
+10% C45	12.5	6.6	3.5	17.8	6	18.0	9	18.3	9
15% C45	13.7	7.1	4.5	17.3	5	18.1	8.5	18.0	9
20% C45	14.9	7.7	5.5	17.4	5.5	17.6	8.5	17.9	9
25% C45	16.2	8.4	6.5	17.1	4	17.5	7.5	17.6	8.5
+10% C45TH	12.9	6.8	3.2	17.5	6	18.0	8.5	18.1	8.5
15% C45TH	14.3	7.5	4.0	17.1	5	17.8	8.5	17.9	9
20% C45TH	15.7	8.2	4.8	16.7	4	17.4	7.5	17.7	8
25% C45TH	17.1	8.9	5.7	16.5	4	17.2	8	17.2	8
+10% C100	12.5	6.6	3.5	17.5	7	18.0	9	18.0	9
20% C100	15.0	7.8	5.5	17.0	6	17.5	7.5	17.7	7.5
30% C100	17.4	9.0	7.5	16.8	5	16.9	6	17.0	6
40% C100	19.9	10.3	9.5	16.3	4	16.6	5	16.6	5
+10% C100TH	12.8	6.8	3.4	17.7	7	18.1	9	18.2	9
20% C100TH	15.6	8.2	5.3	17.3	7	17.8	8	18.0	8.5
25% C100TH	17.0	8.9	6.3	17.3	4	17.7	8	17.8	8
30% C100TH	18.4	9.6	7.2	17.0	6	17.3	7	17.3	7
40% C100TH	21.3	11.0	9.1	16.6	4	17.2	6	16.9	5
+10% C150	12.5	6.6	3.5	17.7	8	18.1	9	18.3	9
20% C150	15.0	7.9	5.6	17.5	6	17.9	9	18.2	9
30% C150	17.6	9.1	7.6	17.4	6	17.8	8	17.8	8
35% C150	18.8	9.8	8.7	17.4	4	17.8	8	17.7	8
40% C150	20.2	10.3	9.6	17.1	5	17.4	7	17.4	7
+10% C150TH	12.9	6.8	3.4	17.6	8	18.0	9	18.2	9
20% C150TH	15.7	8.2	5.3	17.5	6	17.9	9	18.1	9
30% C150TH	18.6	9.6	7.2	17.5	5	17.9	8.5	17.8	7
40% C150TH	21.5	11.0	9.1	17.3	5	17.7	7.5	17.4	6

[a] Protein conversion factor adjusted for ratio composition of SRW (× 5.7) and BSG (× 6.25). Dry weight basis.
[b] Lecithin = Percent by weight on flour weight basis.
[c] Computed on dry weight basis.

the former, recoveries of coarse fractions were higher and yields of fine fractions were lower than were found with commercial BSG. For protein level, the reverse was found; the fractions of commercial BSG passing the 78 to 80-mesh screen had up to 3% more protein on the average than did laboratory samples, after consideration of the higher base protein levels of commercial parent BSG. Only commercial samples were subjected to additional analyses for dietary fiber and amino acid composition.

From Table I, it can be seen that ash content reduced with decreasing particle size; total lipids increased, presumably in association with the increasing embryo and aleurone-cell protein; and residual starch plus β-glucan increased slightly as fineness increased. The aggregate result was a threefold reduction in dietary fiber over the range of sieve separates, and 35 to 46% reduction in materials passing through the 78-mesh as compared with the coarse fraction. For the purpose of product enrichment, preparative BSG (through 78-mesh) was 3.9 times higher in protein and 13.3 times higher in fiber than the soft wheat control flour.

Complete protein, fiber, and baking data for the commercial BSG series are given in Table II. Data for the laboratory BSG series are omitted because we found that, in all cases but one, performance of commercial BSG was acceptable at the same or higher levels, with higher protein and fiber contents at the limit of acceptability, than was obtained with laboratory-prepared BSG.

Cookie Performance

Representative cookies from blends of the intermediate drying treatment (100° C) are shown in Fig. 1 (whole BSG) and Fig. 2 (fraction through 78-mesh). Improvements in both spread and top-grain appearance resulting from the additions of lecithin are notable at each level of BSG fortification. Treatment limits for acceptable quality, based on error terms for the cookie test ($LSD_{0.05}$ for diameter = ±0.3 cm and for top-grain score = ±3 points) are underlined in Table II. Up to 10% of low (C45) and medium (C100) heated whole BSG and the corresponding sieved fractions (C45TH and C100TH) were acceptable in cookies

TABLE III
Amino Acid Composition (Dry Weight Basis) of Commercial Brewer's Spent Grain (BSG) and Sieve Separates Dried at 45° C

Component	Sieve Separates (mesh/in.)						Parent BSG	Fraction		Soft red Winter Control
	OV-65	OV-80	OV-100	OV-150	OV-200	TH-200		OV-78	TH-78	
Amino acids (g/100 g recovered)										
Lysine	3.0	2.9	2.4	2.5	2.6	2.5	2.6	3.0	2.3	1.8
Histidine	2.5	2.5	2.4	2.5	2.5	2.5	2.4	2.4	2.3	2.0
Ammonia	2.9	2.8	2.8	2.8	2.5	2.8	2.6	2.8	2.8	3.9
Arginine	4.0	4.2	4.0	3.9	4.1	3.9	4.0	4.4	4.0	3.7
Aspartic acid	7.0	6.2	5.7	5.5	5.7	5.4	6.9	6.6	5.5	5.0
Threonine	3.5	3.6	3.0	3.4	3.5	3.2	3.4	3.5	3.3	2.5
Serine	4.2	4.3	4.3	4.2	4.1	4.1	4.4	4.4	4.1	4.1
Glutamic acid	22.1	21.6	22.1	21.8	19.7	21.6	20.1	22.2	21.9	33.7
Proline	10.6	10.6	10.8	11.1	12.5	12.6	12.1	10.5	11.5	11.8
Cystine	0.7	1.0	1.1	1.2	1.3	1.3	1.0	0.9	1.1	1.3
Glycine	3.7	3.5	3.3	3.1	3.2	3.1	3.3	3.7	3.2	3.3
Alanine	5.8	6.1	6.2	6.2	6.1	5.7	6.0	6.0	6.0	2.9
Valine	5.9	5.6	5.5	5.3	5.2	5.2	5.3	6.0	5.4	5.0
Methionine	1.6	1.8	2.1	2.1	2.2	2.1	2.0	1.6	2.1	1.6
Isoleucine	4.0	4.1	4.0	4.0	4.2	4.0	4.0	4.0	4.1	3.6
Leucine	10.2	10.6	11.2	11.4	11.1	10.7	10.8	10.2	11.0	6.7
Tyrosine	2.7	3.6	3.4	3.6	3.8	3.7	3.6	2.8	3.7	2.5
Phenylalanine	5.0	5.1	5.6	5.5	5.9	5.7	5.8	5.3	5.7	4.7

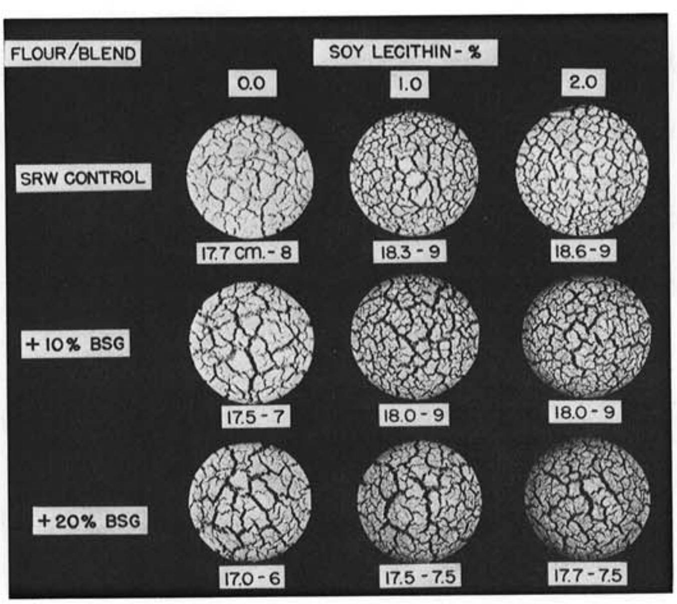

Fig. 1. Cookies from soft red winter flour blends with 10 and 20% whole brewer's spent grain dried at 100°C. Doughs prepared with 0, 1, and 2% soy lecithin.

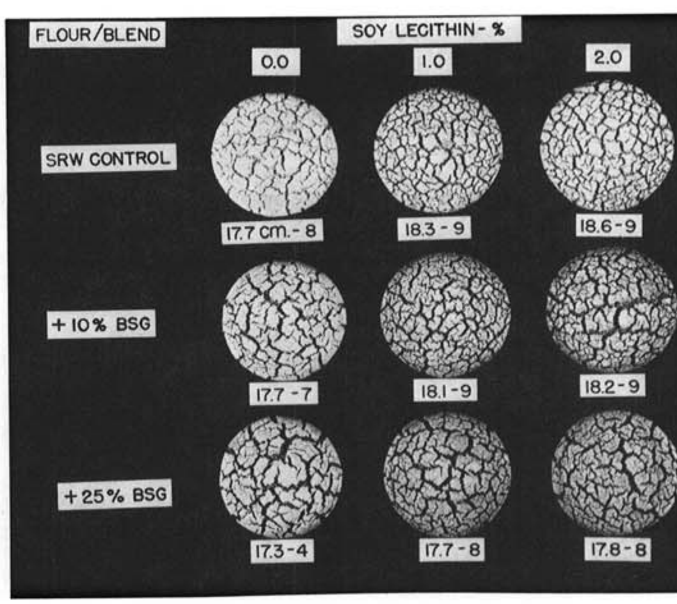

Fig. 2. Cookies from soft red winter flour blends with 10 and 25% sieved fractions of brewer's spent grain, dried at 100°C. Doughs prepared with 0, 1, and 2% soy lecithin.

without addition of surfactant. Crumb protein was increased as much as 28% (from 5.3 to 6.8%) and dietary fiber was increased as much as 133% (from 1.5 to 3.5%) by those treatments. Because the functional properties of BSG were reduced by high heat, up to 30% of C150 and C150TH could be incorporated before cookies lost their acceptable appearance. These blends had a maximum increase of 81% in crumb protein and an increase of about 400% in fiber. Additions of soy lecithin permitted further elevation of the supplement limit and improved performance of doughs at intermediate levels of fortification.

Although we can demonstrate the compatability of BSG and sieved fractions in blends with SRW flour up to 40% BSG, our earlier study (Prentice et al 1977) found an organoleptic limit of about 15% BSG owing to an increasing unacceptable flavor in the cookies tested. In this analytical study, we have assumed an upper limit of 20% BSG. At that level, soft wheat flour supplemented with C100TH gave cookies with protein of 8.2% (55% increase) and dietary fiber of 5.3% (250% increase).

Amino Acid Composition

Recovery data for amino acids from SRW flour and commercial BSG dried at 45°C are listed in Table III. Our recoveries for SRW flour are in close agreement with the composition ranges for first-break flours from hard wheat varieties determined by Nelson and McDonald (1977). Likewise, with the exception of lower lysine values, our data for parent BSG dried at 45°C compare well with average recoveries from unheated mature barley reported by Pomeranz and Robbins (1972). At a drying temperature of 45°C, the amino acid compositions of the sieve separates were not radically different, although the coarse fractions (over 80-mesh) were about 10% higher in lysine, threonine, and valine, while being lower in proline, methionine, and phenylalanine. Similar differences were also noted for preparative samples from the 78-mesh separation.

The adverse effect of increased drying temperature on lysine recovery from BSG may be seen when the data are compared on a sample weight basis in Table IV. For the parent BSG and fractions finer than 78–80 mesh, relatively less lysine was lost for the temperature interval from 45 to 100°C than for the interval from 100 to 150°C. Lysine levels in the 78-mesh throughs dried at 45 or 100°C were about five times higher than that in SRW flour.

The results of amino acid determinations of crumb from cookies fortified with 10 to 20% whole BSG dried at 45°C and the through 78-mesh fraction are given in Table V. Lysine recovery was about 30% higher in the cookie containing 20% sieved BSG than in the SRW control. At corresponding levels of supplement (data not shown), the lysine recovery from crumb containing 100°C BSG was reduced by an average of 7%, and for the 150°C drying, about 24% less lysine was recovered than for the 45°C blends. Threonine recoveries were not affected adversely by the heat levels employed in this experiment.

When lysine recoveries are converted to the basis of cookie-crumb weight in Table VI, the low level of this essential amino acid is apparent. Because the blends of flour and BSG are diluted by other ingredients and are degraded by additional heat in the cookie-baking process (10 min at 204°C), lysine in finished crumb was found to range from 0.11% in the control to 0.21% (90% increase) at the highest acceptable level (20%) of BSG addition. The concomitant increase in crumb protein was 55% and in computed dietary fiber was 220%.

Thus, the lysine level was enriched at a more rapid rate than the general protein level as a result of the intrinsically higher concentration of that amino acid in BSG, in spite of the demonstrated losses from heat treatment. This advantage, combined with the substantial increase in fiber that accompanies the introduction of BSG into wheat products, the continuing supply, and availability, suggests a potential for some utilization in human nutrition. To achieve further increases in protein and fiber fortification while maintaining the physical integrity of the product would require additional research to overcome the organoleptic limitations on BSG supplementation levels.

TABLE IV
Lysine Content of Commercial Brewer's Spent Grain (BSG) and Sieve Separates Dried at Three Temperatures[a]

BSG Sample	Drying Temperature 45° C	100° C	150° C
OV-65	0.62	0.38	0.32
OV-80	0.70	0.50	0.45
OV-100	0.84	0.78	0.61
OV-150	1.19	1.06	0.84
OV-200	1.38	1.13	0.90
TH-200	1.43	1.31	0.97
Parent	1.02	0.97	0.70
OV-78	0.50	0.45	0.42
TH-78	1.03	0.95	0.72

[a]Lysine content expressed as g/100 g of sample, dry weight basis. Soft red winter control flour = 0.21 g lysine/100 g.

TABLE V
Amino Acid Composition (Dry Weight Basis) of Cookie Crumb, Fortified at Three Levels with Whole Brewer's Spent Grain (BSG) and the Throughs of the 78-Mesh Sieve Dried at 45° C

Component	BSG Fortification 10% WHOLE	10% TH-78	15% WHOLE	15% TH-78	20% WHOLE	20% TH-78	Soft red Winter Control
Amino acids (g/100 g recovered)							
Lysine	1.9	2.1	2.0	2.0	2.1	2.2	1.7
Histidine	2.5	2.5	2.5	2.4	2.6	2.5	2.7
Ammonia	3.8	3.8	3.8	3.6	3.7	3.5	4.1
Arginine	3.4	3.4	3.4	3.5	3.4	3.5	3.0
Aspartic Acid	5.1	5.2	5.2	5.4	5.2	5.6	4.3
Threonine	3.1	3.0	3.1	3.1	3.0	3.1	2.8
Serine	4.1	4.2	4.3	4.1	4.3	4.0	4.4
Glutamic acid	29.8	29.6	29.1	28.6	28.0	27.6	32.9
Proline	11.3	11.2	10.8	11.3	11.3	11.3	11.5
Cystine	1.0	1.0	0.8	0.8	1.2	1.0	0.9
Glycine	3.4	3.4	3.4	3.2	3.3	3.4	3.3
Alanine	3.8	3.8	4.1	4.2	4.3	4.4	3.0
Valine	5.4	5.2	5.4	5.2	5.2	5.2	5.4
Methionine	2.3	2.2	2.2	2.3	2.3	2.3	2.0
Isoleucine	3.8	3.8	3.8	4.0	3.9	3.9	3.6
Leucine	8.0	8.2	8.6	8.6	8.8	8.9	6.9
Tyrosine	2.5	2.7	2.6	2.8	2.6	2.5	2.5
Phenylalanine	4.8	4.8	4.8	5.0	5.0	5.2	5.0

TABLE VI
Lysine Content of Cookie Crumb Fortified with Whole Brewer's Spent Grain (BSG) and Sieved Fractions[a]

BSG Fortification	Drying Temperature					
	45° C		100° C		150° C	
	Whole	TH-78	WHOLE	TH-78	WHOLE	TH-78
+10% BSG	0.14	0.16	0.16	0.12	0.13	0.12
+15% BSG	0.17	0.18	···	···	···	···
+20% BSG	0.19	0.21	0.20	0.16	0.14	0.14
+25% BSG	0.22	0.23	···	0.21	···	···
+30% BSG	···	···	0.25	0.20	0.15	0.18
+35% BSG	···	···	···	···	0.19	···
+40% BSG	···	···	0.24	0.26	0.20	0.21

[a] Lysine content expressed as g/100 g of cookie crumb, dry weight basis. Soft red winter control cookie crumb = 0.11 g lysine/100 g.

ACKNOWLEDGMENTS

The authors appreciate the technical assistance of James Refsguard and John Carden in performing fiber analyses, of George Robbins and James Gilbertson in the amino acid determinations, and of John R. Donelson in the cookie-baking studies. Gifts of brewer's spent grain by the Stroh Brewing Company, Detroit, MI, and of soy lecithin by the Central Soy Company, Chicago, IL, are gratefully acknowledged.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. Approved methods of the AACC. Methods 08-01, 44-16, and 46-12, approved April 1961. The Association: St. Paul, MN.

BROBST, K. M., SCOBELL, H. D., and STEELE, E. M. 1973. Analysis of carbohydrate mixtures by liquid chromatography. Am. Soc. Brew. Chem. Proc. 4:43.

FINLEY, J. W., WALKER, C. E., and HAUTALA, E. 1976. Utilisation of press water from brewer's spent grains. J. Sci. Food Agric. 27:655.

FINNEY, K. F., MORRIS, V. H., and YAMAZAKI, W. T. 1950. Micro versus macro cookie-baking procedures for evaluating the cookie quality of wheat varieties. Cereal Chem. 27:42.

HUNT, L. A. 1969. Brewers grains and yeast: Market products, not by-products. Master Brew. Assoc. Am. Tech. Q. 6:69.

KISSELL, L. T., and YAMAZAKI, W. T. 1975. Protein enrichment of cookie flours with wheat gluten and soy flour derivatives. Cereal Chem. 52:638.

LINTON, J. H., and SIBALD, I. R. 1971. The acceptability of mixtures of spent yeast and brewers' spent grains as components of cattle diets. Brewer's Dig. 46:58.

NELSON, P. N., and McDONALD, C. E. 1977. Properties of wheat flour protein in flour from selected mill streams. Cereal Chem. 54:1182.

POMERANZ, Y., and ROBBINS, G. S. 1972. Amino acid composition of maturing barley. Cereal Chem. 49:560.

PRENTICE N., and D'APPOLONIA, B. L. 1977. High-fiber bread containing brewer's spent grain. Cereal Chem. 54:1084.

PRENTICE, N., KISSELL, L. T., LINDSAY, R. C., and YAMAZAKI, W. T. 1977. Utilization of brewers' spent grain in high fiber cookies. (Abstr. 97). Cereal Foods World 22:470.

RAJCHEL, C. L., ZABIK, M. E., and EVERSON, E. 1975. Wheat bran and middlings—a source of dietary fiber in banana, chocolate, nut, and spice cakes. Baker's Dig. 49(3):27.

TOWNSLEY, P. M. 1974. Uses for brewery waste products. Master Brew. Assoc. Am. Tech. Q. 11:262.

TSEN, C. C., PETERS, E. M., SCHAFER, T., and HOOVER, W. J. 1973. High protein cookies. I. Effects of soy fortification and surfactants. Baker's Dig. 57(4):34.

[Received August 7, 1978. Accepted November 7, 1978]