Protein and Amino Acid Contents of Successive Layers Removed by Abrasive Milling of Sorghum Grain[1]

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ABSTRACT

Grain from six sorghum varieties which differ in endosperm texture was subjected to controlled, stepwise abrasive grinding until approximately 45% of the kernel was removed. The grinding was controlled so that each successive fraction consisted of approximately 2% of the beginning sample weight. Protein content of the fractions from a grain with 15.2% protein varied from 8.1 to 35.4%. By combination of the various fractions, a sample which had 25% protein and represented 27% of the original grain was obtained. Grain with lower protein content (10.8%) gave fractions with 7.6 to 25.6% protein; and proper combination of the fractions gave a sample with 23% protein, which represented 15% of the original grain. Varieties with a floury endosperm texture could not be successfully milled. Significant changes in the amino acid contents of the fractions were observed. The experiments indicate that it is theoretically possible to obtain appreciable quantities of fractions with improved protein content and quality. These fractions may be useful in formulating high-protein foods, especially in areas of the world where sorghum is the major food crop. The residual portion of the kernel is low in fat and ash, and could be used as refined grits.

Several approaches are being concurrently investigated to attempt to improve the content and quality of protein in cereal grains throughout the world. Breeding is a long-term approach, whereas improved processing techniques and better utilization of existing cereals and oilseed proteins are significant in the long and short term. Sorghum is an important food crop in Asia and Africa, and ranks third in total grain production of all cereals in the U.S. The most efficient way of improving sorghum-grain utilization is a combination of better processing techniques with better varieties of sorghum.

Sorghum in Asia and Africa is consumed with a minimum of milling. Usually it is ground and eaten after crude sifting to remove the larger chunks of pericarp. In the U.S., sorghum is milled by modified wheat-milling equipment. In some cases, milling is accomplished by abrasion and impaction to remove the bran or pericarp and germ (1). In the modified wheat-milling procedure, the products obtained are not refined and have considerable color. The abrasive techniques provide higher yields of more refined products, especially when proper varieties of sorghum are used. Much of the by-products is used for livestock feed, although markets are available for low-protein flour fractions obtained during milling.

Different parts of the sorghum kernel contain variable quantities of protein and other constituents. Watson et al. (2) found that the peripheral endosperm cells of sorghum isolated by a wet-milling procedure contained from 29.4 to 40% protein. Normand et al. (3) found that sorghum grain could be milled by tangential abrasive techniques to provide a sizeable quantity of a fraction containing up to 27%

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protein, depending upon initial protein content and variety. Sorghum grain yielded fractions with higher protein content than did wheat, barley, or rice. Each of the fractions obtained in their study represented 8 to 10% of the whole grain, and only protein content was measured.

Anderson and Burbridge (4) outlined an integrated approach to milling sorghum that appears promising. The bran is removed by use of an abrasive rice mill, followed by tempering of the debranned kernels and degermination by impact milling. The dried stocks from degermination are sieved and classified into +14 and +20 grits and germ. The fine particles of endosperm are hammer-milled into flour. Approximately 75% yield of grits was obtained when 18% of the kernel was removed as bran. The bran could be used for livestock feed. Even more efficient use of sorghum might occur if bran removal were accomplished in several successive passes, because some of the fines probably would be high in protein content and might even have higher contents of essential amino acids. Therefore, the integrated process might utilize new improved varieties of sorghum, with stepwise removal of bran, to produce significant quantities of a high-protein product which might find use in baked products and other foods. This might be particularly promising in certain areas of Asia and Africa.

The purpose of our research was to study the composition of fractions removed from sorghum grain by stepwise, controlled abrasive milling in a laboratory rice pearler. The information will supplement data already established by Normand et al. (3), and will establish whether it is theoretically possible to obtain significant quantities of high-protein, high-quality fractions from sorghum grain.

MATERIALS AND METHODS

Varieties of Sorghum

Clean grain of six varieties of sorghum was milled. The varieties were: SC 283, B 398, B 3197, Tx 09, NSA 740, and 70LH201 (Table I). The first five were grown at the Texas A&M University Agricultural Research and Extension Center at Lubbock, Tex. This grain was the same as used in the milling research reported by Maxson et al. (5). The physical and chemical properties of these grains, except 70LH201, were described in detail at that time (5). 70LH201 is an experimental hybrid sorghum which produces grain with a white, thin pericarp and a high proportion of corneous endosperm. It is currently being considered for release by the Texas Agricultural Experiment Station. Grain of 70LH201 was produced in Swisher County, Tex., in 1970. All grain was cleaned, and the small and large kernels were eliminated by sieving. The clean, air-dried grain samples had 10% moisture.

Milling Procedure

Successive layers of sorghum kernels were removed by milling the grain sample in a Satake Grain Testing Mill equipped with a No. 40-grit Carborundum wheel rotating at 900 r.p.m. This mill is similar to a Strong-Scott barley pearler. The initial sample weight was 150 g. The sample was milled long enough to remove approximately 2% of the initial sample weight, then the stocks were sifted over a No. 30 U.S. Standard sieve on a Tyler Rotap for 3 min. The overs of the No. 30 sieve were remilled to provide the next fraction, and the process was repeated until more than 45% of the initial grain weight was removed. For most varieties, a total of 24 fractions was obtained. The fractions were subjected to protein analyses and in certain cases several fractions were combined to provide a blend. The grain was

TABLE I. COMPOSITION OF BLENDS OBTAINED BY COMPOSITING SELECTED FRACTIONS FROM SUCCESSIVE ABRASIVE MILLING OF SORGHUM GRAIN

Description of Grain	Variety	Cumulative Weight of kernel removed %	Quantity % based on original grain wt.	Protein[a] %	Lipids[a] %	Ash[a] %
All-corneous endosperm; thin, white pericarp	SC 283	Whole-grain	100	15.2	2.9	1.31
		7.9–14.2	6.3	29.8	13.6	4.50
		14.2–33.1	18.9	27.4	6.8	3.11
		Residue	58.1	8.6	0.4	0.37
Intermediate endosperm; brownish-red, medium-thick pericarp	B 398	Whole-grain	100	14.7	4.1	1.51
		9.8–15.5	5.7	27.4	14.0	3.84
		15.5–23.9	8.4	30.6	9.8	2.83
		23.9–33.4	9.5	24.1	6.1	1.99
		Residue	56.5	8.2	0.7	0.35
Intermediate endosperm; thick, white pericarp	B 3197	Whole-grain	100	15.5	3.1	1.53
		8.0–17.2	9.2	28.9	11.2	3.83
		17.2–25.3	8.1	31.6	8.0	2.98
		25.3–36.8	11.5	24.6	4.9	2.12
		Residue	53.3	8.9	0.8	0.40
Intermediate to corneous endosperm; white, thin pericarp	70LH201 (Exp. Hybrid)	Whole-grain	100	10.8	...	...
		8.4–13.9	5.5	24.4	13.6	4.00
		13.9–22.4	8.5	24.4	9.7	2.94
		Residue	52.2	6.6	0.6	0.32

[a]Expressed on dry-weight basis.

not tempered, and the appropriate time to mill each successive pass for each grain sample was determined by at least one trial milling prior to the trials when the analytical and yield data were recorded. Values reported are means for two laboratory replicates.

Selected fractions from 70LH201 and SC 283 were analyzed for amino acid composition. Fractions were selected on the basis of protein content to provide information on the distribution of amino acids in the different layers of the sorghum kernel.

Analytical

Fat, ash, moisture, and protein (N X 6.25) were determined by AACC Methods (6). Amino acid analyses were with a Beckman 120-C analyzer, following the procedure of Spackman et al. (7).

RESULTS

The variety of sorghum influences the milling characteristics of the grain, which changes the protein content of the abraded material (Fig. 1). Grain with soft, floury endosperm breaks during abrasive milling, and the fine fraction is from all anatomical portions of the broken kernels. This accounts for the relatively low protein content of the fractions from the floury-endosperm varieties Tx 09 and NSA 740. NSA 740 and Tx 09 fractions never reached a maximum, even after more than 25% of the kernel was removed. Milling was discontinued because of kernel breakage. The highest protein fractions were obtained from SC 283, which has a thin pericarp and all-corneous endosperm. Grain from B 398 and B 3197, which have intermediate floury-to-corneous endosperm proportions, gave slightly lower protein fractions. The highest-protein fraction for B 3197 was at approximately 20% kernel removed, whereas maximums for B 398, 70LH201, and SC 283 were at 17.5% of the kernel removed.

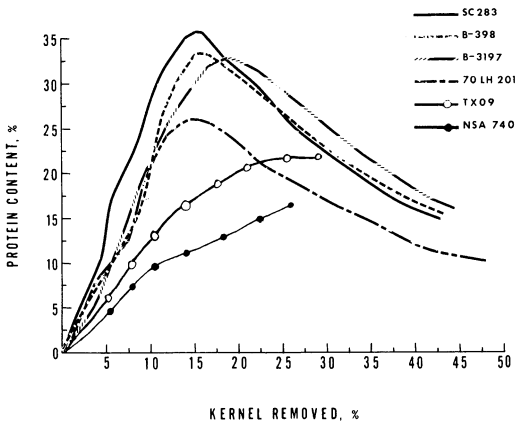

Fig. 1. Protein contents of the fractions removed by abrasive milling of sorghum grain vs. the total quantity of the grain removed.

To provide additional information, fractions from all varieties except NSA 740 and Tx 09 were selected on the basis of protein content and color. The fat, ash, and protein contents of these blends are presented in Table I. For SC 283, a fraction comprising 6.3% of the kernel contained significantly large quantities of fat, protein, and ash. This fraction was probably derived from the aleurone layer, peripheral endosperm, and germ portions of the kernel, because visual examination indicated that the pericarp was essentially removed from the grain after 6.0% of the kernel was removed. The next blend of fractions from SC 283 (18.9% of the kernel) contained 27.4% protein content; but the fat and ash contents were reduced, which indicated that the fraction was primarily from the peripheral endosperm area and the germ. The residue from milling was low in fat, ash, and protein contents. The data for B 398 and B 3197 were similar to that for SC 283.

Protein content of the grain influences the protein content of the fractions; however, the data for the grain from 70LH201 indicate that a large quantity of a fraction containing 24.4% protein could be obtained even though initial grain protein content was only 10.8%.

Composition data of the high-protein fractions are comparable to the values reported for wheat protein concentrate (8). When sorghum samples with white pericarp were milled, the flour fractions had a light, off-white color which could compete with the color of wheat protein concentrate. Fractions from B 398 had undesirable colors. They were brownish-red to dull pink, due to the colored pericarp of the grain.

Amino Acid Content of Milled Fractions

The wide range in protein contents of the fractions demonstrated that the abrasive removal of selected high-protein fractions was theoretically possible. The amino acid distribution of the fractions (from SC 283 and 70LH201) is presented in Tables II and III. Amino acid composition was related to the origin of the layers. This is illustrated graphically for eight amino acids in Fig. 2. The content of essential amino acids, especially lysine and threonine, was increased in the initial

TABLE II. AMINO ACID DISTRIBUTION OF PROTEIN IN FRACTIONS OF SC 283 GRAIN REMOVED BY SUCCESSIVE ABRASIVE MILLING

	Whole Grain	Total Quantity of Original Grain Removed, %						
		3.33	7.86	11.13	15.86	18.60	31.06	41.86
Fraction number	0	1	4	7	10	12	19	24
Protein[a]	15.17	8.13	22.12	31.94	35.35	32.07	20.62	15.38
Lysine[b]	1.58	3.32	2.94	2.38	2.21	2.02	1.45	1.17
Histidine	1.78	1.23	1.94	2.00	2.01	2.03	1.89	1.82
Arginine	3.56	5.54	5.88	5.23	4.72	4.52	3.54	2.92
Aspartic acid	6.13	7.87	6.92	6.76	6.36	6.61	6.45	6.44
Threonine	2.77	3.94	3.30	2.97	2.77	2.87	2.96	3.06
Serine	3.76	4.92	4.38	4.13	3.93	4.02	4.36	4.03
Glutamic acid	20.57	10.70	17.45	19.94	20.28	21.55	22.89	23.15
Proline	7.45	5.40	6.60	7.14	7.27	7.98	8.29	8.71
Glycine	2.50	6.15	3.98	3.10	2.63	2.62	2.47	2.40
Alanine	8.83	6.89	8.27	8.74	9.02	9.64	9.89	10.21
Valine	4.61	4.92	4.84	4.79	4.70	4.86	5.09	4.94
Methionine	1.71	1.23	1.49	1.63	1.70	1.62	1.79	1.82
Isoleucine	3.43	3.44	3.53	3.57	3.59	3.71	3.88	3.90
Leucine	12.85	7.87	10.85	12.21	12.90	16.51	14.50	14.95
Tyrosine	3.82	3.20	3.66	3.79	3.93	4.15	4.27	4.29
Phenylalanine	4.48	3.57	4.52	4.51	4.67	4.93	5.04	5.20

[a]% expressed on dry-weight basis.

[b]Expressed as g. per 100 g. protein.

TABLE III. AMINO ACID DISTRIBUTION OF PROTEIN IN FRACTIONS OF 70LH201 GRAIN REMOVED BY SUCCESSIVE ABRASIVE MILLING

	Whole Grain	Total Quantity of Original Grain Removed, %									
		3.87	8.4	12.60	13.93	15.87	20.33	22.40	27.53	30.73	42.60
Layer number	0	1	3	6	7	8	11	12	15	17	24
Protein[a]	10.8	7.6	16.2	24.72	25.60	25.61	22.13	21.17	18.40	16.20	11.50
Lysine[b]	2.02	4.17	3.71	2.53	2.22	2.08	1.85	1.86	1.55	1.61	1.43
Histidine	2.21	2.10	2.41	2.27	2.06	2.01	1.97	2.06	1.87	1.96	1.91
Arginine	3.96	6.35	6.03	4.88	4.23	3.98	3.76	3.70	3.41	3.38	3.09
Aspartic acid	6.93	8.33	7.85	7.53	6.85	6.65	6.84	6.94	6.61	6.59	6.47
Threonine	3.49	4.15	3.77	3.54	3.29	3.19	3.13	3.37	3.23	3.07	3.09
Serine	4.72	4.84	4.64	4.82	4.28	4.21	4.46	4.56	4.41	4.49	4.55
Glutamic acid	23.46	12.99	17.33	22.65	21.76	21.43	23.12	23.46	23.46	23.70	24.03
Proline	8.71	5.75	6.84	8.37	7.14	8.05	8.38	9.00	8.47	8.86	9.1
Glycine	3.29	5.09	4.86	3.84	3.27	3.06	3.29	2.90	2.76	2.70	2.64
Alanine	10.00	6.83	8.06	9.77	9.35	9.37	9.90	10.11	9.99	10.10	9.94
Valine	5.31	5.34	5.44	5.69	5.06	4.92	4.98	5.38	5.08	5.32	5.04
Methionine	1.54	1.37	1.55	1.73	1.56	1.61	1.65	1.60	1.55	1.55	1.50
Isoleucine	4.26	3.43	3.67	4.13	3.93	3.88	4.13	4.09	4.12	4.13	4.27
Leucine	14.89	8.07	10.45	13.92	13.53	13.59	14.99	14.83	15.02	15.22	15.65
Tyrosine	4.47	3.41	3.85	4.36	4.14	4.18	5.08	4.54	4.52	4.56	4.56
Phenylalanine	5.60	9.02	4.73	5.42	5.10	5.21	5.85	5.75	5.62	5.81	5.76

[a]% expressed on dry-weight basis.

[b]Expressed as g. per 100 g. protein.

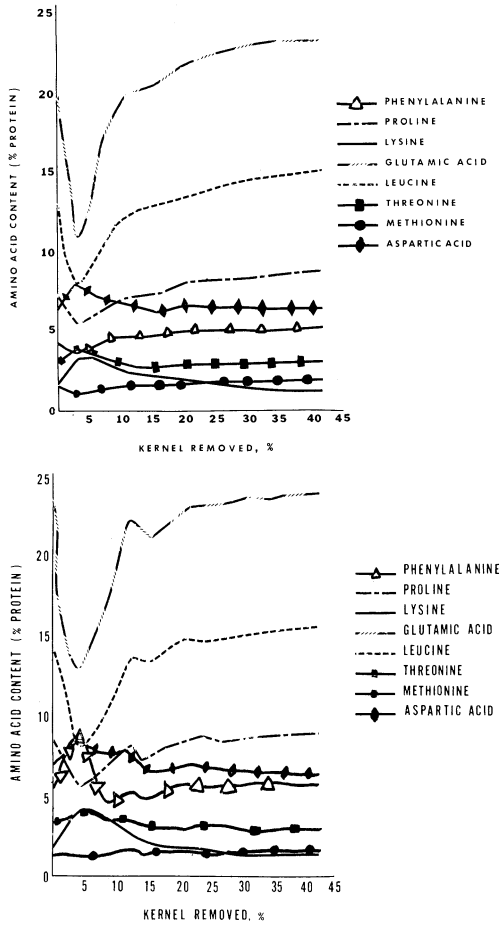

Fig. 2. Amino acid distribution of sorghum as influenced by total quantity of material abraded from the grain of SC 283 (top) and 70LH201 (bottom).

fractions, and tended to decrease in the fractions from deeper within the kernel. The increase in distribution of lysine along with the increased protein content may make the fractions useful for nutritional food supplements. Proline and glutamic acid tended to increase as the layers were removed, except in the initial fractions. Data for both varieties were relatively similar.

DISCUSSION

The high protein content of some milling fractions, along with the increased distribution of lysine in the protein, occurs because the sorghum kernel has a substantial quantity of peripheral-endosperm area, which contains the highest quantity of protein in the kernel. It has a protein content higher than the germ. For

instance, the protein content of germ obtained by hand dissection was 16.33% for grain with 10.36% protein (9). Hubbard et al. (10) found that the protein content was 18.0 to 19.1% for hand-dissected germ from five sorghum varieties which had an average protein content of 12.3%. The protein contents of corneous and floury endosperm isolated from a sorghum with 12.7% protein were only 14.5 and 11.66%, respectively (11). Therefore, the high-protein fractions are composed predominantly of material removed from the peripheral-endosperm area with some pericarp and germ.

The initial increase in lysine and other amino acids (Fig. 2) is explained by the amino acid distribution of protein in the germ, pericarp, and endosperm (9). The lysine distribution of sorghum germ, pericarp, and endosperm was 3.82, 3.0, and 1.2% of the protein, respectively. The whole-grain protein was 1.61% lysine. They found that glutamic acid, proline, alanine, tyrosine, and leucine were decreased in the germ and pericarp but increased in the endosperm. Therefore, the initial fractions abraded from the sorghum kernel in this study are high in lysine and low in glutamic acid because they contain a large proportion of germ and pericarp. Then, as the fractions are obtained from deeper inside the kernel, the lysine decreases, but glutamic acid and proline increased dramatically.

The amino acid composition of the peripheral endosperm of sorghum is unknown, but that of hard wheat was lower in lysine content than the inner endosperm (12). Shoup et al. (13) indicated that the amino acid distribution in sorghum milling fractions which consisted of mainly corneous endosperm was inferior to that of milled fractions composed of mainly floury endosperm. This might explain why the lysine content after 18 to 20% of the kernel has been removed is approximately equal to that for the whole grain.

We believe that a significant quantity of high-quality, high-protein fractions from sorghum can be produced relatively easily with modifications of existing milling procedures. We believe that the integrated milling scheme proposed by Anderson and Burbridge (4) could be used to obtain the fractions by removing the bran in several steps. Therefore, the recommended removal of 18% of the kernel during debranning might permit an 8 to 10% yield of a fraction with high protein content. Perhaps debranning to 20 to 22% or greater levels would be practical. The fractions produced would be comparable in composition to that of wheat protein concentrate (8).

The economics and practicality of this proposal are beyond our consideration. To be successful, the process would require a corneous-endosperm sorghum with a thin, white pericarp, and preferably with tan plant color to reduce pigmentation. New hybrid sorghums which will meet these requirements are under development.

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