

AMINO ACID CONTENT OF SORGHUM HYBRIDS
AND THEIR MILL PRODUCTS

by

JOATHAM KAPASI-KAKAMA

B. S., University College, Nairobi, 1968

9984

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1972

Approved by:

C W Dwyer
Major Professor

LD
2668
TH
1972
K36
C2

TABLE OF CONTENTS

INTRODUCTION	1
REVIEW OF LITERATURE	4
Processing of Grain Sorghum	4
Procedures used in the processing of grain sorghum	4
Amino Acid Composition of Cereals	7
Amino Acid Content of Sorghum	9
Nutritive Value of Sorghum Products	10
Fractionation of Sorghum Protein	11
MATERIALS AND METHODS	13
Grain Sorghum Hybrids	13
Analysis of sorghum grains	13
Physical	13
Chemical	14
Experimental Milling	14
Milling without peeling	14
Analysis of mill products	17
Milling the peeled grain	17
Grain peeling	17
Analysis of brush machine products	18
Milling	18
Analysis of the products	18
RESULTS AND DISCUSSION	23
Grain Sorghum Hybrids and Their Milling Performance	23
Proximate Analysis of Mill Products	26

Protein and Amino Acid Content	32
Analysis of variance	32
Correlations between amino acids and protein	53
Correlations between lysine and other amino acids	67
SUMMARY	72
SUGGESTIONS FOR FUTURE RESEARCH	75
LITERATURE CITED	76
ACKNOWLEDGMENTS	80
APPENDIX	81

INTRODUCTION

Sorghum, together with some other cereal crops, ranks among the plants domesticated earliest by man. The sorghum culture is supposed to have started in Eastern Africa about 5000 to 7000 years ago. Whereas, for many centuries millions of people in Asia and Africa have been obtaining nourishment from the cereal, it is only recently that much attention has been paid to sorghum, enabling it to receive the recognition that it deserves as one of the leading crops in the world.

Grain sorghum is the third most abundant cereal grain in the world, being exceeded only by wheat and rice. As might be expected sorghum is as abundant in variety as in bulk, and at the time of writing, a World Collection of sorghum varieties numbering more than six thousand has been rounded up from all over the sorghum growing regions of the world (Quinby and Schertz, 1970). It is grown on all six continents between latitudes 45 degrees South and 45 degrees North where average summer temperatures are more than 20 degrees Centigrade and the frost free season is 125 or more days. In fact, unlike the other cereal plants, sorghum is so versatile that it can grow well in areas of low rainfall (15-20 in. annually), and is highly productive in humid areas and under irrigation.

Martin (1970) reports that in 1966 about 56 million metric tons (2.2 million bushels) of grain sorghum was produced on 52 million hectares (130 million acres) or more. The United States and Asia each accounted for about one-third of the world production while Africa produced about one-quarter of the total yield.

Although the North American Continent was one of the last areas to be invaded by the sorghum plant, it is here that most spectacular advances in

sorghum culture have been made. In the United States there was a seven-fold increase in production of the grain between 1940 and 1968. During the same period acreage more than doubled, and the yields per acre more than trebled.

The improved performance in the United States by grain sorghum has been brought about by extensive agricultural research which has resulted in better crop husbandry including irrigation, use of chemical fertilizers, introduction of better hybrids, better techniques for insect, disease control, and weed control.

The major utilization in the United States has been in livestock feeding, consequently most of the work on breeding, processing, and nutritive evaluation of grain sorghum has been undertaken with livestock and poultry in mind. However, in the last twenty years or so, limited research has been carried out on the possibility of incorporating sorghum products into some foods processed for human consumption. In fact, some headway has been made in that direction, and, in addition to its use in cookies and breakfast foods, sorghum flour has been used in the development of such much-talked about mixtures as "Freedom Meal" in which grain sorghum contributes 26% of the product, the other ingredients being: wheat 26%, corn meal 21%, toasted non-fat soy meal 15%, non-fat dry milk 10%, and vitamin and mineral additives 2% (Gerrish, 1967).

Vegetable mixture No. 9 (Incaparina) was also developed with the following composition: corn meal 29%, sorghum 29%, cottonseed flour 38%, torula yeast 3%, calcium carbonate 1%, and vitamin A 4500 IU (Bressani, 1966).

The utilization of grain sorghum as a source for human food has been limited by the following characteristics: sorghum grain does not respond satisfactorily to milling equipment and techniques that have been developed

to deal with wheat. Thus, the product yields are usually low with high fat and ash values. Secondly, because most of the varieties and hybrids of sorghum have colored pericarps, the dry milled products are usually colored and speckled, and this makes the flours look less desirable than wheat products.

For this reason, it is essential that varieties and hybrids of improved milling and nutritive characteristics, with lighter pericarps and devoid of pigmented undercoats be the main target of sorghum breeders. Also, despite the work that has been done in the development of milling techniques and evaluation of the chemical composition of grain sorghum, much remains to be done.

The purpose of the present study was to investigate the milling performance and the amino acid composition of the mill products from some of the grain sorghum hybrids that have been recently released. These studies also considered the possibility that some samples might have desirable characteristics for production of human food products.

REVIEW OF LITERATURE

Processing of Grain Sorghum

Until quite recently practically all the grain sorghum produced in the United States has been used for industrial and feed purposes. Even today, little sorghum grain finds its way into food applications. Consequently, there has been only limited work done on the milling of sorghum to produce products of satisfactory quality for human consumption. However, there is an urgent need to develop adequate procedures by which grain sorghum may be processed since there is bound to be more and more demand for food for the world population, and grain sorghum will inevitably contribute its proportionate share, even in countries where at the present moment it is not being used, for the alleviation of the food problem.

Procedures Used in the Processing of Grain Sorghum

Generally there are two procedures that may be used for processing of grain sorghum. The first one which is primarily concerned with production of starch is a wet process similar to that used for maize. By this process bran, germ, high-protein material, and high-fiber material are separated from the grain, leaving a fraction that is low in protein, ash, fiber and oil and very high in starch. Watson (1970) has described an appropriate procedure. Freeman and Watson (1969), investigated the possibility of dry-peeling grain sorghum as a first step prior to the wet milling procedure and found that the following advantages were possible:

- (a) Production of whiter starch.
- (b) Improved separation of starch and protein.
- (c) Increased yield and purity of germ.

(d) Concentration of the wax that is associated with the pericarp.

However, there was one big disadvantage that would make commercial application of the technique uneconomical; 15 to 20% of the grain was found to be removed as hulls and this resulted in a reduction of starch yield.

In connection with wet processing, some studies on the use of chemicals in separation of the pericarp from the grain have been carried out. Subba Rao et al. (1953) reported that treating the grain with hydrochloric acid produced whiter products that cooked faster than untreated whole grain. On the other hand, application of boiling 2.5% sodium hydroxide solution, though more suitable than the other chemicals for pericarp removal, produced grain with greyish-yellow color which required more time for cooking.

Dry-milling is the other processing technique that has been applied to cereal grains. The objective in dry milling is to produce the cleanest possible separation of germ, endosperm, and bran; and the recovery of maximum amounts of endosperm. Hahn (1969) reviewed the methods that are currently being used in dry milling of sorghum. Roller milling of grain sorghum was found to be inadequate as to yield, degree of refinement, and purity of products because of the harder and specky nature of grain sorghums. Other methods include degermination by impact or attrition-type equipment, pearling and decortication processes and fine grinding and air-classification.

A number of investigations on pearling and decortication of grain sorghum have been made. Normand et al. (1965) used a tangential abrasive device to remove successive peripheral layers from endosperms of wheat, barley, grain sorghum and glutinous rice. They found that protein content of successive peripheral layers in the four grains differed according to the depth of abrasion, and, in the majority of cases, the highest protein

concentration was found in the layers near the periphery of the whole grain. Shepherd and Woodhead (1969) investigated the performance of grain sorghum in an abrasive rice polisher (CeCoCo) and found that yields of clean whole grain varied between 26 and 84% with the majority falling in the 60 to 75% range. The sorghums with vitreous endosperm performed better and those with white pericarps, in addition, gave the best products. The bran yields varied between 7 to 24% with the majority in the 10 to 14% range. For optimum performance, moisture content in the region of 15% was desirable.

Viraktamath et al. (1971) also studied the pearling of grain sorghum with conventional rice milling equipment. A commercial Dandekar-type rice mill was found to satisfactorily remove husks and bran from grain sorghum that had been moistened with 3-5% water and conditioned for 15 minutes.

A recently introduced technique in dry milling is fine grinding and air classification. Reports by Stringfellow et al. (1961), Pfeifer et al. (1963), Peplinski and Stringfellow (1963), and Stringfellow and Peplinski (1966) indicated that sorghum products showed a better response to air classification, so far as fat, ash and protein fractionation was concerned, than corn, rice or soybean. The finest fraction contained the highest values of protein, ash, and fat. It was also found that the softer grain sorghums showed better response than the harder ones.

A method for the production of high yield grits with low fat and practically free of the hull has been developed by Weinecke and Montgomery (1965). A 6-in. diameter stainless steel wire brush rotating within a 7-in. diameter perforated cylinder was used in removing the hull and germ from the grain. The +25W grits yield ranged between 64.3 and 76.9%, while that on the +16W showed a range of 61.5 to 72.8%. For all four sorghums tested, hull

removal approached 100%.

Despite its limitations as a procedure for grain sorghum dry milling, roller milling remains a good procedure that can be adapted for the production of satisfactory sorghum products. Anderson (1969) produced high quality sorghum flour (1% fat, 0.5% ash) by prepeeling of the grain in water, milling the peeled grain in an experimental Buhler mill and reducing the shorts from the mill in an Alpine Kolloplex pin mill. A product with 0.9% fat and 0.3% ash at an extraction of 80% is reported to have been obtained from the peeled grain. Roller milling of grain sorghum in combination with other equipment was also investigated by Anderson et al. (1969). In one set of experiments, the grain was tempered to 18% moisture for one hour, and 21% moisture 10 minutes before dehulling in NU brush degerminator or NU solid-rotor degerminator. The grits were milled using a combination of the Buhler and Alpine Pin mills as mentioned above. The grits from the NU brush machine gave a low fat product up to approximately 75% extraction, but a sharp increase in fat content was observed as the extraction increased. Recently, Shoup et al. (1970) used an experimental peeler to remove the bran and a Miag Multomat experimental flour mill to remove germ and reduce the peeled endosperm to flour. The products from peeled grain had lower ash, fat, fiber and pigmentation than those from unpeeled grain.

Amino Acid Composition of Cereals

Cereals and cereal products play a major role in the protein nutrition of the world, particularly in the developing regions. For this reason, it is necessary that more and more time be spent on the evaluation of the nutritive value of the proteins from these products. A search of the

literature reveals that in the last twenty years considerable attention has been paid to evaluation of the nutritional value of cereals and their products by chemical and biological assays. In addition, the development of the automated amino acid analyzer has made it possible to make rapid evaluations of the amino acid profile of any substance.

The amino acid composition of hard wheats was examined by Hepburn et al. (1965). It was observed that samples of similar nitrogen content showed very small variations in amino acid concentrations. At the same time great differences were shown between higher nitrogen and lower nitrogen samples with greater concentrations in the lower nitrogen samples for all the amino acids, except glutamic acid, phenylalanine, and proline. In other words, apart from glutamic acid, phenylalanine, and proline there was an inverse relationship between amino acids and nitrogen content of the hard wheats. Villegas et al. (1970) investigated the lysine content of wheat, rye and triticale proteins and found the lysine values in triticale and rye to be about 20% and 30% higher, respectively, than the value in the wheat proteins. Variation of lysine in each kind of grain was inversely related to protein content.

Waggle et al. (1967) examined the amino acid composition of flour mill products from nine different wheat mixes and observed the amounts to be highest in the germ, followed by bran and red dog, and least in the flour.

Jansen et al. (1962) found by rat growth studies, lysine to be the first limiting amino acid in teff and pearl millet. Taira (1968) also found lysine to be first limiting in foxtail millet. There was, also, negative correlation at 1% level between lysine and crude protein.

Various studies have been carried out on the nutritive value of corn

(maize) (Flynn et al., 1954; Hansen et al., 1946; Jarquin et al., 1970; Keeney, 1970; and de Oliveira et al. (1971). The results have indicated normal corn to be limiting in lysine and tryptophan. Also an inverse relationship between crude protein content and nutritive value was observed.

Amino Acid Content of Sorghum

Grain sorghum has had its share of nutritional investigations of its quality. Hubbard et al. (1950) observed the protein, oil, ash and vitamin composition to be higher in germ than bran, endosperm and whole grain. Deyoe and Shellenberger (1965) reported variation in protein and amino acid composition of sorghum grains as a result of difference in hybrids and location. Virupaksha and Sastry (1968) noted varietal and hybrid variation in the protein content of grain sorghum. Also the results indicated a most likely negative correlation between percent lysine in protein and percent protein in the grain. In addition, an isoleucine to leucine ratio of about 1:4 was observed. In general, there was gross similarity between the amino acid compositions of corn and sorghum. Earlier Bressani et al. (1962) found small variation in the amino acid composition due to varietal differences.

Variations in protein and amino acid content were also registered at Purdue University by Pickett (1969) in a study of varieties from the World Collection. Again negative correlations were observed between lysine and protein. The isoleucine:leucine ratio ranged between .272 and .380. Varietal differences in protein, lysine, and leucine content of grain sorghum were further observed by Deosthale et al. (1970) in a study with 332 grain sorghum varieties. Once more, lysine and protein showed a negative correlation.

Nutritive Value of Sorghum Products

The nutritive value of different varieties of grain sorghum was investigated by Breuer and Dohm (1972) using rat growth experiments and significant differences were observed between varieties. It was further discovered that the nutritive value was negatively correlated to the protein digestibility.

Studies using chick growth experiments (Vavich et al., 1959; Waggle et al., 1966; and Shoup et al., 1970) have indicated sulfur-amino acids, glycine, arginine, and lysine to be the limiting amino acids. There were no significant effects on performance due to location or hybrid. Furthermore, whereas no significant difference in response in growth was observed between high- and low-protein grains, low-protein grain produced greater weight gains.

The amino acid profile and nutritional value of milled sorghum grain products was examined by Shoup et al. (1969) using chemical and nutritional studies with female albino rats. Protein ranged from 6.5% in soft flour to 20.6% in hard vitreous products. The white products had low protein levels while tan and speckled materials were found in high-protein products. The germ-bran fraction had relatively higher contents of lysine, arginine, and glycine; and relatively lower values of isoleucine, leucine, and phenyl-alanine compared to whole grain. The amino acids in each fraction increased with protein content increases in the fraction. There were negative correlations between lysine, cystine, methionine, threonine, and tryptophan on one hand, and protein content of the endosperm fractions. Weight gains were highest in rats fed on germ-bran, intermediate gains on whole grain group, and lowest gain on endosperm fractions. Weight gains and lysine percentage in the diet showed a positive relationship.

Fractionation of Sorghum Protein

Another contribution to the understanding of the protein quality of sorghum grain was made through the study of Skoch et al. (1970). They compared the distribution of albumin, prolamine, glutelin and globulin, and insoluble fractions in opaque-2 corn kernels and sorghum grain, and their amino acid composition. In both grains, similar trends were observed in variability of the amino acid composition of the protein fraction and protein content of the grain.

The quantity of extractable protein in opaque-2 corn was observed to be twice that in sorghum grain. However, the major soluble protein in both grains was glutelin.

The main observations in the amino acid composition of the protein fraction were:

- (a) Observed increase of proline, and decrease of leucine in the albumin fraction as the protein content of the whole sorghum grain increased.
- (b) Decrease of lysine and glycine in the nonsolubilized protein fraction with increase of protein content of the sorghum grain.
- (c) Lysine, arginine, and glycine concentrations in both albumin and globulin fractions of sorghum protein were observed to be nearly twice their values in whole grain sorghum.
- (d) The amino acid compositions of the glutelin fractions of both opaque-2 corn and sorghum grain were similar and tended to fall midway between those of the globulins and prolamine, the prolamine values being the lower ones. However, proline and histidine values were higher than their corresponding values in globulins.

- (e) In both opaque-2 corn and sorghum grain, the amino acid composition of the residue fractions followed the same pattern of variation as was observed for whole grain protein.

**THIS BOOK
CONTAINS
NUMEROUS PAGES
WITH MULTIPLE
PENCIL AND/OR
PEN MARKS
THROUGHOUT THE
TEXT.**

**THIS IS THE BEST
IMAGE AVAILABLE.**

MATERIALS AND METHODS

Grain Sorghum Hybrids

Seven hybrids of grain sorghum were supplied by the Kansas State University Agricultural Experiment Station. The hybrids Asgrow Dorado, Dekalb C-42Y, McNair 654, Pioneer 846, RS 506, RS 671, and RS 700 were selected from among the 38 that had been grown in a performance test plot at Minneola, Ford County in Southwestern Kansas in 1971. The test site had been summer-fallowed in 1970 following a 1969 sorghum crop. No fertilizers, herbicides or insecticides were used.

The hybrids were selected on the basis of diversity in parentage and on field performance. Asgrow Dorado, Dekalb C-42Y, McNair 654 and RS 671 had yields that were greater than the test average (62 Bu/acre), while Pioneer 846 and RS 506 had average yields, and RS 700 was slightly below average in yield performance. Apart from DeKalb C-42Y which had a yellow pericarp, the rest had brown pericarps. In addition, McNair 654 was a bird resistant type and RS 700 had an intensely pigmented undercoat. Of the seven hybrids, RS 506 had a predominantly floury endosperm while the rest could be adequately described as intermediate in nature.

Analysis of Sorghum Grains

(1) Physical

- (a) Test Weights were determined using a Winchester Bushel meter and expressed as pounds per bushel.
- (b) Thousand Kernel Weight (TKW) was determined using an electronic seed counter.

- (c) Hardness was tested by milling 50 gm of grain in a Strong-Scott Laboratory Barley Pearler for 2 minutes, and screening the material on a U. S. No. 12 Tyler Screen in a Tyler Rotap for 3 minutes. The overs of the screen as a percent of the original were used as the measurement for hardness.
- (d) A sieve analysis was carried out on samples that had been cleaned and freed of broken kernels by hand picking. Two hundred grams of the clean grain was sieved using U. S. No. 5, 6, 7, and 8 Tyler screens on a Tyler Rotap for 3 minutes. The weight of the product on each screen was determined. The Kernel Size Index (KSI) was calculated as reported by Maxson et al. (1971) from this data using the following formula:

$$\text{KSI} = 1/2[(0.5)(+5W) + (0.6)(+6W) + (0.7)(+7W) + (0.8)(+8W)] .$$

(2) Chemical

- (a) Moisture, Kjeldahl nitrogen, ash, crude fat (ether extract) were determined according to the Official Methods of Analysis of the AOAC (11th Ed., 1970). Crude protein was determined by multiplying Kjeldahl nitrogen values by 6.25.
- (b) Amino Acid Analysis was conducted on acid hydrolyzates of samples using a Spinco Automatic Amino Acid Analyzer, Model 120C, according to the procedure of Moore et al. (1958) and Spackman et al. (1958).

Experimental Milling

Two milling experiments were conducted:

1. Milling Without Peeling

The original grain was cleaned by use of a Forster Grain Scourer for

the removal of adhering glumes, and further cleaned by use of a Carter Dockage Tester.

For each of the seven hybrids the clean grain was tempered to approximately 16% moisture at least 20 hours before milling.

The milling equipment consisted of a Buhler Experimental Flour Mill and an Alpine Kolloplex Pin Mill. Milling was conducted as in Flow 1. The Buhler part of the milling was conducted following the approved continuous method of the Cereal Laboratory Methods of A.A.C.C. (7th Edition, 1962).

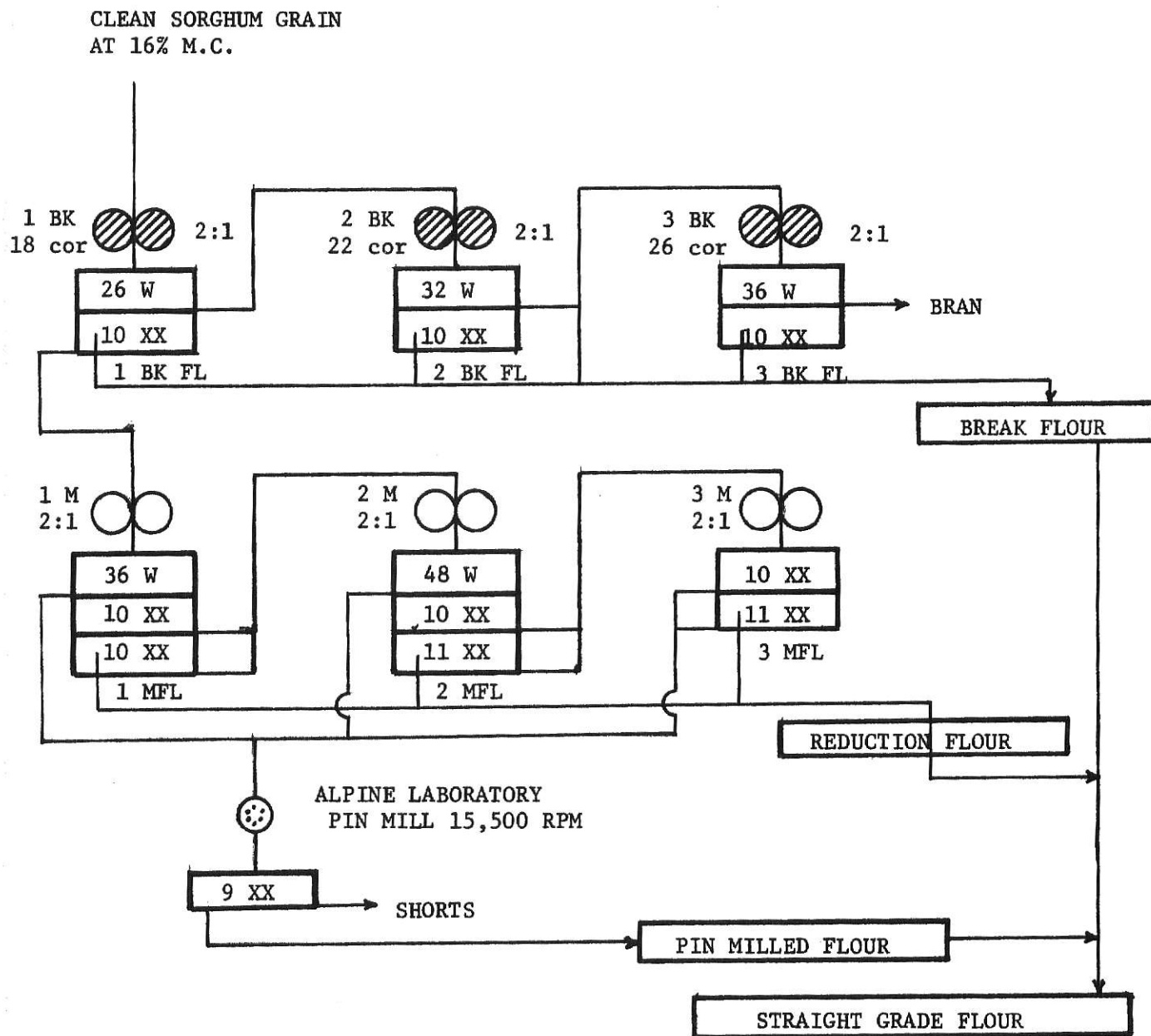
The roll gap settings were: 0.011" for first break; 0.007" for second break; 0.003" for third break rolls; and a bit less than 0.0015" for the three middling rolls. A feed rate of 60-70 gm per minute was used.

The products from the three primary rolls (1Bk Fl, 2Bk Fl, and 3Bk Fl) were in each case combined to form the break flour, and the products from secondary rolls (1MF1, 2MF1, and 3MF1) were combined to form the reduction flour.

The shorts fraction was further milled in the Alpine Kolloplex pin mill at 15,500 revolutions per minute. The pin milled product was then sifted on a 9XX screen in a sifter box for five minutes. The overs of the screen were designated shorts, and the throughs, pin mill flour. Thus, in all, five products including bran were obtained. In addition, a 67.9% straight grade flour fraction was made by mixing some of the break and reduction flours in their yield proportions, and enough pin mill flour to make up the 67.9%. [67.9% was chosen because it was the lowest combined break, reduction, and pin mill flour yield.]

**THIS BOOK
CONTAINS
NUMEROUS PAGES
WITH DIAGRAMS
THAT ARE CROOKED
COMPARED TO THE
REST OF THE
INFORMATION ON
THE PAGE.**

**THIS IS AS
RECEIVED FROM
CUSTOMER.**



Flow 1. Milling of Non-Peeled Sorghum Grain Using a Bühler Experimental Flour Mill and an Alpine Pin Mill

(1) Analysis of the Mill Products.

(a) Color Analysis.

The color of the endosperm products, break flour, reduction flour, pin mill flour, straight grade flour and shorts, was determined using the green wavelength of an Agtron Color Reflectance Spectrophotometer, Model M-500A. The zero was set using reflecting disc number 41, and the maximum reflectance (100%) was set by means of reflecting disc number 85.

(b) Chemical Analysis.

Moisture, Kjeldahl nitrogen, crude protein, ash, crude fat, and amino acids were determined using procedures already mentioned.

2. Milling the Peeled Grain

Grain Peeling. Peeling was accomplished by means of the Brush Machine developed at Kansas State University (Shoup et al., 1970). A nylon brush replaced the steel one that was originally used. Instead of a perforated screen, a solid base coated with strips of emery paper was used.

Grain, previously tempered to approximately 22% moisture for 75 minutes, was fed to the brush machine from a hopper by means of a vibrating device, traveled down the length of the machine and was collected at the opposite end. On its way through the machine, the grain got partially peeled.

The peeled grain was graded into whole grain, grits and bran by means of a Tyler Screen series shown in Flow 2. The whole grain and grit fractions were aspirated using a South Dakota Aspirator and the light material, mainly consisting of bran and germ, was added to the fine grits and bran fraction, referred to as fines in the rest of the manuscript.

(a) Analysis of the Brush Machine Products.

Samples from the products were analyzed for moisture, Kjeldahl nitrogen, crude protein, ash, crude fat, and amino acids using the methods mentioned in connection with the original grain samples.

(b) Milling.

Tempering and milling of peeled whole grain was accomplished in the manner already mentioned for non-peeled grain except the short fraction from the pin mill was remilled in the pin mill (see Flow 2). The two pin mill flours were combined to form the pin mill flour and the overs of the 9XX sieve after the second sifting were classified as shorts. The other mill fractions were classified as they were for unpeeled grain.

Analysis of the Products. Color and chemical analyses of products similar to those on the unpeeled grain samples were carried out.

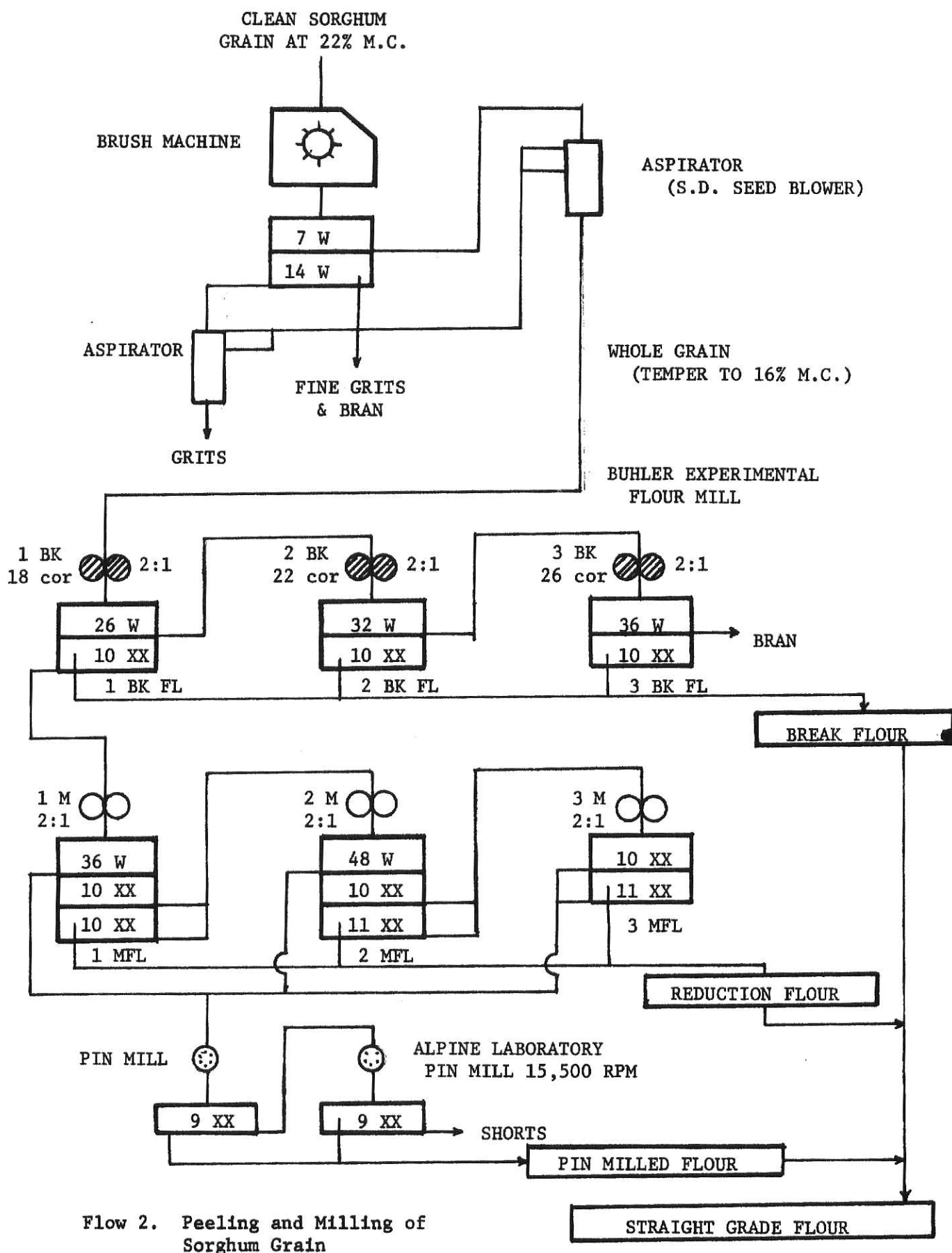


TABLE 1a. GRAIN SORGHUM FIELD TRIAL PERFORMANCE

Hybrid	Asgrow Dorado	Dekalb C-42Y	McNair 654	Pioneer 846	RS 506	RS 671	RS 700
Acre Yield, Bu.	68	71	67	62	62	67	59
Grain Moisture, %	11	12	12	11	12	12	12
Bushel Weight, Lbs.	57	59	57	56	57	56	55

TABLE 1b. PROXIMATE ANALYSIS^a OF GRAIN SORGHUMS

Hybrid	Asgrow Dorado	Dekalb C-42Y	McNair 654	Pioneer 846	RS 506	RS 671	RS 700
Protein, %	12.3	10.7	11.9	11.9	12.1	12.0	13.2
Ash, %	1.73	1.74	1.74	1.74	1.44	1.54	1.55
Crude Fat, %	3.0	3.7	3.4	3.4	3.4	3.0	3.0

^aValues at 14% moisture.

EXPLANATION OF PLATE I

Color Improvements in the Endosperm Mill Products
as a Result of Pre-Peeling

W refers to products from original unpeeled grain.
P refers to products from brush peeled grain.

**THIS BOOK
CONTAINS SEVERAL
DOCUMENTS THAT
ARE OF POOR
QUALITY DUE TO
BEING A
PHOTOCOPY OF A
PHOTO.**

**THIS IS AS RECEIVED
FROM CUSTOMER.**

RESULTS AND DISCUSSION

Grain Sorghum Hybrids and Their Milling Performance

Data in Tables 1-4 show the physical and milling characteristics of the seven sorghum hybrids that were tested. Test weights were reasonably high and did not vary much (Table 1). Hardness values were low and could suggest the possibility of a higher floury endosperm fraction in each hybrid. Sieve analysis revealed that kernels from RS 506 were the largest as indicated by more than 53% retention by the 6W sieve. On the other hand, kernels of Dekalb C-42Y, Pioneer 846, and RS 671 contained more medium sized kernels than the rest. The ranges for Asgrow Dorado, McNair 654 and RS 700 fell in between. However, all the hybrids showed more than 90% retentions by sieve Nos. 6 and 7; and only Asgrow Dorado kernels were retained on sieve No. 5.

Table 2 shows results obtained from brush peeling the seven grains. Pioneer 846 and Asgrow Dorado produced more than 70% whole grain (+7W grits), and RS 506 approximately 50%, the rest had yields between 60 and 70%. When the two grits fractions are considered, however, all the hybrids gave reasonably good yields of around 80%. Visual examination revealed the peeling to have been more severe on RS 671, and Dekalb C-42Y, and non-effective on RS 506. In fact, the kernels of RS 506 had only small amounts of pericarp material removed. Kernels broke before they could be peeled. For this reason, it was found impossible to produce a peeled product from RS 506 under the conditions of the experiment. Thus, brush machine products from RS 506 were not used for further milling. The remaining hybrids gave whole grain products that were generally partially peeled, with mostly intact germ.

TABLE 1. SOME PHYSICAL CHARACTERISTICS OF GRAIN SORGHUM HYBRIDS

Brand	Hybrid	Pericarp Color	Test Weight	Thousand Kernel Wt.	Hardness	Sieve Analysis				
						+5W	+6W	+7W	+8W	KSI
			Lbs./Bu.	Gms.	%	%	%	%	%	%
Asgrow	Dorado	Brown	58.5	25.063	36	0.5	34.7	59.0	5.8	67.00
DeKalb	C-42Y	Yellow	59.9	26.738	33	---	19.0	67.2	3.3	67.08
McNair	654	Brown	58.4	25.907	33	---	37.0	58.7	3.0	65.73
Pioneer	846	Brown	59.4	24.096	35	---	17.0	75.8	5.5	67.63
RS	506	Brown	57.5	29.070	26	---	53.8	44.0	2.0	64.65
RS	671	Brown	57.7	22.831	26	---	11.3	79.7	8.0	69.98
RS	700	Lt. Brown	57.1	23.923	24	---	30.5	61.5	7.0	66.95

TABLE 2. PERFORMANCE OF GRAIN SORGHUMS^a IN A BRUSH PEELER

Product Yield ^b	Asgrow Dorado %	Dekalb C-42Y %	McNair 654 %	Pioneer 846 %	RS 506 %	RS 671 %	RS 700 %
+7W Grits	72.2	61.1	63.2	75.2	49.8	64.0	66.8
-7W + 14W Grits	13.0	16.8	16.7	6.1	29.9	13.7	15.2
-14W and Bran (asp.)	7.3	9.6	9.6	8.0	11.3	12.0	8.8
Recovery	92.5	87.5	89.5	90.3	91.0	89.7	90.8

^aGrain was tempered to approximately 22% moisture for 75 minutes prior to peeling.

^bYield expressed on as is basis.

Yields from the brush machine showed a nonsignificant negative correlation ($r = -.75$) with thousand kernel weights (TKW), and a nonsignificant positive correlation ($r = .54$) with hardness values. The recoveries of 87-93% for all hybrids appeared reasonable considering the high moisture at which peeling took place.

Results from the milling of non-peeled grain in the Buhler mill and Alpine pin mill are shown in Table 3a. The low Buhler mill recoveries seemed to point to a problem that conventional wheat flour mills must contend with while milling grain sorghums, even the most floury ones. Pin milling the shorts from the Buhler did help raise the total flour extraction for all hybrids, but did not go as high as 75% which can be easily realized in wheat milling. There was a nonsignificant positive correlation ($r = .64$) between extraction and TKW.

Milling the peeled grain did not improve the quantity of flour extracted despite the fact that two pin mill runs were made. Table 3b shows data that were obtained from milling peeled grain. An overall marked improvement was observed, however, in the color analysis results. The products from peeled grains generally gave higher values than corresponding products from unpeeled grains (Table 4). This, of course, shows that the former products were lighter than the latter ones. Dekalb C-42Y products had the best results in both groups.

Proximate Analysis of Mill Products

- (a) Crude Protein values (Table 5) were similar (5-7%) for break flours from non-peeled and peeled grain. Similarity of protein values was also observed in the reduction flours, except in

TABLE 3a. PERFORMANCE OF THE GRAIN SORGHUMS IN A BUHLER EXPERIMENTAL FLOUR MILL AND ALPINE PIN MILL
A - NON-PEELED GRAIN^a

Products	Hybrid						
	Asgrow Dorado %	Dekalb C-42Y %	McNair 654 %	Pioneer 846 %	RS 506 %	RS 671 %	RS 700 %
1 Break Flour	3.5	3.8	3.1	3.8	4.4	3.7	3.5
2 Break Flour	2.9	2.9	2.7	2.9	3.3	2.9	3.1
3 Break Flour	1.0	1.1	1.0	1.0	1.1	1.0	1.1
TOTAL Break Flour	7.4	7.8	6.8	7.7	8.8	7.6	7.7
1 M Flour	10.9	14.0	10.3	9.3	12.9	12.7	11.9
2 M Flour	7.3	8.7	8.9	8.3	8.7	7.8	5.7
3 M Flour	3.9	4.6	4.5	4.7	3.1	3.4	2.9
TOTAL M (Reduction)	22.1	27.3	23.7	22.3	24.8	23.9	20.5
TOTAL Break and Reduction Flour	29.5	35.1	30.5	30.0	33.5	31.5	28.2
Pin Mill Flour	39.9	38.7	40.7	37.9	40.1	39.4	46.0
Shorts	8.7	5.9	7.5	8.0	5.9	7.9	6.5
Bran and Germ	10.3	11.3	11.3	10.3	8.7	10.9	11.2
Extraction	69.4	73.8	71.3	67.9	73.6	70.9	74.2
Recovery	88.4	91.0	90.0	86.2	88.2	89.7	91.9

^aClean grain was tempered to 16% moisture content 24 hours before milling.

TABLE 3b. PERFORMANCE OF GRAIN SORGHUMS IN A BUHLER EXPERIMENTAL FLOUR MILL
AND ALPINE LABORATORY PIN MILL
B - PEELED GRAIN^a

Products	Hybrid				RS
	Asgrow Dorado %	Dekalb C-42Y %	McNair 654 %	Pioneer 846 %	
Peeled Grain ^b	78.0	66.6	69.8	81.9	69.0
1 Break Flour	2.4	2.3	2.0	2.6	2.3
2 Break Flour	1.6	1.2	1.2	1.7	1.6
3 Break Flour	0.6	0.5	0.6	0.7	0.5
TOTAL Break Flour	4.6	4.0	3.8	5.0	4.4
1 M Flour	7.1	6.5	5.4	6.6	5.0
2 M Flour	5.9	5.5	5.0	6.1	5.8
3 M Flour	4.8	5.0	5.0	5.5	5.1
TOTAL M (Reduction Flour)	17.8	17.0	15.4	18.2	15.9
TOTAL Break and Reduction Flour	22.4	21.0	19.2	23.2	20.3
Total Pin Mill Flour	32.7	27.9	32.1	38.8	32.5
Shorts	3.0	2.3	2.4	3.6	3.2
Bran and Germ	9.7	7.4	8.4	8.7	6.3
Extraction ^c	55.1	48.9	51.3	52.0	52.8
Extraction ^d	70.7	73.1	73.3	75.7	76.3
Recovery ^c	67.8	58.6	62.1	74.3	62.3
Recovery ^d	87.0	88.0	89.0	90.7	90.3
					73.6
					2.9
					2.0
					0.7
					5.6
					7.0
					5.6
					4.4
					17.0
					22.6
					31.1
					2.9
					8.6
					53.7
					73.1
					65.2
					87.7

^aPeeled grain was tempered to 16% moisture content 22 to 25 hours prior to milling.

^bYield on 16% moisture content.

^cBased on the original non-peeled grain.

^dBased on the peeled grain.

TABLE 4. COLOR ANALYSIS OF MILLED PRODUCTS FROM GRAIN SORGHUMS
BY THE AGRON REFLECTANCE SPECTROPHOTOMETER^a

		Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Straight Grade ^b
% Reflectance						
<u>Non-Peeled</u>						
Asgrow	Dorado	89.0	86.5	65.0	8.0	69.3
Dekalb	C-42Y	92.0	88.2	73.0	24.0	81.8
McNair	654	86.5	87.0	62.3	1.0	73.8
Pioneer	846	89.3	84.0	53.0	3.5	66.5
RS	506	70.0	63.8	12.3	5.0	32.3
RS	671	88.0	87.0	56.5	15.0	67.8
RS	700	81.0	74.0	26.0	1.0	40.8
<u>Peeled</u>						
Asgrow	Dorado	83.0	86.0	71.5	34.4	77.0
Dekalb	C-42Y	94.5	97.5	88.8	56.0	92.5
McNair	654	88.0	94.0	78.0	27.0	83.0
Pioneer	846	97.9	89.0	76.8	52.0	84.0
RS	671	96.0	97.5	78.8	64.0	87.5
RS	700	73.0	72.5	28.5	21.0	43.0

^aThe Agron green wavelength was used. Color standards were No. 41 for zero and No. 85 for maximum reflectance.

^bStraight grade flour was made by mixing break and reduction flour in their yield proportions and adding enough pin mill flour to make 67.9% extraction.

TABLE 5. CRUDE PROTEIN^a CONTENT OF SORGHUM MILL PRODUCTS

Products	Hybrid				
	Asgrow Dorado %	Dekalb C-42Y %	McNair 654 %	Pioneer 846 %	RS 506 % RS 671 % RS 700 %
<u>Non-Peeled</u>					
Original Grain	12.3	10.7	11.9	12.1	11.4 12.0 13.2
Break Flour	6.6	6.3	7.0	6.0	5.7 6.6 6.1
Reduction Flour	8.4	8.2	8.8	8.0	7.9 8.8 8.0
Pin Mill Flour	14.6	12.9	14.4	14.5	14.4 15.7 16.9
Shorts	16.3	12.3	15.3	15.6	17.3 17.5 20.4
Bran and Germ	15.0	13.8	14.6	11.7	11.1 11.6 11.7
<u>Peeled</u>					
Fine Grits and Bran (Asp.)	10.7	10.5	11.4	7.6	9.0 8.6
Grits	12.1	10.9	12.2	12.3	13.0 13.7
Whole Grain (+7W)	12.4	11.3	12.6	13.0	13.8 13.1
Break Flour	6.7	6.2	6.9	6.3	6.4 6.1
Reduction Flour	8.4	6.7	8.7	10.5	8.9 8.3
Pin Mill Flour	15.2	13.3	15.0	15.1	17.0 18.0
Shorts	19.1	16.0	19.5	20.6	21.5 25.3
Bran and Germ	15.9	16.6	15.9	15.4	18.3 15.7

^aValues on 14% moisture basis.

Pioneer 846 where the value of peeled product appeared higher, 10.5% compared to 7.9-9.0% observed for the rest of the products. On the other hand, values for pin mill flour, shorts, and bran were higher in the peeled products, possibly due to the double pin milling operation for pin mill flour and shorts, and removal of the low-protein pericarps by the peeling process. Peeled whole grain protein values were generally higher than those of grits and original whole grain. This could be explained by the higher germ proportion in peeled grain as compared with original grain and grits.

The distribution of protein in the products (Table 8) indicated that pin mill flour contained 50-63% in the unpeeled grain and 55-60% in the peeled grain. The combined break and reduction flours accounted for 17 to 27% of the recovered protein, while the bran and shorts accounted for 19 to 26% in the products from the original grain. The corresponding protein values for the two groups of fraction from peeled grain were 18-20% for the flours and 20-25% for the feed fraction. For this reason there is a need to develop methods that would improve upon the refinement of the pin mill flour.

- (b) Ash values (Table 6) were approximately 30% less in the endosperm fractions from peeled grain than in the unpeeled grain fractions. The distribution of the ash (Table 9) showed that a marked improvement had been made in reducing the ash content of the endosperm fractions through peeling. The combined endosperm fractions from peeled grain contained 38 to 48% of the recovered ash compared

to 65 to 71% for the products from the unpeeled grain.

- (c) Crude Fat values (Table 7) were also less in the endosperm products from the peeled grain than in the corresponding ones from the original grain. The distribution of the recovered fat was markedly low in the peeled endosperm products (37-42%) in contrast to the values of 56-68% for the products from unpeeled grain. Thus, as in the case of ash, brush peeling resulted in improved products.

Protein and Amino Acid Content

The distributions of the amino acids (gm amino acid/100 gm protein), except tryptophan which was not analyzed, are shown in Tables 11-17 for products from non-peeled grain and in Tables 18-23 for products from peeled grain. The corresponding amino acid compositions (gm amino acid/100 gm sample, dry basis) are shown in Tables 11a-17a and 18a-23a (Appendix) for non-peeled and peeled grain, respectively.

Analysis of Variance

Analysis of variance of protein and amino acid distribution in the protein, shown in Table 24, indicated the variation of protein and amino acids in similar products was not significant ($P \leq 0.01$) in the unpeeled grain. The table also shows that only aspartic acid exhibited significant ($P \leq 0.05$) variation, being highest in the RS 506 hybrid and lowest in McNair 654. Asgrow Dorado, RS 506, Dekalb C-42Y, Pioneer 846 and RS 671 had similar aspartic acid values, but differed significantly from McNair 654.

In products from the same unpeeled hybrid, there were no significant ($P \leq 0.01$) differences in variance for the following amino acids: serine, glutamic acid, half-cystine, valine, isoleucine and phenylalanine. Lysine,

TABLE 6. ASH CONTENT^a OF SORGHUM MILL PRODUCTS

Products	Hybrid				
	Asgrow Dorado %	Dekalb C-42Y %	McNair 654 %	Pioneer 846 %	RS 506 % RS 671 % RS 700 %
<u>Non-Peeled</u>					
Original Grain	1.73	1.74	1.74	1.44	1.63 1.54 1.55
Break Flour	0.75	0.77	0.79	0.66	0.72 0.69 0.67
Reduction Flour	1.04	1.04	0.94	0.87	1.04 1.05 0.95
Pin Mill Flour	1.30	1.02	1.22	1.23	1.31 1.22 1.22
Shorts	0.79	0.77	0.79	0.57	0.57 0.56 0.63
Bran and Germ	4.48	4.72	4.50	4.26	4.22 4.30 4.02
<u>Peeled</u>					
Fine Grits and Bran (Asp.)	2.59	2.46	2.76	1.76	2.58 2.64
Grits	0.99	0.89	0.96	0.98	1.06 0.94
Whole Grain (+7W)	1.48	1.40	1.47	1.37	1.28 1.27
Break Flour	0.49	0.54	0.57	0.42	0.42 0.48
Reduction Flour	0.59	0.41	0.54	0.43	0.42 0.63
Pin Mill Flour	0.75	0.70	0.78	0.79	0.80 0.90
Shorts	0.31	0.41	0.42	0.28	0.38 0.29
Bran and Germ	6.28	6.10	5.90	6.04	8.19 5.36

^aValues on 14% moisture basis.

TABLE 7. CRUDE FAT CONTENT^a OF SORGHUM MILL PRODUCTS

Products	Hybrid				
	Asgrow Dorado %	Dekalb G-42Y %	McNair 654 %	Pioneer 846 %	RS 506 % RS 671 % RS 700 %
Non-Peeled					
Original Grain	3.0	3.7	3.4	3.4	3.2 3.0 3.0
Break Flour	1.4	1.4	1.4	1.2	1.8 1.3 1.2
Reduction Flour	1.9	1.9	1.7	1.7	1.9 1.9 1.9
Pin Mill Flour	2.5	2.3	2.3	2.6	2.8 2.3 2.1
Shorts	1.6	1.9	1.7	1.2	1.5 1.2 1.1
Bran and Germ	9.9	11.1	10.0	9.9	10.3 9.1 9.1
Peeled					
Fine Grits and Bran (Asp.)	5.1	5.6	5.4	5.2	4.9 5.5
Grits	1.9	1.9	1.5	2.7	2.3 1.7
Whole Grain (+7W)					
Break Flour	3.1	4.4	3.0	3.2	2.1 3.3
Reduction Flour	1.5	1.2	1.3	1.2	1.2 1.3
Pin Mill Flour	1.3	1.1	1.0	1.5	1.0 1.3
Shorts	1.5	1.7	1.3	1.4	1.4 1.9
Bran and Germ	0.6	0.7	0.4	0.8	0.6 0.8
	13.9	14.4	12.1	14.7	15.9 11.8

^aValues on 14% moisture basis.

TABLE 8. DISTRIBUTION OF PROTEIN^a IN GRAIN SORGHUM PRODUCTS

Products	Hybrid				
	Asgrow Dorado %	Dekalb C-42Y %	McNair 654 %	Pioneer 846 %	RS 506 % 671 % 700 %
<u>Non-Peeled</u>					
Break Flour	4.4	4.9	4.2	4.5	4.4
Reduction Flour	16.7	22.4	18.7	17.5	18.4
Pin Mill Flour	52.3	49.9	52.2	53.9	54.1
Shorts	12.7	7.3	10.2	12.3	12.1
Bran and Germ	13.9	15.5	14.7	11.8	11.0
Recovery ^b	91.0	93.6	94.4	84.3	89.39
					95.37
					94.85
<u>Peeled</u>					
Break Flour	3.5	3.7	3.0	3.1	3.1
Reduction Flour	16.8	17.0	16.3	18.8	15.4
Pin Mill Flour	55.9	55.4	58.7	57.6	60.3
Shorts	6.4	5.5	5.7	7.3	8.6
Bran and Germ	17.4	18.4	16.3	13.2	12.6
Recovery ^b	72.3	62.6	68.9	84.0	76.3
					71.4

^aExpressed as percent of recovered protein at 14% moisture basis.^bBased on the protein content of the original grain.

TABLE 9. DISTRIBUTION OF ASH IN GRAIN SORGHUM PRODUCTS^a

Products	Hybrid				
	Asgrow Dorado %	Dekalb C-42Y %	McNair 654 %	Pioneer 846 %	RS 506 % 671 % 700 %
<u>Non-Peeled</u>					
Break Flour	4.3	4.5	4.0	4.3	5.1 4.1 4.0
Reduction Flour	17.2	21.5	16.6	16.2	20.8 19.4 15.0
Pin Mill Flour	38.8	30.0	37.1	39.0	42.4 37.0 43.2
Shorts	5.2	3.5	4.4	3.8	2.7 3.4 3.2
Bran and Germ	35.5	40.5	37.9	36.7	29.0 36.1 34.6
<u>Peeled</u>					
Break Flour	2.3	2.9	2.5	2.2	2.1 3.0
Reduction Flour	10.6	9.3	9.6	8.3	7.6 12.1
Pin Mill Flour	24.7	26.2	29.1	32.6	29.8 31.7
Shorts	0.9	1.0	1.2	1.1	1.4 1.0
Bran and Germ	61.5	60.6	57.6	55.8	59.1 52.2

^aExpressed as percent of recovered ash at 14% moisture basis.

TABLE 10. DISTRIBUTION OF CRUDE FAT IN GRAIN SORGHUM PRODUCTS^a

Products	Hybrid				
	Asgrow Dorado %	Dekalb C-42Y %	McNair 654 %	Pioneer 846 %	RS 506 % RS 671 % RS 700 %
<u>Non-Peeled</u>					
Break Flour	3.9	3.8	3.5	4.0	5.8 3.9 3.6
Reduction Flour	15.7	18.0	15.0	14.7	17.3 17.8 15.4
Pin Mill Flour	37.2	30.8	34.8	38.1	41.4 35.6 38.1
Shorts	5.1	3.9	4.7	3.7	3.2 3.7 2.8
Bran and Germ	38.1	43.5	42.0	39.5	32.3 39.0 40.1
<u>Peeled</u>					
Break Flour	3.2	2.7	3.0	2.8	3.1 3.4
Reduction Flour	10.7	10.4	9.4	12.5	9.5 10.3
Pin Mill Flour	22.7	26.5	25.3	24.9	27.1 27.5
Shorts	0.9	0.9	0.6	1.3	1.1 1.1
Bran and Germ	62.5	59.5	61.7	58.5	59.2 57.7

^aExpressed as percent of recovered crude fat at 14% moisture basis.

TABLE 11. AMINO ACID DISTRIBUTION IN MILL FRACTIONS FROM NON-PEELED ASGROW DORADO SORGHUM HYBRID

Product	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran-Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	14.3	14.4	14.1	7.7	9.8	17.0	18.9	17.5	12.4
Amino Acid: ^b									
Lysine	2.02	3.26	2.23	3.65	2.17	1.78	1.40	3.77	4.01
Histidine	2.37	3.19	2.77	2.96	3.17	2.27	1.97	2.56	2.77
Arginine	3.66	6.08	4.69	5.52	4.68	3.27	2.74	6.00	6.60
Aspartic Acid	7.36	8.57	7.89	8.29	9.01	6.68	6.50	8.09	9.45
Threonine	3.45	4.10	3.98	4.45	4.31	3.25	3.18	3.52	4.48
Serine	4.98	6.01	6.15	5.79	5.99	4.93	4.81	4.97	5.94
Glutamic Acid	23.71	26.97	28.54	22.36	26.83	23.39	24.50	17.81	22.35
Proline	8.60	10.81	11.66	9.94	10.16	9.59	9.88	7.09	9.23
Glycine	3.14	3.96	3.63	4.37	3.94	2.70	2.50	4.22	4.81
Alanine	10.36	11.11	11.27	9.05	10.15	9.80	10.34	7.89	9.74
Half Cystine	1.80	2.06	3.01	2.95	3.29	1.01	0.99	0.71	1.63
Valine	4.49	6.04	6.28	6.37	5.61	4.98	4.92	5.13	6.03
Methionine	1.51	1.88	2.68	1.92	1.93	1.54	1.15	1.51	1.89
Isoleucine	4.05	4.78	5.78	4.49	4.11	4.93	4.70	3.88	4.42
Leucine	15.49	17.89	19.68	14.55	15.13	20.68	19.98	13.02	14.97
Tyrosine	4.24	5.54	5.52	4.49	5.12	4.02	4.45	3.43	3.95
Phenylalanine	5.67	6.82	7.39	5.78	6.62	5.34	5.63	4.65	5.64

^a% dry basis.^bGrams of amino acid per 100 grams of protein.

TABLE 12. AMINO ACID DISTRIBUTION IN MILL PRODUCTS FROM NON-PEELED DEKALB C-42Y SORGHUM HYBRID

Product	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran-Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	12.4	13.1	12.6	7.3	9.6	15.0	14.3	14.6	12.3
Amino Acids: ^b									
Lysine	2.36	3.09	2.20	3.55	2.04	1.51	1.63	5.64	3.46
Histidine	2.52	3.16	2.61	3.18	3.10	2.63	2.35	3.31	2.39
Arginine	4.03	6.14	4.49	4.98	4.36	3.88	3.09	9.19	4.75
Aspartic Acid	7.47	8.29	8.27	8.22	8.99	8.26	6.60	9.79	6.97
Threonine	3.39	3.93	3.93	4.07	4.35	3.95	3.31	4.38	2.61
Serine	5.13	5.74	6.21	5.50	6.06	5.67	5.07	5.93	5.21
Glutamic Acid	23.59	25.14	24.30	22.37	26.64	27.82	22.86	18.88	19.82
Proline	9.38	10.23	11.36	9.95	10.97	11.50	9.29	7.75	9.07
Glycine	3.44	4.02	3.55	4.28	3.94	3.39	2.80	5.83	4.53
Alanine	10.19	10.03	9.98	9.76	10.20	10.78	10.57	8.36	8.61
Half Cystine	1.73	3.64	2.87	3.58	2.38	2.06	0.92	2.75	1.74
Valine	5.53	5.80	4.90	6.32	5.43	5.14	5.14	6.28	5.26
Methionine	1.22	2.20	1.64	2.17	1.77	1.26	1.18	1.73	1.09
Isoleucine	4.13	5.01	4.78	4.95	4.20	4.55	4.48	4.06	3.66
Leucine	14.80	16.80	18.13	15.06	14.41	15.61	18.70	11.40	12.78
Tyrosine	4.20	4.52	5.68	4.72	5.00	5.36	4.19	4.06	2.96
Phenylalanine	5.51	5.94	7.41	5.92	6.53	6.74	5.36	5.72	5.72

^a% dry basis.^bGrams of amino acid per 100 grams of protein.

TABLE 13. AMINO ACID DISTRIBUTION IN MILL PRODUCTS FROM NON-PEELED MCNAIR 654 SORGHUM HYBRID

Product	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	12.3	12.8	12.7	7.4	10.2	16.8	17.8	15.6	11.6
Amino Acids: ^b									
Lysine	2.25	2.39	2.41	2.55	2.01	1.75	1.51	3.74	3.33
Histidine	2.39	2.60	2.87	2.78	3.24	2.13	2.29	2.56	2.60
Arginine	4.09	4.73	4.60	4.24	5.40	3.48	2.74	6.16	6.04
Aspartic Acid	7.35	8.27	7.64	6.39	8.54	6.42	6.53	7.94	9.23
Threonine	3.38	3.85	3.85	3.32	4.37	3.30	3.22	3.48	4.32
Serine	4.86	6.04	5.96	4.72	6.13	4.89	4.67	4.80	6.23
Glutamic Acid	21.52	26.91	25.60	20.70	27.18	22.78	24.08	16.59	21.20
Proline	8.45	11.59	10.88	8.19	10.52	9.26	9.38	6.27	9.56
Glycine	3.34	4.16	3.67	3.26	3.72	3.10	2.82	4.20	5.02
Alanine	9.38	10.84	10.43	7.99	10.13	9.72	10.28	7.50	9.15
Half Cystine	1.92	2.08	2.14	1.25	2.63	0.84	1.03	0.75	1.84
Valine	5.11	6.01	5.87	4.89	5.35	4.86	6.46	4.88	4.98
Methionine	1.49	1.09	2.14	1.57	1.80	1.23	1.19	1.28	1.87
Isoleucine	3.82	4.36	5.41	3.84	3.94	4.04	4.31	3.41	4.59
Leucine	13.84	17.42	17.54	14.46	14.23	17.87	19.31	11.83	14.89
Tyrosine	3.99	5.05	5.06	3.88	5.21	4.21	4.25	3.29	5.06
Phenylalanine	5.24	6.61	6.73	4.80	6.52	5.31	5.63	4.40	7.16

^a% dry basis.^bGrams of amino acid per 100 grams of protein.

TABLE 14. AMINO ACID DISTRIBUTION IN MILL PRODUCTS FROM NON-PEELED PIONEER 846 SORGHUM HYBRID

Product	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	14.1	15.1	14.3	7.0	9.3	16.9	18.1	13.7	8.9
Amino Acids: ^b									
Lysine	1.82	2.41	1.77	3.64	2.23	2.15	1.00	3.84	3.42
Histidine	2.31	2.57	2.36	2.91	2.39	2.99	2.50	3.13	2.15
Arginine	3.65	5.27	4.56	5.78	3.66	5.05	2.97	8.06	5.01
Aspartic Acid	7.19	7.77	8.67	7.92	7.45	8.23	8.01	10.44	8.02
Threonine	3.40	3.83	4.11	4.08	3.64	3.75	3.82	4.72	3.31
Serine	4.97	5.36	6.91	5.57	5.02	5.81	5.70	6.69	4.82
Glutamic Acid	24.50	26.42	27.51	23.63	22.88	27.73	30.26	20.71	16.51
Proline	9.09	10.27	11.71	10.16	9.50	11.34	11.58	7.21	7.02
Glycine	3.09	3.48	3.78	4.28	2.94	3.19	2.92	6.00	4.85
Alanine	10.69	11.06	11.13	8.99	8.61	11.01	11.24	8.10	7.43
Half Cystine	1.58	2.69	3.51	2.45	2.70	2.88	2.69	2.18	1.64
Valine	5.23	6.04	5.07	6.08	4.41	5.01	5.26	5.38	4.90
Methionine	1.47	1.83	1.52	1.90	1.09	1.51	1.42	1.37	0.72
Isoleucine	4.28	5.29	5.38	4.51	3.73	4.95	4.40	3.49	3.63
Leucine	16.34	16.21	20.67	14.71	14.83	20.12	17.24	9.47	10.44
Tyrosine	4.55	5.34	6.07	4.75	4.43	6.04	5.25	3.87	4.55
Phenylalanine	5.73	6.79	8.44	5.95	5.03	8.63	6.59	5.20	5.13

^a% dry basis.^bGrams of amino acid per 100 grams of protein.

TABLE 15. AMINO ACID DISTRIBUTION OF MILL PRODUCTS FROM NON-PEELED RS 671 SORGHUM HYBRID

Product	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	14.0	16.1	15.1	7.7	10.3	18.2	20.4	13.5	10.5
Amino Acids: ^b									
Lysine	1.89	1.89	1.55	2.16	2.88	1.01	1.18	4.48	3.76
Histidine	2.45	2.33	2.49	2.56	2.94	1.93	2.10	2.70	2.44
Arginine	4.07	3.96	3.36	3.74	4.89	3.61	3.16	8.44	6.40
Aspartic Acid	7.48	8.23	7.93	7.06	8.03	7.62	6.68	9.70	8.84
Threonine	3.56	3.62	3.67	3.62	3.94	3.81	3.35	4.28	4.34
Serine	5.05	5.37	5.42	4.82	5.59	6.17	4.98	5.56	5.85
Glutamic Acid	24.72	28.14	27.96	20.08	25.88	28.54	25.82	17.47	21.03
Proline	9.14	10.62	11.24	8.87	10.93	10.95	9.92	7.67	9.15
Glycine	3.21	2.77	2.95	3.27	3.81	3.21	2.35	5.28	5.37
Alanine	10.92	11.03	10.88	7.63	10.19	11.02	10.40	7.88	9.15
Half Cystine	2.04	1.45	1.24	1.84	2.26	2.91	1.26	1.90	1.57
Valine	5.40	5.29	5.50	4.30	5.93	5.89	5.26	5.06	5.91
Methionine	1.52	0.99	1.28	1.20	1.96	2.10	1.36	1.79	1.54
Isoleucine	4.29	3.98	4.80	3.20	4.89	5.14	4.36	4.11	4.27
Leucine	16.06	18.15	19.10	10.84	17.08	18.24	17.42	11.89	13.77
Tyrosine	4.57	3.87	5.43	4.26	5.27	5.33	5.08	4.61	3.91
Phenylalanine	5.82	5.00	6.95	5.16	6.76	6.81	6.44	6.09	5.90

^a% dry basis.^bGrams of amino acid per 100 grams of protein.

TABLE 16. AMINO ACID DISTRIBUTION IN MILL PRODUCTS FROM NON-PEELED RS 700 SORGHUM HYBRID

Product	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	15.3	15.3	15.9	7.1	9.3	19.6	23.7	13.6	10.0
Amino Acids: ^b									
Lysine	1.74	2.10	1.88	3.65	2.83	1.91	1.37	4.81	4.04
Histidine	2.37	2.32	2.56	3.25	2.70	2.38	2.51	2.83	2.48
Arginine	3.62	4.32	4.54	6.05	5.82	3.76	4.28	8.16	7.10
Aspartic Acid	7.09	7.81	8.04	8.66	7.68	6.59	7.69	10.39	10.02
Threonine	3.37	3.95	3.86	4.36	3.89	3.15	3.77	4.69	4.39
Serine	4.93	5.88	6.19	6.67	5.36	4.88	5.86	6.78	6.41
Glutamic Acid	24.46	29.05	29.40	23.98	25.13	21.60	30.54	19.28	24.26
Proline	8.74	10.40	11.29	10.33	10.14	9.74	11.44	7.39	8.66
Glycine	2.90	3.11	3.13	4.82	3.65	2.83	2.82	5.69	5.19
Alanine	10.44	11.73	11.31	10.77	9.94	9.47	12.47	8.04	10.38
Half Cystine	1.93	2.64	2.46	2.36	2.46	2.22	1.72	2.31	1.67
Valine	5.10	5.91	5.34	6.75	5.76	5.48	6.04	5.09	6.06
Methionine	1.44	1.55	1.92	2.39	2.51	1.59	1.58	0.95	1.71
Isoleucine	4.15	4.52	4.97	4.95	4.77	3.99	4.32	4.27	4.35
Leucine	15.87	19.09	19.52	15.76	16.85	15.51	21.56	12.15	15.30
Tyrosine	4.65	3.31	5.24	5.53	4.70	4.71	5.70	4.50	4.13
Phenylalanine	5.83	4.25	6.44	7.38	5.73	5.80	5.41	6.50	5.92

^a% dry basis.^bGrams of amino acid per 100 grams of protein.

TABLE 17. DISTRIBUTION OF AMINO ACIDS IN MILL PRODUCTS FROM NON-PEELED RS 506 SORGHUM HYBRID

Products	Original Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A	B	C	D	E	F
Protein ^a	13.3	6.7	9.2	16.7	20.1	12.9
Amino Acids: ^b						
Lysine	1.98	2.51	1.89	1.61	1.51	3.87
Histidine	2.36	2.85	2.71	2.60	2.29	3.04
Arginine	4.01	4.57	4.32	4.02	2.76	8.13
Aspartic Acid	7.28	8.78	8.72	8.93	7.78	10.00
Threonine	3.28	4.24	4.07	4.16	3.59	4.53
Serine	4.74	5.62	5.29	7.12	6.07	5.84
Glutamic Acid	23.64	23.22	25.82	29.84	30.67	19.19
Proline	9.31	9.53	10.39	11.95	10.86	7.13
Glycine	3.02	3.79	3.63	3.32	2.61	5.58
Alanine	10.10	9.50	10.63	9.90	11.90	7.81
Half Cystine	1.43	2.34	2.06	1.60	2.15	1.71
Valine	5.25	5.07	5.28	4.34	6.12	5.44
Methionine	1.19	1.38	1.51	1.41	1.90	1.39
Isoleucine	4.35	3.53	4.07	4.26	5.25	3.64
Leucine	16.37	12.62	14.52	15.87	21.85	9.56
Tyrosine	4.45	4.62	4.91	5.46	5.35	3.89
Phenylalanine	5.84	5.81	6.37	6.85	6.82	5.17

^a% sample on dry basis.^bGrams of amino acid per 100 gram protein.

TABLE 18. AMINO ACID DISTRIBUTION IN MILL PRODUCTS FROM BRUSH-PEELED ASGROW DORADO SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Protein ^a	14.4	7.8	9.8	17.6	22.3	18.4
Amino Acids: ^b						
Lysine	3.26	3.07	2.39	1.76	0.94	6.04
Histidine	3.19	2.73	2.47	2.34	1.82	2.67
Arginine	6.07	4.86	3.55	3.67	2.15	9.38
Aspartic Acid	8.57	7.94	8.25	8.72	7.88	9.78
Threonine	4.10	4.06	3.78	4.66	3.87	4.35
Serine	6.01	5.33	4.86	9.38	7.03	5.87
Glutamic Acid	26.97	21.46	22.75	26.178	30.63	17.20
Proline	10.81	10.20	10.27	11.68	13.20	6.37
Glycine	3.96	4.13	3.21	4.78	2.30	6.33
Alanine	11.17	8.52	9.59	11.20	11.94	8.23
Half Cystine	2.06	2.82	0.83	2.05	0.82	2.02
Valine	6.04	4.86	4.67	5.64	5.09	6.20
Methionine	1.88	1.95	0.94	1.91	1.18	1.91
Isoleucine	4.78	4.63	4.18	5.74	4.74	3.84
Leucine	17.89	15.06	16.22	20.66	21.09	9.86
Tyrosine	5.55	4.70	2.67	7.04	5.67	3.56
Phenylalanine	6.82	6.74	3.64	9.29	6.78	5.29

^a% sample on dry basis.^bGrams of amino acid per 100 gram protein.

TABLE 19. AMINO ACID DISTRIBUTION IN MILL PRODUCTS FROM BRUSH-PEELED DEKALB C-42Y SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Protein ^a	13.1	7.2	7.8	15.5	18.7	19.3
Amino Acids: ^b						
Lysine	3.09	3.54	3.35	2.12	1.58	5.30
Histidine	3.16	3.09	2.95	2.86	2.60	2.73
Arginine	6.14	5.71	5.02	4.30	3.80	9.53
Aspartic Acid	8.29	7.84	7.55	7.84	7.09	9.05
Threonine	3.93	4.03	4.03	3.64	3.38	5.18
Serine	5.74	5.46	5.55	5.91	5.35	5.48
Glutamic Acid	25.14	21.37	22.19	26.81	26.25	15.16
Proline	10.23	9.46	10.19	11.04	11.30	6.09
Glycine	4.02	4.26	4.07	3.14	2.51	5.19
Alanine	10.03	9.13	9.95	10.80	10.81	6.93
Half Cystine	3.64	3.65	3.32	2.60	2.00	1.63
Valine	5.80	5.84	6.03	5.95	5.29	5.03
Methionine	2.20	1.94	2.23	1.67	1.33	1.62
Isoleucine	5.01	4.55	4.87	4.82	4.92	3.37
Leucine	16.80	13.85	15.67	18.40	18.32	8.54
Tyrosine	4.52	4.69	5.04	4.87	4.41	3.07
Phenylalanine	5.94	6.14	6.29	6.29	5.66	4.29

^a% sample on dry basis.^bGrams of amino acid per 100 gram protein.

TABLE 20. AMINO ACID DISTRIBUTION IN MILL PRODUCTS FROM BRUSH-PEELED McNAIR 654 SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Protein ^a	14.6	7.9	10.1	17.4	22.6	18.5
Amino Acids: ^b						
Lysine	2.39	3.34	2.06	1.85	1.21	5.04
Histidine	2.60	2.93	2.40	2.87	2.54	2.85
Arginine	4.73	5.93	4.42	4.47	3.47	10.23
Aspartic Acid	8.27	7.92	7.48	7.65	7.08	9.31
Threonine	3.85	4.07	3.68	3.80	3.95	4.03
Serine	6.04	5.77	5.02	5.58	5.87	5.36
Glutamic Acid	26.91	22.47	23.35	27.13	28.37	16.85
Proline	11.59	9.92	10.35	11.26	11.50	5.91
Glycine	4.16	4.24	3.17	2.86	2.77	5.41
Alanine	10.84	9.27	9.30	10.76	11.15	7.30
Half Cystine	2.08	2.17	2.39	2.47	4.00	2.16
Valine	6.01	5.60	5.89	4.39	5.59	5.48
Methionine	1.09	2.27	1.75	1.77	1.84	1.79
Isoleucine	4.36	4.67	4.04	4.72	5.14	3.68
Leucine	17.42	14.64	17.12	19.33	19.68	9.87
Tyrosine	5.05	3.95	4.37	5.21	4.83	3.52
Phenylalanine	6.61	4.94	5.57	6.29	6.34	4.52

^a% sample on dry basis.^bGrams of amino acid per 100 gram protein.

TABLE 21. AMINO ACID DISTRIBUTION IN MILL PRODUCTS FROM BRUSH-PEELED PIONEER 846 SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Protein ^a	15.1	7.3	12.2	17.5	23.9	17.9
Amino Acids: ^b						
Lysine	2.41	3.15	1.78	1.95	1.12	5.68
Histidine	2.57	2.98	2.42	2.74	2.37	2.76
Arginine	5.27	5.08	4.04	4.14	3.22	8.53
Aspartic Acid	7.77	7.23	6.23	7.54	7.21	8.99
Threonine	3.83	3.71	3.30	3.73	3.54	3.98
Serine	5.36	4.90	4.83	5.87	6.51	5.64
Glutamic Acid	26.41	20.17	24.79	25.51	28.02	17.06
Proline	10.27	9.23	10.03	10.68	10.25	5.75
Glycine	3.48	3.56	2.47	2.72	2.91	5.94
Alanine	11.06	8.56	9.30	11.37	11.56	7.22
Half Cystine	2.69	2.67	3.23	0.85	2.07	2.07
Valine	6.03	5.28	4.61	5.58	5.93	5.66
Methionine	1.83	1.93	1.03	1.91	1.63	1.76
Isoleucine	5.29	4.40	3.83	4.95	5.13	3.53
Leucine	16.21	14.03	16.15	18.73	19.86	9.33
Tyrosine	5.34	4.20	4.82	4.92	4.84	3.85
Phenylalanine	6.79	4.82	6.19	6.11	6.30	5.25

^a% sample on dry basis.^bGrams of amino acid per 100 gram protein.

TABLE 22. AMINO ACID DISTRIBUTION IN MILL PRODUCTS FROM BRUSH-PEELED RS 671 SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Protein ^a	16.1	7.5	10.3	19.8	24.9	21.3
Amino Acids: ^b						
Lysine	1.89	3.20	1.95	1.53	0.97	6.37
Histidine	2.32	2.99	2.40	2.43	2.31	2.68
Arginine	3.96	4.25	3.37	3.55	2.40	10.68
Aspartic Acid	8.23	8.28	7.52	6.72	6.69	9.65
Threonine	3.62	4.11	3.70	3.52	3.35	4.11
Serine	5.37	5.35	5.15	4.99	5.28	5.70
Glutamic Acid	28.14	24.24	25.42	24.94	27.88	17.37
Proline	10.62	10.53	10.40	9.61	11.45	5.44
Glycine	2.77	3.57	2.73	2.58	2.38	5.66
Alanine	11.03	10.20	10.54	10.59	11.26	7.58
Half Cystine	1.45	2.36	2.85	2.26	3.00	3.07
Valine	5.29	5.92	5.59	5.25	5.39	5.90
Methionine	0.99	1.07	1.36	1.69	1.86	1.50
Isoleucine	3.98	4.08	3.21	4.43	4.83	3.07
Leucine	18.15	15.91	17.19	17.39	19.62	9.42
Tyrosine	3.87	4.75	4.46	4.48	4.84	3.64
Phenylalanine	5.00	5.78	5.67	5.35	6.02	4.76

^a% sample on dry basis.^bGrams of amino acid per 100 gram protein.

TABLE 23. AMINO ACID DISTRIBUTION IN MILL PRODUCTS FROM BRUSH-PEELED RS 700 SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Protein ^a	15.3	7.1	9.7	21.0	29.4	18.3
Amino Acids: ^b						
Lysine	2.10	3.07	2.35	1.74	1.11	5.01
Histidine	2.32	2.69	2.54	2.58	2.35	3.12
Arginine	4.32	4.93	4.21	3.08	2.92	10.20
Aspartic Acid	7.81	8.43	7.79	7.82	6.96	7.68
Threonine	3.95	4.22	4.42	3.94	3.46	3.61
Serine	5.88	5.80	6.11	5.71	5.58	4.97
Glutamic Acid	29.03	22.97	23.87	27.34	28.28	16.47
Proline	10.40	10.63	10.82	11.34	11.34	5.86
Glycine	3.11	3.91	3.43	2.73	2.53	5.02
Alanine	11.73	9.26	9.83	11.28	11.44	7.82
Half Cystine	2.64	2.48	1.79	1.74	1.64	1.26
Valine	5.91	5.38	5.26	5.35	5.41	5.73
Methionine	1.55	1.93	2.42	2.10	1.59	1.99
Isoleucine	4.52	5.23	4.81	5.00	4.94	3.57
Leucine	19.09	16.62	17.83	20.38	19.41	9.68
Tyrosine	3.31	5.15	5.18	5.77	5.55	3.18
Phenylalanine	4.25	6.94	7.44	7.91	6.86	4.34

^a% sample on dry basis.^bGrams of amino acid per 100 gram protein.

TABLE 24. ANALYSIS OF VARIANCE OF PROTEIN AND AMINO ACIDS IN GRAIN SORGHUM
HYBRIDS AND THEIR MILL PRODUCTS

Product	Non-Peeled Hybrids	Non-Peeled Hybrid Products	Peeled Hybrids	Peeled Hybrid Products
Protein	N	**	*	**
Lysine	N	**	*	**
Histidine	N	**	N	**
Arginine	N	**	N	**
Aspartic Acid	*	**	N	**
Threonine	N	**	N	**
Serine	N	N	N	*
Glutamic Acid	N	N	N	N
Proline	N	**	N	**
Glycine	N	**	*	**
Alanine	N	**	N	**
Half Cystine	N	N	N	N
Valine	N	N	N	N
Methionine	N	N	N	N
Isoleucine	N	N	**	**
Leucine	N	N	N	**
Tyrosine	N	**	N	**
Phenylalanine	N	N	N	**

N Nonsignificant.

* Significant ($P \leq 0.05$).

** Highly significant ($P \leq 0.01$).

arginine, aspartic acid and glycine showed significant variation ($P \leq 0.01$), being highest in the bran-germ fraction, lowest in the shorts, and intermediate in the flour fractions. Their value in the whole grain and the pin milled flour fell into the lower half of the sequence, while the break and reduction flour fractions had values that were next highest. Threonine showed similar variation as the lysine group, except that it was lowest in the whole grain instead of the shorts. Histidine was also significantly ($P \leq 0.01$) different in the products being highest in the break flour and lowest in shorts.

Significant ($P \leq 0.01$) differences were observed for proline and tyrosine between reduction flour and the bran-germ fraction, and between pin mill flour which contained the highest value and the bran-germ fraction which contained the lowest value.

Alanine and leucine showed significant ($P \leq 0.01$) variation between their values in shorts and those in reduction and break flours.

A comparison of peeled grains indicated little variation in amino acids among the hybrids. Significant differences ($P \leq 0.01$) were, however, observed for isoleucine which had higher values in products from RS 671 than in the rest of the hybrids.

Differences in glycine, lysine and protein in the hybrids were also significant ($P \leq 0.05$). Glycine values in Dekalb C-42Y and Asgrow Dorado were significantly different ($P \leq 0.05$) from those in Pioneer 846, RS 700 and RS 671 which had the lowest values. Significant differences for lysine existed between Dekalb C-42Y and the other hybrids. Significant differences in protein were detected between Dekalb C-42Y and Pioneer 846, RS 671 and RS 700.

Amino acid variation in the products occurred in three groups. The first group included serine, half-cystine, valine and methionine, and showed no significant differences ($P \leq 0.05$) between products. The second group consisting of lysine, arginine, histidine, threonine and aspartic acid were highest in the bran-germ fraction and lowest in shorts. Their values in break flour were next highest and the values found in reduction and pin mill flours were next to the lowest. Whole grain values were in the middle of the sequence. Variation in the amino acids between products was highly significant ($P \leq 0.01$) for all values but threonine which was significant at $P \leq 0.05$.

The third grouping of amino acids consisted of glutamic acid, proline, alanine, isoleucine, leucine, tyrosine and phenylalanine. These were highest in either shorts or pin mill flour and lowest in the bran-germ fraction, and were significantly different ($P \leq 0.01$). Values for these amino acids in whole grain, break flour and reduction flour were not significantly different ($P \leq 0.05$). They were significantly different, however, when compared to values in shorts and to those in the bran-germ fraction.

Protein values ($P \leq 0.01$) were highest in shorts, second highest in the bran-germ fraction and pin mill flour, intermediate in the whole grain, next to lowest in the reduction flour and lowest in the break flour.

Correlations Between Amino Acids and Protein

Correlation coefficients between protein in the sample and percent amino acid in the protein are shown in Tables 25-28. In the non-peeled hybrids (Table 25), the following results were obtained:

All amino acids were correlated with protein in the Asgrow Dorado hybrid. Correlations for histidine, serine and methionine were significant ($P \leq 0.05$),

TABLE 25. CORRELATION COEFFICIENTS FOR RELATIONSHIP BETWEEN AMINO ACID DISTRIBUTION AND PROTEIN LEVEL IN NON-PEELED SORGHUM HYBRID

Hybrid	Asgrow Dorado	Dekalb C-42Y	McNair 654	Pioneer 846	RS 506	RS 671	RS 700
Lysine	-.40	.12	-.04	-.62	-.36	-.49	-.65
Histidine	-.88*	-.33	-.76	-.02	-.60	-.79	-.74
Arginine	-.49	.29	-.26	-.23	-.29	-.24	-.54
Aspartic Acid	-.77	.03	-.16	.16	-.26	-.20	-.39
Threonine	-.96**	-.18	-.46	-.12	-.37	-.32	-.52
Serine	-.93*	-.12	-.44	.25	.51	.29	-.38
Glutamic Acid	-.31	.56	-.26	.67	.60	.53	-.40
Proline	-.44	-.43	-.25	.33	.37	.28	.24
Glycine	-.68	-.27	-.11	-.22	-.36	-.39	-.62
Alanine	-.01	.96**	.17	.72	.35	.62	.36
Half Cystine	-.95**	-.14	-.60	.45	-.41	-.05	-.81
Valine	-.78	-.83	.33	-.23	.19	.44	-.30
Methionine	-.92*	.41	-.88*	-.24	.47	.20	-.67
Isoleucine	-.20	-.05	.12	-.30	.79	.55	-.66
Leucine	-.50	.70	-.38	.41	.65	.57	.51
Tyrosine	-.61	-.51	-.36	.49	.47	.57	.33
Phenylalanine	-.64	.48	-.22	.57	-.10	.58	.40

* Significant at 0.05 level.

** Significant at 0.01 level.

while those for threonine and half-cystine were highly significant ($P \leq 0.01$).

In Dekalb C-42Y, only alanine and valine were significantly correlated with protein ($P \leq 0.05$).

Apart from alanine, valine and isoleucine, the correlations between protein and amino acids for McNair 654 were negative. Methionine was the only one significant ($P \leq 0.05$). Low negative correlations were also observed for most of the amino acids in Pioneer 846 products. The highest values for this hybrid were shown by alanine, glutamic acid and lysine, but were nonsignificant.

Low negative correlations were found in RS 671 for all amino acids. All amino acids in RS 700 were nonsignificantly correlated to protein content. Proline, tyrosine and phenylalanine were negatively correlated with protein. For RS 506, lysine, histidine, arginine, aspartic acid, threonine, glycine and phenylalanine were negatively nonsignificantly correlated with protein content, while others were positively correlated (nonsignificant).

Table 26 gives correlation coefficients between protein and amino acids in the products from unpeeled grain. In the original grain, threonine, glutamic acid, alanine, half-cystine, methionine, leucine, tyrosine and phenylalanine had nonsignificant positive correlations with protein content. Other amino acids gave nonsignificant negative correlations, except lysine ($r = -0.78$) which was significantly correlated with protein ($P \leq 0.05$).

All amino acids in the break flours were negatively correlated with protein, with aspartic acid and glutamic acid showing significant ($P \leq 0.05$) relationships.

Tyrosine in the reduction flours had a significant correlation with protein. The remaining amino acids were positively but nonsignificantly

TABLE 26. CORRELATION COEFFICIENTS FOR RELATIONSHIP BETWEEN AMINO ACID DISTRIBUTION AND PROTEIN LEVEL IN NON-PEELED GRAIN PRODUCTS

Product	Original Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Lysine	-.78*	-.26	.23	-.03	-.38	-.06
Histidine	-.63	-.35	.70	-.39	-.09	-.40
Arginine	-.69	-.42	.34	-.14	-.69	-.65
Aspartic Acid	-.69	-.84*	.18	-.48	-.36	-.86*
Threonine	.16	-.69	.41	-.53	.44	-.86*
Serine	-.25	-.59	.64	-.23	.35	-.73
Glutamic Acid	.28	-.79*	.53	-.45	.58	-.22
Proline	-.64	-.67	.52	-.42	.58	-.38
Glycine	-.73	-.49	.44	-.56	-.19	-.93*
Alanine	.25	-.65	.21	-.35	.58	.18
Half Cystine	.42	-.45	.22	.27	.08	-.24
Valine	-.52	-.31	.45	.51	.28	-.44
Methionine	.69	-.22	.22	.60	.46	.27
Isoleucine	-.09	-.22	.25	.31	-.17	.12
Leucine	.26	-.20	.18	-.63	.37	.46
Tyrosine	.48	-.72	.80*	-.18	.75	-.58
Phenylalanine	.31	-.26	.62	-.20	.09	-.03

* Significant at 0.05 level.

correlated with the protein.

Half-cystine, methionine, valine and isoleucine in the pin milled flours were positive (nonsignificantly) correlated with protein values. The relationship between protein and other amino acids were negative and nonsignificant. Amino acid correlation coefficients for the shorts fraction were positive and nonsignificant, except for lysine, glycine and isoleucine which had low negative values.

Glycine ($r = -.93$) was highly significantly correlated with protein in the bran-germ fraction. In the same fraction, aspartic acid ($r = 0.86$) and threonine ($r = -.86$) were significantly related to protein. The remaining amino acids had low positive coefficients.

Protein and amino acid correlations in the peeled hybrid grains (Table 27) were as follows:

Asgrow Dorado had low values which did not appear to be related to the protein.

Only half-cystine ($r = -.85$) was significantly ($P \leq 0.05$) correlated in Dekalb C-42Y to protein.

Amino acids in McNair 654 had small correlation coefficients with protein with half-cystine ($r = .58$) showing the highest value.

Serine was the only amino acid significantly ($P \leq 0.05$) correlated with protein in Pioneer 846. Correlation coefficients were also nonsignificant for RS 671 and RS 700.

Table 28 gives correlation coefficients between amino acids and protein levels in the products from peeled grains.

All the amino acids, except glutamic acid, proline, alanine and leucine, had negative correlation coefficients with the protein content of peeled

TABLE 27. CORRELATION COEFFICIENTS FOR RELATIONSHIP BETWEEN AMINO ACID DISTRIBUTION AND PROTEIN LEVEL IN PEELED SORGHUM HYBRIDS

Hybrid	Asgrow Dorado	Dekalb C-42Y	McNair 654	Pioneer 846	RS 671	RS 700
Lysine	-.04	-.02	-.17	-.18	-.03	-.38
Histidine	-.57	-.50	-.07	-.58	-.11	-.21
Arginine	.03	.28	-.02	-.11	-.27	-.16
Aspartic Acid	.34	.33	-.00	-.30	-.17	-.49
Threonine	.11	.23	.12	.07	-.39	-.61
Serine	.54	.11	.26	.94*	.16	-.24
Glutamic Acid	.35	.01	.24	.42	-.07	.41
Proline	.17	-.14	-.03	-.00	-.25	.04
Glycine	-.01	-.16	-.16	-.06	.06	-.44
Alanine	.57	-.06	.24	.47	-.11	.42
Half Cystine	-.71	-.85*	.66	-.50	.27	-.51
Valine	.45	-.40	-.31	.59	-.46	-.08
Methionine	-.07	-.75	-.24	.03	.75	-.48
Isoleucine	.25	-.26	-.26	.32	.34	-.13
Leucine	.40	-.05	-.18	.38	-.04	.18
Tyrosine	.35	-.49	.28	.20	-.18	.16
Phenylalanine	.15	-.45	.35	.47	-.14	-.00

* Significant at 0.05 level.

TABLE 28. CORRELATION COEFFICIENTS FOR THE RELATIONSHIP BETWEEN PROTEIN CONTENT AND AMINO ACID DISTRIBUTION IN PEELED GRAIN SORGHUM PRODUCTS

Product	Whole Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Lysine	-.83	-.04	-.83	-.80	-.58	.34
Histidine	-.84*	-.10	-.83	-.67	-.16	.69
Arginine	-.79	.23	-.56	-.92*	-.33	.63
Aspartic Acid	-.34	-.11	-.70	-.64	-.33	.43
Threonine	-.59	.01	-.68	-.39	-.18	.31
Serine	-.52	.10	-.60	-.40	-.10	.30
Glutamic Acid	.32	.02	.74	-.64	.25	.13
Proline	.08	.03	-.28	-.61	-.16	-.28
Glycine	-.82	.35	-.94*	-.46	.02	-.13
Alanine	.73	.12	-.35	-.60	.38	-.15
Half Cystine	-.78	-.43	-.07	-.36	-.06	.72
Valine	-.45	-.28	-.73	-.49	.19	.01
Methionine	-.75	.27	-.66	.20	.41	-.82
Isoleucine	-.57	-.22	-.60	-.53	.01	-.86*
Leucine	.46	-.18	.14	-.39	.20	-.33
Tyrosine	-.38	.63	-.18	-.17	.59	.03
Phenylalanine	-.43	.32	-.14	.07	.67	-.01

* Significant at $P \leq 0.05$.

whole grains. Lysine, arginine, histidine, half-cystine and methionine had negative coefficients in the region of $r = -.80$, but only histidine ($r = -.84$) was significantly correlated ($P \leq 0.05$) to protein.

In the break flours poor correlations were exhibited by all the amino acids except tyrosine ($r = .63$). The amino acid distribution in the reduction flours showed negative correlations for all the amino, except glutamic acid and leucine. Glycine ($r = -0.94$) was the only amino acid significantly ($P \leq 0.05$) correlated with protein. Other amino acids with high, but non-significant, correlations were lysine ($r = -0.83$), histidine ($r = -.83$), glutamic acid ($r = .74$) and valine ($r = -.73$).

In the pin milled flours, the three basic amino acids had the best correlations with protein, with arginine significant ($P \leq 0.05$). Other amino acids showed poor correlations with protein. Correlations in the peeled whole grain, reduction flour and pin mill flour fractions followed a similar trend.

The shorts fractions had amino acid distributions that were poorly correlated with protein content. Amino acids of the bran-germ fractions had low correlation coefficients, except for isoleucine ($r = -.86$), methionine ($r = -.82$), half-cystine ($r = .72$), histidine ($r = .69$) and arginine ($r = .63$).

Tables 25a-28a give the correlation coefficients between protein content and amino acid composition of grain sorghum products.

Table 25a shows correlation coefficients for non-peeled hybrids. The data indicates positively significant correlations between proteins and most of the amino acids.

In Asgrow Dorado r values of 0.86 to 0.99 were found for nearly all the

TABLE 25a. CORRELATION COEFFICIENTS FOR RELATIONSHIP BETWEEN AMINO ACID COMPOSITION AND PROTEIN LEVEL IN NON-PEELED SORGHUM HYBRIDS

Hybrid	Asgrow Dorado	Dekalb C-42Y	McNair 654	Pioneer 846	RS 506	RS 671	RS 700
Lysine	.42	.51	.55	.12	.39	-.04	.14
Histidine	.89*	.86*	.87*	.93*	.94*	.90*	.98*
Arginine	.52	.64	.54	.48	.40	.39	.62
Aspartic Acid	.93*	.88*	.91*	.92*	.94*	.91*	.91*
Threonine	.98*	.90*	.94**	.93*	.93*	.96**	.93*
Serine	.99**	.97**	.96**	.95**	.95**	.95**	.94*
Glutamic Acid	.90*	.73	.84	.96**	.95**	.95**	.94*
Proline	.90*	.10	.82	.92*	.93*	.95**	.96**
Glycine	.67	.79	.84*	.58	.60	.55	.63
Alanine	.94*	1.00**	.91*	.97**	.94*	.97**	.95**
Half Cystine	-.68	.45	-.11	.81	.87*	.64	.94*
Valine	.97**	.74	.92*	.98**	.93*	.98**	.98**
Methionine	.86*	.53	.89*	.94*	.92*	.85*	.53
Isoleucine	.95**	.86*	.95*	.95**	.97**	.97**	.81
Leucine	.89*	.94*	.86*	.88*	.90*	.96**	.45
Tyrosine	.91*	.24	.86*	.93*	.96**	.96**	.98**
Phenylalanine	.94*	.83	.90*	.91*	.93*	.99**	.98**

* Significant at .05 level.

** Significant at .01 level.

amino acids. Only histidine and proline had low values.

Dekalb C-42Y correlations were low between protein and lysine, arginine, glutamic acid, proline, glycine, half-cystine, valine, methionine and tyrosine. The correlations between protein level of McNair 654 and amino acid levels were high, except those of lysine, arginine and half-cystine.

In Pioneer 846 correlations between protein level and amino acids were positively significant ($P \leq 0.05$), except those for glycine ($r = .58$), arginine ($r = .48$) and lysine ($r = .12$) which were low. Lysine, arginine and glycine were also the only amino acids not significantly correlated with protein content of RS 506 and RS 700. RS 671 data indicated lysine, arginine, proline and alanine to be the only amino acids not significantly correlated with protein in the products.

The data in Table 26a shows the correlation coefficients between amino acid composition in products of unpeeled grain and their protein content. In the original grains, all amino acids, but lysine, arginine, glycine, half-cystine and valine, were significantly ($P \leq 0.05$) correlated to protein content. Correlation coefficients in the break flours were low and did not indicate definite trends. Significant correlations ($P \leq 0.05$) were exhibited by histidine, serine, glutamic acid, proline and the aromatic amino acids, tyrosine and phenylalanine in reduction flours. The pin milled flours exhibited a poor relationship between amino acid composition and protein content. Significant correlation coefficients ($P \leq 0.05$) were observed for half-cystine, valine and methionine.

In shorts, only lysine and half-cystine were not significantly ($P \leq 0.05$) related to protein contents. The bran-germ fractions, like break flours had low amino acid composition to protein correlations.

TABLE 26a. CORRELATION COEFFICIENTS FOR RELATIONSHIP BETWEEN AMINO ACID COMPOSITION AND PROTEIN LEVEL IN NON-PEELED GRAIN PRODUCTS

Product	Original Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Lysine	-.31	.02	.46	.37	.54	.53
Histidine	.91*	.44	.85*	.21	.88*	.64
Arginine	.50	-.06	.58	.39	.90*	.13
Aspartic Acid	.96**	-.41	.63	.17	.90*	.38
Threonine	.94**	-.08	.76	.76	.94*	.22
Serine	.91*	-.06	.85*	.30	.89*	.27
Glutamic Acid	.87*	.33	.85*	.20	.91*	.34
Proline	.78*	.14	.87*	.42	.94**	-.03
Glycine	.47	-.09	.73	.50	.87*	-.27
Alanine	.85*	-.13	.71	.69	.94**	.71
Half Cystine	.73	-.29	.45	.45	.26	-.08
Valine	.49	-.07	.74	.85*	.83*	.54
Methionine	.88*	-.10	.40	.78*	.81*	.32
Isoleucine	.81*	-.10	.59	.67	.83*	.62
Leucine	.81*	-.14	.67	.51	.90*	.67
Tyrosine	.88*	-.08	.94**	.38	.95**	-.18
Phenylalanine	.90*	.20	.82*	.25	.84*	.30

* Significant at 0.05 level.

** Significant at 0.01 level.

Table 27a gives correlation coefficients between amino acid composition and protein in peeled grain hybrids. Products from Asgrow Dorado had amino acid compositions that were primarily positive and significantly ($P \leq 0.05$) correlated to protein. Basic amino acids, glycine, half-cystine and methionine were, however, nonsignificantly correlated with the protein.

Correlations between protein content and amino acids were positive and significant ($P \leq 0.05$) for Dekalb C-42Y, except for lysine, half-cystine, leucine, arginine, glycine and alanine which had nonsignificant coefficients.

The correlation coefficients for McNair 654, RS 671 and RS 700 followed a similar trend. The coefficients were positive and significant ($P \leq 0.05$) for all amino acids, except lysine, arginine and glycine.

The data in Table 28a provides information regarding the correlation coefficients for amino acid composition in peeled grain product and their protein content. In peeled whole grains, alanine and leucine were significantly correlated ($P \leq 0.05$) to protein. Nonsignificant correlation coefficients were found between amino acid compositions and protein in break flours. Glutamic acid ($r = .99$) and proline ($r = 0.98$) had coefficients that were highly significant ($P \leq 0.01$) to protein in reduction flours.

Amino acids in the pin milled flours were poorly correlated with the protein content, except alanine and isoleucine which were significantly ($P \leq 0.05$) correlated to protein. In shorts, lysine, histidine, arginine, serine and half-cystine were poorly correlated with protein. Histidine, arginine and serine were positive and significantly ($P \leq 0.05$) correlated to protein.

TABLE 27a. CORRELATION COEFFICIENT FOR RELATIONSHIP BETWEEN AMINO ACID COMPOSITION AND PROTEIN LEVEL IN PEELED SORGHUM HYBRIDS

Hybrid	Asgrow Dorado	Dekalb C-42Y	McNair 654	Pioneer 846	RS 671	RS 700
Lysine	.32	.61	.36	.26	.39	.26
Histidine	.79	.96**	.98**	.98**	.91*	.96**
Arginine	.40	.74	.53	.52	.58	.41
Aspartic Acid	.97**	.96**	.94**	.95**	.90*	.98**
Threonine	.97**	.91*	1.00**	.99**	.96**	.98**
Serine	.91*	.96**	.99**	.99**	.99**	.99**
Glutamic Acid	.89*	.78	.89*	.92*	.89*	.95*
Proline	.84	.75	.81	.86*	.82	.92*
Glycine	.59	.77	.68	.66	.67	.75
Alanine	.94*	.83	.91*	.92*	.92*	.97**
Half Cystine	.34	.46	.88*	.53	.90*	.84*
Valine	.97**	.94*	.95*	.99**	.99**	1.00**
Methionine	.78	.84*	.89*	.92*	.95**	.94*
Isoleucine	.92*	.86*	.95**	.93*	.92*	.97**
Leucine	.84*	.59	.83*	.86*	.82	.92*
Tyrosine	.85*	.79	.93	.95**	.95**	.92*
Phenylalanine	.86*	.84*	.93*	.97**	.97**	.90*

* Significant at 0.05 level.

** Significant at 0.01 level.

TABLE 28a. CORRELATION COEFFICIENTS FOR THE RELATIONSHIP BETWEEN PROTEIN CONTENT AND AMINO ACID COMPOSITION OF PEELED GRAIN SORGHUM PRODUCTS

Products	Whole Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Lysine	-.67	.60	-.46	-.20	.39	.79
Histidine	-.55	.58	.91*	.30	.79	.90*
Arginine	-.60	.53	.58	-.64	.63	.90*
Aspartic Acid	.32	.60	.71	.46	.93*	.82
Threonine	.29	.73	.66	.59	.89*	.66
Serine	.27	.65	.77	.01	.75	.85*
Glutamic Acid	.82	.58	.99**	.78	.96**	.83
Proline	.83	.64	.98**	.60	.86*	.80
Glycine	-.55	.70	-.40	-.09	.86*	.55
Alanine	.95**	.47	.93*	.88*	.98**	.69
Half Cystine	-.65	-.23	.60	-.03	.19	.82
Valine	.68	.31	.65	.37	.95**	.69
Methionine	-.60	.45	-.36	.84*	.82	-.43
Isoleucine	-.11	.33	.41	.56	.98**	-.20
Leucine	.87*	.41	.84	.77	.97**	.68
Tyrosine	-.06	-.21	.82	.44	.94*	.66
Phenylalanine	-.08	-.03	.72	.42	.97**	.59

* Significant ($P \leq 0.05$).

** Significant ($P \leq 0.01$).

Correlations Between Lysine and Other Amino Acids

The relationship between lysine, the first limiting amino acid in grain products, the other essential amino acids and those nonessential amino acids that were most abundant in sorghum grain products, is given by the data in Tables 29 and 30.

In Table 29, the data shows lysine to be significantly ($P \leq 0.05$) correlated positively with arginine and glycine, and negatively with glutamic acid and proline in all samples of peeled hybrids. Alanine and leucine also gave high negative correlations with lysine in all samples, except Asgrow Dorado. Histidine gave high positive correlation coefficients in RS 671 and RS 700. A similar trend in correlation coefficient between lysine and the above named amino acids was observed in unpeeled hybrids. The coefficients for non-peeled grain, however, appeared lower than in the peeled grains.

The data in Table 30 gives correlation coefficients between lysine in the products and other amino acids. In the non-peeled whole grain, glycine was the only amino acid significantly ($P \leq 0.05$) correlated with lysine.

The correlations for peeled grains were all positive, except nonsignificant correlation coefficients for glutamic acid, proline and alanine.

In break flours, correlation coefficients were lower in peeled products than in non-peeled products. Reduction flours from peeled grains had correlation coefficients that were primarily positive, while those for reduction flours from non-peeled grain were primarily negative. Pin milled flours gave a trend similar to that shown by reduction flours.

Finally, the ratios between the average isoleucine and leucine values were, as expected, low: 0.267, 0.277, 0.249, 0.234, and 0.317 for whole grain, break flour, reduction flour, pin mill flour, shorts and bran from

TABLE 29. CORRELATION COEFFICIENTS FOR THE RELATIONSHIP BETWEEN LYSINE AND OTHER AMINO ACID DISTRIBUTIONS IN GRAIN SORGHUM HYBRIDS

Amino Acid	Peeled Hybrid				
	Asgrow Dorado	Dekalb C-42Y	McNair 654	Pioneer 846	RS 671 RS 700
Histidine	.57	-.08	.55	.58	.95** .93*
Arginine	.99**	.94*	.98**	.98**	.92* .97**
Aspartic Acid	.83	.56	.92*	.80	.92* .38
Threonine	.25	.92*	.58	.74	.84 .09
Glutamic Acid	-.86*	-.87*	-.94*	-.92*	-.94* -.97**
Proline	-.95**	-.91*	-.93*	.95**	-.90* -.93*
Glycine	.86*	.97**	.95**	.96**	1.00** .99**
Alanine	-.69	-.87*	-.91*	-.85*	-.97** -.92*
Valine	.67	-.39	.11	.07	.76 .36
Methionine	.60	.16	.19	.30	-.20 -.25
Isoleucine	-.47	-.85*	-.73	-.66	-.71 .75
Leucine	-.77	-.90*	-.99**	.96**	-.98** -.96**
Phenylalanine	-.54	-.65	-.85*	-.63	-.51 -.54

* Significant ($P \leq 0.05$).

** Highly significant ($P \leq 0.01$).

TABLE 29 (CONTINUED)

Amino Acid	Non-Peeled Hybrid						
	Asgrow Dorado	Dekalb C-42Y	McNair 654	Pioneer 846	RS 506	RS 671	RS 700
Histidine	.53	.76	.20	.72	.83	.78	.73
Arginine	.96**	.96**	.82	.90*	.96**	.95**	.96*
Aspartic Acid	.58	.69	.40	.61	.73	.89*	.90*
Threonine	.53	.55	.02	.75	.64	.83	.88*
Glutamic Acid	-.73	.84	-.83	-.81	-.90*	-.79	-.68
Proline	-.49	-.93*	-.87*	-.65	-.92	-.64	-.61
Glycine	.90*	.84*	.85*	.86*	.95**	.93*	.99**
Alanine	-.89*	.10	-.91*	-.81	-.89*	-.66	-.70
Valine	.59	-.55	-.57	.48	.07	-.20	.00
Methionine	.49	.92*	.00	.36	-.37	-.16	.16
Isoleucine	-.49	.88*	-.96**	-.37	-.70	-.25	.37
Leucine	-.81	.60	-.85*	-.71	-.84*	-.62	.21
Phenylalanine	-.38	.80	-.70	-.34	-.50	-.17	.02

* Significant ($P \leq 0.05$).** Highly significant ($P \leq 0.01$).

TABLE 30. CORRELATION COEFFICIENTS FOR THE RELATIONSHIP BETWEEN LYSINE AND OTHER AMINO ACID DISTRIBUTIONS IN GRAIN SORGHUM PRODUCTS

Amino Acid	Peeled					
	Whole Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Histidine	.99**	.79	.89*	.91*	.78	-.02
Arginine	.92*	.66	.82	.82	.82	-.28
Aspartic Acid	.51	-.16	.20	.72	-.32	.71
Threonine	.77	-.03	.40	.29	-.36	-.19
Glutamic Acid	-.05	-.09	-.85*	.97**	-.85*	.54
Proline	-.06	-.50	-.02	.80	-.38	.25
Glycine	.77	.51	.80	.22	.20	.84*
Alanine	-.49	.20	.31	.92*	-.88*	.39
Valine	.51	.67	.68	.72	.03	.63
Methionine	.77	.17	.76	.26	-.11	-.31
Isoleucine	.58	-.23	.76	.54	-.28	-.15
Leucine	.38	-.61	.11	.61	-.89*	-.00
Phenylalanine	.62	-.29	.26	.11	-.76	.87*

* Significant ($P < 0.05$).

** Highly significant ($P < 0.01$).

TABLE 30 (CONTINUED)

Amino Acid	Non-Peeled					
	Original Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Histidine	.64	.82*	-.21	.66	-.14	.55
Arginine	.63	.93*	.48	.48	-.10	.74
Aspartic Acid	.68	.54	-.63	-.15	-.45	.42
Threonine	-.14	.68	-.50	-.39	-.52	.39
Glutamic Acid	-.71	.71	-.25	-.42	-.46	.82*
Proline	.06	.68	-.06	-.23	-.59	-.74
Glycine	.89*	.92	.02	-.36	-.02	.00
Alanine	-.65	.66	-.13	-.34	-.04	.85*
Valine	.18	.97**	.50	-.44	.31	.81*
Methionine	-.39	.66	.60	-.55	-.13	.81*
Isoleucine	-.51	.60	.85*	-.12	.32	.96**
Leucine	-.79	.43	.98**	.23	.56	.83*
Phenylalanine	-.76	.06	-.01	.15	-.90*	.97**

* Significant ($P \leq 0.05$).** Highly significant ($P \leq 0.01$).

SUMMARY

Seven sorghum hybrids were milled as unpeeled grain in a Buhler experimental laboratory flour mill. The shorts were reduced by means of an Alpine Kolloplex pin mill.

Six of the seven hybrids were, in addition, brush-peeled and then milled into flour and feed fractions.

Proximate and color analyses were carried out on the products. Amino acids, except tryptophan, were also determined using a Beckman 120C automatic amino acid analyzer.

Results indicated that peeled grains gave endosperm products with lighter colors and lower ash and fat content. They also indicated non-significant variations in protein content and amino acid levels among hybrids in both peeled and non-peeled grains. Significant differences were, however, observed among products for all the amino acids, except serine, half-cystine, valine and methionine, in the peeled grain products. In addition, glutamic acid, isoleucine, leucine and phenylalanine did not vary significantly among products in non-peeled grains.

Correlation coefficients between amino acid distribution and protein content were generally negative and nonsignificant. The correlation coefficients were, however, mostly positive and highly significant when the amino acid composition was compared to protein levels. Lysine was the only amino acid that did not show a significant correlation coefficient with protein when it was considered as percent of the sample.

The relationship between lysine distribution and those of other amino acids was examined and indicated:

- (a) Arginine and glycine were significantly ($P \leq 0.05$) correlated to lysine in both peeled and non-peeled hybrids.
- (b) Glutamic acid was negatively correlated with lysine in both peeled and non-peeled grains.
- (c) Among similar products, only break flours and bran-germ fractions from non-peeled grains gave high but nonsignificant coefficients of correlation.

Leucine composition was high when compared to isoleucine, resulting in low isoleucine:leucine ratios of 0.234 to 0.371 which were in agreement with 0.272 to 0.380 reported by Pickett (1969) for whole grains.

In general, results indicated that amino acid distribution of endosperm products did not follow smooth and easily discernible trends and were frequently low. Amino acid composition data gave better correlation coefficients than amino acid distributions when both were compared with protein content.

Closer examination of the hybrids revealed that Dekalb C-42Y possessed some desirable characteristics:

It had the best field trial performance having the highest yield and test weight.

It produced the highest yield of flour from the Buhler when milled without prior peeling, and color of its endosperm products was best in both non-peeled and peeled grain. Though the hybrid did not give a good yield of whole endosperm from brush peeling, the grits fraction from Dekalb C-42Y however, appeared the most wholesome when compared with the others. Reduction of the grits in a pin mill into flour could produce a product that has better color than the color of the products from the other six hybrids tested.

Furthermore, its milling quality was found superior by earlier workers

whose work has already been cited. In addition it has a light yellow pericarp and does not possess a pigmented undercoat.

The other hybrids tested may possess one or two qualities that might compare favorably with Dekalb C-42Y, but none of them matches all the desirable properties listed for Dekalb C-42Y. Therefore it appears that Dekalb C-42Y alone among the group might make a good selection for use as source of flour for human consumption.

SUGGESTIONS FOR FUTURE RESEARCH

- (a) Screening of sorghum varieties and hybrids for food purposes should be primarily directed to those varieties and hybrids having light pericarps and intermediate endosperm hardness. This could reduce need for expensive and low yield operations such as pre-peeling before milling that might be considered a necessary step in improving the color of sorghum products.
- (b) Roller milling by itself does not recover much of available sorghum endosperm as good quality flour, and it produces approximately 40-50% yields of shorts. Shorts fractions were shown to contain significant amounts of protein and it would be desirable to investigate suitable procedures for purifying the shorts before pin milling.

LITERATURE CITED

1. AMERICAN ASSOCIATION OF CEREAL CHEMISTS. Cereal laboratory methods, 7th ed. The Association: St. Paul, Minn. (1962).
2. ANDERSON, R. A. Production of quality sorghum flour on wheat milling equipment. The Northwestern Miller 10(10): 10 (1969).
3. ANDERSON, R. A., MONTGOMERY, R. R., and BURBRIDGE, L. H. Low-fat endosperm fractions from grain sorghum. Cer. Sci. Today 14: 366 (1969).
4. ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. Methods of analysis, 11th ed. The Association: Washington, D. C. (1970).
5. BRESSANI, R., ELIAS, R. G., and BRAHAM, E. Cottonseed protein in human foods. In: World protein resources, ed. by R. F. Gould, chapter 3 (1966).
6. BRESSANI, R., and RIOS, B. J. Chemical and essential amino acid composition of twenty-five selections of sorghum. Cer. Chem. 39: 50 (1962).
7. BREUR, L. H., JR., and DOHM, C. K. Comparative nutritive value of several sorghum grain varieties and hybrids. J. Agri. Food Chem. 20: 83 (1972).
8. DEOSTHALE, Y. G., MOHAN, V. S., and RAO, K. V. Varietal differences in protein, lysine, and leucine content of grain sorghum. J. Agri. Food Chem. 18: 644 (1970).
9. DEYOE, C. W., and SHELLENBERGER, J. A. Amino acids and proteins in sorghum grains. J. Agri. Food Chem. 13: 446 (1965).
10. DUTRA DE OLIVEIRA, J. E., and PEREIRA DA SILVA, M. L. Nutritive value of opaque-2 corn and its mixture with hybrid corn and wheat. J. Food Sci. 36: 370 (1971).
11. FREEMAN, J. E., and WATSON, S. A. Peeling sorghum grain for wet peeling. Cer. Chem. 13: 466 (1965).
12. FLYNN, L. M., ZUBER, M. S., LEWEKE, D. H., GRAINGER, R. B., and HOGAN, A. G. Relation between protein content of corn and concentration of amino acids and nicotinic acid. Cer. Chem. 31: 217 (1954).
13. GERRISH, O. B. Potential for food use of grain sorghum. Grain Sorghum Producers Association--Fifth Biennial Grain Sorghum Research and Utilization Conference: Amarillo, Texas, page 16 (1967).
14. HAHN, R. R. The dry milling of grain sorghum. Cer. Sci. Today 14(7): 234 (1969).

15. HANSEN, D. W., BRIMHALL, B., and SPRAGUE, G. F. Relationship of zein to the total protein in corn. *Cer. Chem.* 23: 329 (1946).
16. HEPBURN, F. N., and BRADLEY, W. B. The amino acid composition of hard wheat varieties as a function of nitrogen content. *Cer. Chem.* 42: 140 (1965).
17. HUBBARD, J. E., HALL, H. H., and EARLE, F. R. Composition of the component parts of the sorghum kernel. *Cer. Chem.* 27: 415 (1950).
18. JANSEN, G. R., DE MAIO, L. R., and HAUSE, N. L. Amino acid composition, and lysine supplementation of teff. *J. Agri. Food Chem.* 10: 62 (1962).
19. JARQUIN, R., ALBERTAZZI, C., and BRESSANI, R. Value of opaque-2 corn for chicks. *J. Agri. Food Chem.* 18: 269 (1970).
20. KEENY, D. R. Protein and amino acid composition of maize grain as influenced by variety and fertility. *J. Agri. Food Chem.* 21: 182 (1970).
21. MARTIN, J. H. History and classification of sorghum bicolor (Linn.) Moench. In: *Sorghum production and utilization* by J. S. Wall and W. M. Ross, chapter 1. Avi Publishing Company, Inc.: Westport, Conn. (1970).
22. MAXSON, E. D., FRYAR, W. B., ROONEY, L. W., and KRISHNAPRASAD, M. N. Milling properties of sorghum grain with different proportions of corneous to floury endosperm. *Cer. Chem.* 48: 478 (1971).
23. MOORE, S., SPACKMAN, D. H., and STEIN, W. H. Chromatography of amino acids on sulfonated polystyrene resins (an improved system). *Anal. Chem.* 30: 1185 (1958).
24. NORMAND, F. L., HOGAN, J. T., and DEOBALD, H. G. Protein content of successive peripheral layers milled from wheat, barley, grain sorghum, and glutinous rice by tangential abrasion. *Cer. Chem.* 42: 359 (1965).
25. PEIFER, V. F., STRINGFELLOW, A. C., and GRIFFIN, E. L., JR. Fractionating corn, sorghum, and soy flours by fine grinding and air classification. *Amer. Miller and Processor* 88(8): 11 (1960).
26. PEPLINSKI, A. J., STRINGFELLOW, A. C., and BURBRIDGE, L. H. Fractionating commercial frits and grits from grain sorghum. *Amer. Miller and Processor* 91(10): 10 (1963).
27. PICKETT, R. C. Variation in amino acid content of sorghum from the world collection. *Grain Sorghum Producers Association--Sixth Grain Sorghum Research and Utilization Conference: Amarillo, Texas, page 19 (1969).*

28. QUINBY, J. R., and SCHERTZ, K. F. In: Sorghum production and utilization ed. by J. S. Wall and W. M. Ross, chapter 3, page 73 (1970).
29. SHEPHERD, A. D., and WOODHEAD, A. H. Sorghum processing. East African Industrial Research Organization Annual Report, page 28 (1969-1970).
30. SHOUP, F. K., DEYOE, C. W., CAMPBELL, J., and PARRISH, D. B. Amino acid composition and nutritional value of milled sorghum grain products. Cer. Chem. 46: 164 (1969).
31. SHOUP, F. K., DEYOE, C. W., FARREL, E. P., HAMMOND, D. L., and MILLER, G. D. Sorghum grain dry milling. Food Technol. 24: 1028 (1970).
32. SHOUP, F. K., DEYOE, C. W., SANFORD, P. E., and MURPHY, L. S. Nutritive value of six commercial sorghum grain hybrids. Poult. Sci. 49: 168 (1970).
33. SKOCH, L. V., DEYOE, C. W., SHOUP, F. K., BATHURST, J., and LIANG, D. Fractionation of sorghum grain. Cer. Chem. 47: 472 (1970).
34. STRINGFELLOW, A. C., PEIFER, V. F., and GRIFFIN, E. L., JR. Air classification of rice flour. Rice J. 64(7): 30 (1961).
35. STRINGFELLOW, A. C., and PEPLINSKI, A. J. Air classification of sorghum flours from varieties representing different hardnesses. Cer. Sci. Today 11: 438 (1966).
36. SPACKMAN, D. H., STEIN, W. H., and MOORE, S. Automatic recording apparatus for use in the chromatography of amino acids. Anal. Chem. 30: 1190 (1958).
37. SUBBA RAO, G. N., BAINS, B. S., BHATIA, D. S., and SUBRAHMANYAN, V. Processing of millets and cereals (other than rice) into rice substitutes. Trans. Amer. Assoc. Cer. Chem. 1(2): 167 (1953).
38. TAIRA, H. Amino acid composition of different varieties of foxtail millet (*setaria italica*). J. Agri. Food Chem. 16: 1025 (1968).
39. VAVICH, M. G., KEMMERER, A. R., NIMBKAR, B., and STITH, L. S. Nutritive value of low and high protein sorghum for growing chicks. Poult. Sci. 38: 36 (1959).
40. VILLEGAS, E., McDONALD, C. E., and GILLES, K. A. Variability in the lysine content of wheat, rye, and triticale proteins. Cer. Chem. 47: 746 (1970).
41. VIRAKTAMATH, C. S., RAGHAVENDRA, G., and DESIKACHAR, H. S. R. Use of rice milling equipment for commercial pearling of grain sorghum (jowar) and culinary uses for pearled sorghum products. J. Food Sci. and Technol. 8: 11 (1971).

42. VIRUPAKSHA, T. K., and SASTRY, L. V. S. Studies on the protein content and amino acid composition of some varieties of grain sorghum. J. Agri. Food Chem. 16: 199 (1968).
43. WAGGLE, D. H., DEYOE, C. W., and SANFORD, P. E. Relationship of protein level of sorghum grain to its nutritive value as measured by chick performance and amino acid composition. Poult. Sci. 45: 1135 (1966) Abstract.
44. WAGGLE, D. H., LAMBERT, M. A., MILLER, G. D., FARREL, E. P., and DEYOE, C. W. Extensive analyses of flours and millfeeds made from nine different wheat mixes. II. Amino acids, minerals, vitamins, and gross energy. Cer. Chem. 44: 48 (1968).
45. WATSON, S. A. Wet milling process and products. In: Sorghum production and utilization ed. by J. S. Wall and W. M. Ross, chapter 17. Avi Publishing Company, Inc.: New Port, Conn. (1970).
46. WEINECKE, L. A., and MONTGOMERY, R. R. Experimental unit now suitable for scale-up to mill size production. Amer. Miller and Processor 93(9): 8-9, 33 (1965).

ACKNOWLEDGMENTS

The writer wishes to express sincere appreciation to Dr. Charles W. Deyoe, major professor, for his guidance in the execution of research and preparation of this manuscript.

The writer expresses special gratitude to Professor A. B. Ward for his assistance with the milling experiments, and for serving on the advisory committee.

Gratitude is expressed to Dr. William J. Hoover, Head, Department of Grain Science and Industry, for the use of facilities and materials in the department.

Appreciation is expressed to the East African Community and U. S. Agency for International Development for the financial assistance during the course of study.

Appreciation is also expressed to Professor Ted L. Walter for supplying the sorghum grain samples and to Dr. R. A. Waller for his assistance with the statistical analyses.

Special acknowledgment is due to Dr. David R. Lineback for serving on the Advisory Committee and reviewing the manuscript.

The writer is grateful to Deborah Lemon and Carolyn Geng for their valuable assistance with the amino acid analyses, and to other members of the Department of Grain Science and Industry, who assisted him during the course of the study.

APPENDIX

TABLE 11a. AMINO ACID COMPOSITION OF MILL PRODUCTS FROM NON-PEELED ASGROW DORADO SORGHUM HYBRID

Products	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	14.3	14.4	14.1	7.7	9.8	17.0	18.9	17.5	12.4
Amino Acids: ^a									
Lysine	0.29	0.41	0.31	0.28	0.21	0.30	0.27	0.66	0.50
Histidine	0.34	0.40	0.39	0.23	0.31	0.39	0.37	0.45	0.34
Arginine	0.52	0.76	0.66	0.42	0.46	0.56	0.52	1.05	0.82
Aspartic Acid	1.05	1.07	1.11	0.63	0.98	1.13	1.23	1.40	1.17
Threonine	0.49	0.51	0.56	0.34	0.42	0.55	0.60	0.62	0.56
Serine	0.71	0.75	0.87	0.44	0.59	0.84	0.91	0.87	0.74
Glutamic Acid	3.39	3.35	4.03	1.70	2.64	3.97	4.64	3.11	2.77
Proline	1.23	1.34	1.65	0.76	1.00	1.63	1.87	1.24	1.14
Glycine	0.45	0.49	0.51	0.33	0.39	0.46	0.47	0.74	0.60
Alanine	1.48	1.40	1.59	0.69	1.00	1.67	1.96	1.38	1.21
Half Cystine	0.26	0.26	0.43	0.23	0.32	0.17	0.19	0.13	0.20
Valine	0.64	0.75	0.89	0.49	0.55	0.85	0.93	0.90	0.75
Methionine	0.22	0.23	0.38	0.15	0.19	0.26	0.22	0.26	0.24
Isoleucine	0.58	0.59	0.81	0.34	0.40	0.84	0.89	0.68	0.55
Leucine	2.21	2.22	2.78	1.11	1.49	3.51	3.79	2.27	1.86
Tyrosine	0.61	0.69	0.80	0.34	0.50	0.68	0.84	0.60	0.49
Phenylalanine	0.81	0.85	1.04	0.44	0.65	0.91	1.07	0.81	0.70

^aGrams per 100 gm sample dry basis.

TABLE 12a. AMINO ACID COMPOSITION OF MILL PRODUCTS FROM NON-PEELED DEKALB C-42Y SORGHUM HYBRID

Product	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	12.4	13.1	12.6	7.3	9.6	15.0	14.3	14.6	12.3
Amino Acids: ^a									
Lysine	0.29	0.41	0.28	0.26	0.20	0.23	0.23	0.90	0.42
Histidine	0.31	0.41	0.33	0.23	0.30	0.39	0.34	0.53	0.29
Arginine	0.50	0.81	0.57	0.36	0.42	0.58	0.44	1.47	0.58
Aspartic Acid	0.93	1.09	1.05	0.60	0.86	1.24	0.94	1.57	0.85
Threonine	0.42	0.52	0.50	0.30	0.42	0.59	0.47	0.70	0.32
Serine	0.63	0.75	0.79	0.40	0.58	0.85	0.73	0.93	0.64
Glutamic Acid	2.94	3.30	3.07	1.64	2.55	4.16	3.27	3.03	2.43
Proline	1.17	1.34	1.44	0.73	1.05	1.72	1.33	1.24	1.11
Glycine	0.43	0.53	0.45	0.31	0.38	0.51	0.40	0.94	0.56
Alanine	1.27	1.32	1.26	0.71	0.98	1.61	1.51	1.34	1.06
Half Cystine	0.22	0.48	0.36	0.26	0.23	0.31	0.13	0.44	0.21
Valine	0.69	0.76	0.62	0.46	0.52	0.77	0.74	1.01	0.65
Methionine	0.15	0.29	0.21	0.16	0.17	0.19	0.17	0.28	0.13
Isoleucine	0.51	0.66	0.60	0.36	0.40	0.68	0.64	0.65	0.45
Leucine	1.84	2.21	2.29	1.10	1.38	2.33	2.67	1.83	1.56
Tyrosine	0.52	0.59	0.72	0.35	0.48	0.80	0.60	0.65	0.36
Phenylalanine	0.69	0.78	0.93	0.43	0.63	1.01	0.77	0.92	0.70

^aGrams per 100 gm sample dry basis.

TABLE 13a. AMINO ACID COMPOSITION OF MILL PRODUCTS FROM NON-PEELED McNAIR 654 SORGHUM HYBRID

Product	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	12.3	12.8	12.7	7.4	10.2	16.8	17.8	15.6	11.6
Amino Acids: ^a									
Lysine	0.31	0.35	0.34	0.21	0.21	0.29	0.27	0.64	0.93
Histidine	0.33	0.38	0.41	0.23	0.33	0.36	0.41	0.44	0.53
Arginine	0.57	0.69	0.66	0.35	0.55	0.58	0.49	1.05	1.90
Aspartic Acid	1.02	1.21	1.09	0.52	0.87	1.08	1.16	1.35	1.73
Threonine	0.47	0.56	0.55	0.27	0.45	0.55	0.57	0.59	0.75
Serine	0.67	0.88	0.85	0.39	0.63	0.82	0.83	0.82	0.99
Glutamic Acid	2.98	3.93	3.64	1.70	2.77	3.83	4.28	2.82	3.13
Proline	1.17	1.69	1.55	0.67	1.07	1.56	1.67	1.07	1.10
Glycine	0.46	0.61	0.52	0.27	0.38	0.52	0.50	0.71	1.00
Alanine	1.30	1.58	1.48	0.65	1.03	1.63	1.83	1.28	1.35
Half Cystine	0.27	0.30	0.30	0.10	0.27	0.14	0.18	0.13	0.40
Valine	0.71	0.88	0.83	0.40	0.55	0.81	1.15	0.83	1.02
Methionine	0.21	1.60	0.30	0.13	0.18	0.21	0.21	0.22	0.33
Isoleucine	0.53	0.64	0.77	0.32	0.40	0.68	0.77	0.58	0.68
Leucine	1.92	2.55	2.50	1.19	1.45	3.00	3.43	2.01	0.83
Tyrosine	0.55	0.74	0.72	0.32	0.53	0.71	0.76	0.56	0.65
Phenylalanine	0.73	0.97	0.96	0.39	0.66	0.89	1.00	0.75	0.84

^aGrams per 100 gm sample dry basis.

TABLE 14a. AMINO ACID COMPOSITION OF MILL PRODUCTS FROM NON-PEELED PIONEER 846 SORGHUM HYBRID

Product	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	14.1	15.1	14.3	7.0	9.3	16.9	18.1	13.7	8.9
Amino Acids: ^a									
Lysine	0.26	0.36	0.25	0.26	0.21	0.36	0.18	0.53	0.30
Histidine	0.33	0.39	0.34	0.20	0.22	0.51	0.45	0.43	0.19
Arginine	0.51	0.79	0.65	0.41	0.34	0.85	0.54	1.10	0.44
Aspartic Acid	1.01	1.17	1.24	0.56	0.70	1.39	1.45	1.43	0.71
Threonine	0.48	0.59	0.59	0.29	0.34	0.63	0.69	0.64	0.29
Serine	0.70	0.81	0.99	0.39	0.47	0.99	1.03	0.91	0.43
Glutamic Acid	3.45	3.98	3.54	1.66	2.14	4.69	5.48	2.83	1.46
Proline	1.28	1.55	1.51	0.71	0.89	1.92	2.10	0.98	0.62
Glycine	0.44	0.52	0.49	0.30	0.27	0.53	0.53	0.92	0.43
Alanine	1.51	1.67	1.43	0.63	0.80	1.86	2.04	1.11	0.66
Half Cystine	0.22	0.41	0.45	0.17	0.25	0.49	0.49	0.30	0.15
Valine	0.74	0.91	0.65	0.43	0.41	0.85	0.95	0.74	0.43
Methionine	0.21	0.28	0.20	0.13	0.10	0.26	0.26	0.19	0.06
Isoleucine	0.60	0.80	0.69	0.32	0.35	0.84	0.80	0.48	0.32
Leucine	2.31	2.44	2.66	1.03	1.38	3.40	3.12	1.29	0.92
Tyrosine	0.64	0.81	0.78	0.33	0.41	1.02	0.95	0.53	0.40
Phenylalanine	0.81	1.02	1.09	0.42	0.47	1.46	1.19	0.71	0.45

^aGrams per 100 gm sample dry basis.

TABLE 15a. AMINO ACID COMPOSITION OF MILL PRODUCTS FROM NON-PEELED RS 671 SORGHUM HYBRID

Product	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	14.0	16.1	15.1	7.7	10.3	18.2	20.4	13.5	1.05
Amino Acids: ^a									
Lysine	0.26	0.30	0.23	0.17	0.30	0.18	0.24	0.60	0.40
Histidine	0.34	0.37	0.38	0.20	0.30	0.35	0.43	0.36	0.26
Arginine	0.57	0.64	0.51	0.29	0.50	0.65	0.64	1.14	0.67
Aspartic Acid	1.04	1.32	1.20	0.54	0.83	1.39	1.36	1.31	0.93
Threonine	0.50	0.58	0.56	0.28	0.41	0.69	0.68	0.58	0.46
Serine	0.70	0.86	0.82	0.37	0.58	1.13	1.01	0.75	0.62
Glutamic Acid	3.45	4.52	4.23	1.54	2.66	5.20	5.25	2.36	2.21
Proline	1.28	1.71	1.70	0.68	1.12	1.99	2.02	1.03	0.96
Glycine	0.45	0.46	0.45	0.25	0.39	0.59	0.48	0.71	0.57
Alanine	1.52	1.77	1.65	0.58	1.05	2.01	2.12	1.06	0.96
Half Cystine	0.29	0.23	0.19	0.14	0.23	0.53	0.26	0.26	0.17
Valine	0.75	0.85	0.83	0.33	0.61	1.07	1.07	0.68	0.62
Methionine	0.21	0.16	0.19	0.09	0.20	0.38	0.28	0.24	0.16
Isoleucine	0.60	0.64	0.73	0.25	0.50	0.94	0.89	0.56	0.45
Leucine	2.24	2.91	2.89	0.83	1.76	3.32	3.54	1.61	1.45
Tyrosine	0.64	0.62	0.82	0.33	0.54	0.97	1.03	0.62	0.41
Phenylalanine	0.81	0.80	1.05	0.40	0.69	1.24	1.31	0.82	0.62

^aGrams per 100 gm sample dry basis.

TABLE 16a. AMINO ACID COMPOSITION OF MILL PRODUCTS FROM NON-PEELED RS 700 SORGHUM HYBRID

Product	Original Grain	Peeled Grain	Grits	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ	Fines
Product Code	A	A ₁	G	B	C	D	E	F	H
Protein ^a	15.3	15.3	15.9	7.1	9.3	19.6	23.7	13.6	10.0
Amino Acids: ^a									
Lysine	0.27	0.32	0.30	0.26	0.26	0.38	0.32	0.65	0.40
Histidine	0.36	0.36	0.41	0.23	0.25	0.47	0.60	0.38	0.25
Arginine	0.55	0.66	0.72	0.43	0.54	0.74	1.01	1.11	0.71
Aspartic Acid	1.09	1.19	1.28	0.62	0.71	1.29	1.82	1.41	1.00
Threonine	0.52	0.60	0.61	0.31	0.36	0.62	0.89	0.64	0.44
Serine	0.75	0.90	0.98	0.48	0.50	0.96	1.39	0.92	0.64
Glutamic Acid	3.74	4.44	4.67	1.71	2.34	4.24	7.23	2.62	2.43
Proline	1.34	1.59	1.79	0.74	0.94	1.91	2.71	1.00	0.87
Glycine	0.44	0.48	0.50	0.34	0.34	0.56	0.67	0.77	0.52
Alanine	1.60	1.79	1.80	0.77	0.93	1.86	1.95	1.09	1.04
Half Cystine	0.30	0.40	0.39	0.17	0.23	0.44	0.41	0.31	0.17
Valine	0.78	0.90	0.84	0.48	0.54	1.08	1.43	0.69	0.61
Methionine	0.22	0.24	0.31	0.17	0.23	0.31	0.37	0.13	0.17
Isoleucine	0.64	0.69	0.79	0.35	0.44	0.78	1.02	0.58	0.43
Leucine	2.43	2.92	3.10	1.12	1.57	3.04	5.10	1.64	1.53
Tyrosine	0.71	0.51	0.83	0.39	0.44	0.92	1.35	0.61	0.41
Phenylalanine	0.89	0.65	1.02	0.53	0.53	1.14	1.28	0.88	0.59

^aGrams per 100 gm sample dry basis.

TABLE 17a. AMINO ACID COMPOSITION OF MILL PRODUCTS FROM NON-PEELED RS 506 SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A	B	C	D	E	F
Protein ^a	13.3	6.7	9.2	16.7	20.1	12.9
Amino Acids: ^a						
Lysine	0.26	0.17	0.17	0.27	0.30	0.50
Histidine	0.31	0.19	0.25	0.44	0.46	0.39
Arginine	0.53	0.30	0.40	0.67	0.56	1.04
Aspartic Acid	0.97	0.59	0.80	1.49	1.56	1.29
Threonine	0.44	0.28	0.37	0.70	0.72	0.58
Serine	0.63	0.38	0.48	1.19	1.22	0.75
Glutamic Acid	3.14	1.54	2.36	4.99	6.16	2.47
Proline	1.24	0.64	0.95	2.00	2.18	0.92
Glycine	0.40	0.25	0.33	0.56	0.52	0.72
Alanine	1.34	0.63	0.97	1.66	2.39	1.00
Half Cystine	0.19	0.16	0.19	0.27	0.43	0.22
Valine	0.70	0.34	0.48	0.73	1.23	0.70
Methionine	0.16	0.09	0.14	0.24	0.38	0.18
Isoleucine	0.58	0.24	0.37	0.71	1.05	0.47
Leucine	2.18	0.84	1.33	2.65	4.39	1.23
Tyrosine	0.59	0.31	0.45	0.91	1.07	0.50
Phenylalanine	0.78	0.39	0.58	1.15	1.37	0.67

^aGrams per 100 gram sample.

TABLE 18a. AMINO ACID DISTRIBUTION OF MILL PRODUCTS FROM BRUSH-PEELED ASGROW DORADO SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran ~ Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Protein ^a	14.4	7.8	9.8	17.6	22.3	18.4
Amino Acids: ^a						
Lysine	0.47	0.24	0.23	0.31	0.21	1.12
Histidine	0.46	0.21	0.24	0.41	0.41	0.50
Arginine	0.88	0.38	0.35	0.64	0.48	1.74
Aspartic Acid	1.24	0.62	0.81	1.53	1.75	1.81
Threonine	0.59	0.32	0.37	0.82	0.86	0.80
Serine	0.87	0.41	0.48	1.65	1.56	1.09
Glutamic Acid	3.89	1.67	2.22	4.60	6.82	3.18
Proline	1.56	0.79	1.00	2.05	2.94	1.18
Glycine	0.57	0.32	0.31	0.84	0.51	1.17
Alanine	1.61	0.66	0.94	1.97	2.66	1.52
Half Cystine	0.30	0.22	0.08	0.36	0.18	0.37
Valine	0.87	0.38	0.46	0.99	1.13	1.15
Methionine	0.27	0.15	0.09	0.33	0.26	0.35
Isoleucine	0.69	0.36	0.41	1.01	1.06	0.71
Leucine	2.58	1.17	1.58	3.63	4.70	1.82
Tyrosine	0.80	0.37	0.26	1.24	1.26	0.66
Phenylalanine	0.98	0.52	0.36	1.63	1.51	0.98

^aGrams per 100 gram sample dry basis.

TABLE 19a. AMINO ACID COMPOSITION OF MILL PRODUCTS FROM BRUSH-PEELED DEKALB C-42Y SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Protein ^a	13.1	7.2	7.8	15.5	18.7	19.3
Amino Acids: ^a						
Lysine	0.41	0.25	0.26	0.38	0.30	1.02
Histidine	0.41	0.22	0.23	0.51	0.49	0.53
Arginine	0.81	0.41	0.39	0.77	0.71	1.84
Aspartic Acid	1.09	0.56	0.59	1.40	1.32	1.74
Threonine	0.52	0.29	0.32	0.65	0.63	1.00
Serine	0.75	0.39	0.43	1.05	1.00	1.06
Glutamic Acid	3.30	1.54	1.74	4.78	4.90	2.92
Proline	1.34	0.68	0.80	1.97	2.11	1.17
Glycine	0.53	0.31	0.32	0.56	0.47	1.00
Alanine	1.32	0.66	0.78	1.92	2.02	1.33
Half Cystine	0.48	0.26	0.26	0.46	0.37	0.31
Valine	0.76	0.42	0.47	1.06	0.99	0.97
Methionine	0.29	0.14	0.17	0.30	0.25	0.31
Isoleucine	0.66	0.33	0.38	0.86	0.92	0.65
Leucine	2.21	0.99	1.23	3.28	3.42	1.65
Tyrosine	0.59	0.34	0.39	0.87	0.82	0.59
Phenylalanine	0.78	0.44	0.49	1.12	1.06	0.83

^aGrams per 100 gram sample dry basis.

TABLE 20a. AMINO ACID COMPOSITION OF MILL PRODUCTS FROM BRUSH-PEELED MCNAIR 654 SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Protein ^a	14.6	7.9	10.1	17.4	22.6	18.5
Amino Acids: ^a						
Lysine	0.35	0.26	0.21	0.32	0.27	0.93
Histidine	0.38	0.23	0.24	0.50	0.58	0.53
Arginine	0.69	0.47	0.45	0.78	0.79	1.90
Aspartic Acid	1.21	0.63	0.76	1.33	1.60	1.73
Threonine	0.56	0.33	0.37	0.66	0.89	0.75
Serine	0.88	0.46	0.51	0.97	1.33	0.99
Glutamic Acid	3.93	1.80	2.36	4.73	6.42	3.13
Proline	1.69	0.79	1.05	1.96	2.60	1.10
Glycine	0.61	0.34	0.32	0.50	0.63	1.00
Alanine	1.58	0.74	0.94	1.88	2.52	1.35
Half Cystine	0.30	0.17	0.24	0.43	0.91	0.40
Valine	0.88	0.45	0.60	0.77	1.27	1.02
Methionine	0.16	0.18	0.18	0.31	0.42	0.33
Isoleucine	0.64	0.37	0.41	0.82	1.16	0.68
Leucine	2.55	1.17	1.73	3.37	4.46	1.83
Tyrosine	0.74	0.32	0.44	0.91	1.09	0.65
Phenylalanine	0.97	0.40	0.56	1.10	1.44	0.84

^aGrams per 100 gram sample dry basis.

TABLE 21a. AMINO ACID COMPOSITION IN MILL PRODUCTS FROM BRUSH-PEELED PIONEER 846 SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Protein ^a	15.1	7.3	12.2	17.5	23.9	17.9
Amino Acids: ^a						
Lysine	0.36	0.23	0.22	0.34	0.27	1.02
Histidine	0.39	0.22	0.30	0.48	0.57	0.49
Arginine	0.79	0.37	0.49	0.73	0.77	1.53
Aspartic Acid	1.17	0.53	0.76	1.32	1.72	1.61
Threonine	0.58	0.27	0.41	0.66	0.85	0.71
Serine	0.81	0.36	0.59	1.03	1.56	1.01
Glutamic Acid	3.98	1.47	3.03	4.83	6.70	3.06
Proline	1.55	0.68	1.22	1.87	2.45	1.03
Glycine	0.52	0.26	0.30	0.48	0.70	1.06
Alanine	1.67	0.62	1.14	1.99	2.77	1.29
Half Cystine	0.41	0.20	0.39	0.15	0.50	0.37
Valine	0.91	0.39	0.56	0.98	1.42	1.01
Methionine	0.28	0.14	0.13	0.33	0.39	0.32
Isoleucine	0.80	0.32	0.47	0.87	1.23	0.63
Leucine	2.44	1.03	1.97	3.29	4.75	1.67
Tyrosine	0.81	0.31	0.59	0.86	1.16	0.69
Phenylalanine	1.02	0.35	0.76	1.07	1.51	0.94

^aGrams per 100 gram sample dry basis.

TABLE 22a. AMINO ACID COMPOSITION OF MILL PRODUCTS FROM BRUSH-PEELED RS 671 SORGHUM HYBRID

Products	Peeled Grain	Break Flour	Reduction Flour	Pin Mill Flour	Shorts	Bran - Germ
Product Code	A ₁	B ₁	C ₁	D ₁	E ₁	F ₁
Protein ^a	16.1	7.5	10.3	19.8	24.9	21.3
Amino Acids: ^a						
Lysine	0.30	0.24	0.20	0.30	0.24	1.36
Histidine	0.37	0.22	0.24	0.48	0.58	0.57
Arginine	0.64	0.32	0.35	0.70	0.60	2.28
Aspartic Acid	1.32	0.62	0.77	1.33	1.67	2.06
Threonine	0.58	0.31	0.38	0.70	0.84	0.88
Serine	0.86	0.40	0.53	0.99	1.32	1.22
Glutamic Acid	4.52	1.81	2.62	4.93	6.95	3.70
Proline	1.71	0.79	1.07	1.90	2.86	1.16
Glycine	0.45	0.26	0.28	0.51	0.59	1.21
Alanine	1.77	0.76	1.09	2.09	2.81	1.62
Half Cystine	0.23	0.18	0.29	0.45	0.75	0.56
Valine	0.85	0.44	0.58	1.04	1.34	1.26
Methionine	0.16	0.08	0.14	0.33	0.46	0.32
Isoleucine	0.64	0.30	0.33	0.88	1.21	0.66
Leucine	2.91	1.19	1.77	3.44	4.89	2.01
Tyrosine	0.62	0.35	0.46	0.88	1.21	0.78
Phenylalanine	0.80	0.43	0.58	1.06	1.56	1.02

^aGrams per 100 gram sample dry basis.

AMINO ACID CONTENT OF SORGHUM HYBRIDS
AND THEIR MILL PRODUCTS

by

JOATHAM KAPASI-KAKAMA

B. S., University College, Nairobi, 1968

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1972

A study was conducted to evaluate the milling quality of seven sorghum hybrids (Asgrow Dorado, Dekalb C-42Y, McNair 654, Pioneer 846, RS 506, RS 671 and RS 700) grown under the same conditions in Southwestern Kansas in the 1971 crop year. Evaluations were also made on the amino acid content of the grains and their mill products.

Two milling tests were conducted. In one, clean grain tempered to 16% moisture was milled on a Buhler experimental laboratory flour mill and shorts were milled further on an Alpine pin mill. Material resulting from the pin mill was sifted on a 9XX cloth.

In the second study, grain tempered to 22% moisture was brush-peeled prior to milling.

Buhler flour yields from peeled grain were slightly lower than those from non-peeled grain. Total recoveries were, however, similar in both experiments. Color of the endosperm products from peeled grain, as measured by Agtron M-500A green wavelength, was improved for all hybrids.

In both tests break flours had lowest protein levels, followed by reduction flours and whole grains. Shorts were highest in protein followed by pin milled flour from non-peeled or bran from the peeled grain.

Pin mill flours contained 50-60% of the recovered protein, with peeled grain products showing higher values. Highest protein values and lowest ash and crude fat values were observed in shorts from peeled grain. Bran-germ fractions from peeled grain retained most of the ash and crude fat, with higher values in the peeled grain fractions.

Generally, peeled grain endosperm products had higher protein and lower ash and crude fat than corresponding ones from unpeeled grain.

No significant differences were observed for protein and amino acid

distribution (grams/16 grams nitrogen) among non-peeled hybrids. In the peeled hybrids, significant differences ($P \leq 0.01$) were observed for protein, lysine, glycine and isoleucine.

In products from non-peeled grain, significant variation ($P \leq 0.01$) was observed for all the amino acids, except serine, glutamic acid, half-cystine, valine, methionine, isoleucine, leucine and phenylalanine.

Correlations between protein and amino acid distribution were primarily negative in both non-peeled and peeled hybrids, but were higher in peeled grains. Amino acid composition values (percent of sample, dry basis) were generally positive and significantly correlated at either $P \leq 0.01$ or $P \leq 0.05$.

Correlations between protein and amino acid distribution in the products were, generally, low and negative, except in the reduction flour and shorts from unpeeled grain where they were primarily positive.

Positive correlations were observed between lysine distribution and histidine and arginine distributions in all hybrids, the endosperm products from peeled grain, and in the break flour and bran-germ fractions from non-peeled grain. Glutamic acid and proline were significantly ($P \leq 0.05$) negatively correlated with lysine in all hybrids.

The ratios between isoleucine and leucine were low: 0.243 to 0.317 for non-peeled grain products, and 0.252 to 0.371 for peeled grain products.